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colour inside

High-voltage switchgear and controlgear – Part 100: Alternating-current circuit-breakers

Appareillage à haute tension – Partie 100: Disjoncteurs à courant alternatif

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 100: Alternating-current circuit-breakers

FOREWORD

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This consolidated version of IEC 62271-100 consists of the second edition (2008) [documents 17A/815/FDIS and 17A/822/RVD] and its amendment 1 (2012) [documents 17A/1009/FDIS and 17A/1019/RVD]. It bears the edition number 2.1.

The technical content is therefore identical to the base edition and its amendment and has been prepared for user convenience. A vertical line in the margin shows where the base publication has been modified by amendment 1. Additions and deletions are displayed in red, with deletions being struck through.

International Standard IEC 62271-100 has been prepared by subcommittee 17A: High-voltage switchgear and controlgear, of IEC technical committee 17: Switchgear and controlgear.

The main changes with respect to the previous edition are listed below:

– the introduction of harmonised (IEC and IEEE) TRV waveshapes for rated voltages of 100 kV and above (amendment 1 to the first edition);
– the introduction of cable and line systems with their associated TRVs for rated voltages below 100 kV (amendment 2 to the first edition);
– the inclusion of IEC 61633 and IEC 62271-308.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

This standard shall be read in conjunction with IEC 62271-1, first edition, published in 2007, to which it refers and which is applicable unless otherwise specified in this standard. In order to simplify the indication of corresponding requirements, the same numbering of clauses and subclauses is used as in IEC 62271-1. Amendments to these clauses and subclauses are given under the same references whilst additional subclauses are numbered from 101.

A list of all parts of IEC 62271 series, under the general title *High-voltage switchgear and controlgear* can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

• reconfirmed,
• withdrawn,
• replaced by a revised edition, or
• amended.

IMPORTANT – The “colour inside” logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 100: Alternating-current circuit-breakers

1 General

1.1 Scope

This part of IEC 62271 is applicable to a.c. circuit-breakers designed for indoor or outdoor installation and for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 000 V.

It is only applicable to three-pole circuit-breakers for use in three-phase systems and single-pole circuit-breakers for use in single-phase systems. Two-pole circuit-breakers for use in single-phase systems and application at frequencies lower than 50 Hz are subject to agreement between manufacturer and user.

This standard is also applicable to the operating devices of circuit-breakers and to their auxiliary equipment. However, a circuit-breaker with a closing mechanism for dependent manual operation is not covered by this standard, as a rated short-circuit making-current cannot be specified, and such dependent manual operation may be objectionable because of safety considerations.

Rules for circuit-breakers with an intentional non-simultaneity between the poles are under consideration; circuit-breakers providing single-pole auto-reclosing are within the scope of this standard.

NOTE 1 Circuit-breakers with an intentional ~~non-simu0ltaneity~~ non-simultaneity between the poles may, in some instances, be tested in accordance with this standard. For example, mechanically staggered pole designs can be tested according to this standard using three-phase direct tests. For synthetic testing, determining the most appropriate tests, particularly in respect to test current, recovery voltage and transient recovery voltage, is subject to agreement between manufacturer and user.

This standard does not cover circuit-breakers intended for use on motive power units of electrical traction equipment; these are covered by IEC 60077 [1][1].

Generator circuit-breakers installed between generator and step-up transformer are not within the scope of this standard.

Switching of inductive loads is covered by IEC 62271-110.

This standard does not cover self-tripping circuit-breakers with ~~mechanical~~ tripping devices ~~or devices which~~ that cannot be made inoperative during testing.

Circuit-breakers installed as by-pass switches in parallel with line series capacitors and their protective equipment are not within the scope of this standard. These are covered by IEC 62271-109 [2] and IEC 60143-2 [3].

NOTE 2 Tests to prove the performance under abnormal conditions should be subject to agreement between manufacturer and user. Such abnormal conditions are, for instance, cases where the voltage is higher than the rated voltage of the circuit-breaker, conditions which may occur due to sudden loss of load on long lines or cables.

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1 Figures in square brackets refer to the bibliography.

1.2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050(151):2001, *International Electrotechnical Vocabulary – Part 151: Electrical and magnetic devices*

IEC 60050(441):1984, *International Electrotechnical Vocabulary – Chapter 441: Switchgear, controlgear and fuses*

IEC 60050(601):1985, *International Electrotechnical Vocabulary – Chapter 601: Generation, transmission and distribution of electricity – General*

IEC 60050(604):1987, *International Electrotechnical Vocabulary – Chapter 601: Generation, transmission and distribution of electricity – Operation*

IEC 60059, *IEC standard current ratings*

IEC 60060-1:1989, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60071-2, *Insulation coordination – Part 2: Application guide*

IEC 60137, *Insulated bushings for alternating voltages above 1 000 kV*

IEC 60255-3:1989, *Electrical relays – Part 3: Single input energizing quantity measuring relays with dependent or independent time*

IEC 60296, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

IEC 60376, *Specification of technical grade sulphur hexafluoride (SF_6) for use in electrical equipment*

IEC 60480, *Guidelines for the checking and treatment of sulphur hexafluoride (SF_6) taken from electrical equipment and specification for its re-use*

IEC 60529, Degrees of protection provided by enclosures (IP Code)

IEC/TS 61634, *High-voltage switchgear and controlgear – Use and handling of sulphur hexafluoride (SF_6) in high-voltage switchgear and controlgear*

IEC 62271-1:2007:*High-voltage switchgear and controlgear – Part 1: Common specifications*

IEC 62271-101:2006, *High-voltage switchgear and controlgear – Part 101: Synthetic testing*

IEC 62271-102: 2001, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

IEC 62271-110, *High-voltage switchgear and controlgear – Part 110: Inductive load switching*

2 Normal and special service conditions

Clause 2 of IEC 62271-1 is applicable.

3 Terms and definitions

For the purpose of this document, the terms and definitions of IEC 60050-441 and IEC 62271-1 apply. Some of them are recalled here for ease of reference.

Additional terms and definitions are classified so as to be aligned with the classification used in IEC 60050-441.

3.1 General terms

3.1.101
switchgear and controlgear
[IEV 441-11-01]

3.1.102
indoor switchgear and controlgear
[IEV 441-11-04]

3.1.103
outdoor switchgear and controlgear
[IEV 441-11-05]

3.1.104
short-circuit current
[IEV 441-11-07]

3.1.105
isolated neutral system
[IEV 601-02-24]

3.1.106
solidly earthed (neutral) system
[IEV 601-02-25]

3.1.107
impedance earthed (neutral) system
[IEV 601-02-26]

3.1.108
resonant earthed (neutral) system,
arc-suppression-coil-earth (neutral) system
[IEV 601-02-27]

3.1.109
earth fault factor
ratio, at a selected location of a three-phase system (generally the point of installation of an equipment) and for a given system configuration, of the highest r.m.s. phase-to-earth power-frequency voltage on a sound phase during a fault to earth (affecting one or more phases at any point) to the r.m.s. phase-to-earth power-frequency voltage which would be obtained at the selected location without the fault

NOTE 1 This factor is a pure numerical ratio (generally higher than 1) and characterises in general terms the earthing conditions of a system as viewed from the stated location, independently of the actual operating values of the voltage at that location. The "earth fault factor" is the product of $\sqrt{3}$ and the "factor of earthing" which has been used in the past.

NOTE 2 The earth fault factors are calculated from the phase-sequence impedance components of the system, as viewed from the selected location, using for any rotating machines the subtransient reactance.

NOTE 3 If, for all credible system configurations, the zero-sequence reactance is less than three times the positive sequence reactance and if the zero-sequence resistance does not exceed the positive sequence reactance, the earth fault factor will not exceed 1,4.

3.1.110
ambient air temperature
[IEV 441-11-13]

3.1.111
temperature rise (of a part of a circuit-breaker)
difference between the temperature of the part and the ambient air temperature

3.1.112
single capacitor bank
bank of shunt capacitors in which the inrush current is limited by the inductance of the supply system and the capacitance of the bank of capacitors being energised, there being no other capacitors connected in parallel to the system sufficiently close to increase the inrush current appreciably

3.1.113
multiple (parallel) capacitor bank
back-to-back capacitor bank
bank of shunt capacitors or capacitor assemblies each of them switched independently to the supply system, the inrush current of one unit being appreciably increased by the capacitors already connected to the supply

3.1.114
overvoltage (in a system)
any voltage between one phase and earth or between phases having a peak value or values exceeding the corresponding peak of the highest voltage for equipment

[IEV 604-03-09, modified]

3.1.115
out-of-phase conditions
abnormal circuit conditions of loss or lack of synchronism between the parts of an electrical system on either side of a circuit-breaker in which, at the instant of operation of the circuit-breaker, the phase angle between rotating vectors, representing the generated voltages on either side, exceeds the normal value

NOTE The requirements of this standard cater for the great majority of applications of circuit-breakers intended for switching during out-of-phase conditions. Out-of-phase angles corresponding to the specified power frequency recovery voltages are given in 6.110.3. For extreme service conditions see 8.103.3.

3.1.116
out-of-phase (as prefix to a characteristic quantity)
qualifying term indicating that the characteristic quantity is applicable to operation of the circuit-breaker in out-of-phase conditions

3.1.117
unit test
test made on a making or breaking unit or group of units at the making current or the breaking current, specified for the test on the complete pole of a circuit-breaker and at the appropriate fraction of the applied voltage, or the recovery voltage, specified for the test on the complete pole of the circuit-breaker

3.1.118
loop
part of the wave of the current embraced by two successive current zero crossings

NOTE A distinction is made between a major loop and a minor loop depending on the time interval between two successive current zero crossings being longer or shorter than the half-period of the alternating component of the current.

3.1.119
short-line fault (SLF)
short-circuit on an overhead line at a short, but significant, distance from the terminals of the circuit-breaker

NOTE As a rule this distance is not more than a few kilometres.

3.1.120
power factor (of a circuit)
ratio of the resistance to the impedance at power frequency of an equivalent circuit supposed to be formed by an inductance and a resistance in series

3.1.121
external insulation
distances in air and the surfaces in contact with open air of solid insulation of the equipment, which are subject to dielectric stresses and to the effects of atmospheric and other external conditions such as pollution, humidity, vermin, etc.
[IEV 604-03-02, modified]

3.1.122
internal insulation
internal solid, liquid or gaseous parts of the insulation of equipment, which are protected from the effects of atmospheric and other external conditions
[IEV 604-03-03]

3.1.123
self-restoring insulation
insulation which completely recovers its insulating properties after a disruptive discharge
[IEV 604-03-04]

3.1.124
non-self restoring insulation
insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge
[IEV 604-03-05]

3.1.125
disruptive discharge
phenomenon associated with the failure of insulation under electric stress, in which the discharge completely bridges the insulation under test, reducing the voltage between the electrodes to zero or nearly to zero

NOTE 1 This term applies to discharges in solid, liquid and gaseous dielectrics and to combinations of these.

NOTE 2 A disruptive discharge in a solid dielectric produces permanent loss of dielectric strength (non-self-restoring insulation); in a liquid or gaseous dielectric, the loss may be only temporary (self-restoring insulation).

NOTE 3 The term "sparkover" is used when a disruptive discharge occurs in a gaseous or liquid dielectric. The term "flashover" is used when a disruptive discharge occurs over the surface of a solid dielectric in a gaseous or liquid medium. The term "puncture" is used when a disruptive discharge occurs through a solid dielectric.

3.1.126
non-sustained disruptive discharge (NSDD)
disruptive discharge associated with current interruption, that does not result in the resumption of power frequency current or, in the case of capacitive current interruption does not result in current in the main load circuit

NOTE Oscillations following NSDDs are associated with the parasitic capacitance and inductance local to or of the circuit-breaker itself. NSDDs may also involve the stray capacitance to ground of nearby equipment.

3.1.127
restrike performance
expected probability of restrike during capacitive current interruption as demonstrated by specified type tests

NOTE Specific numeric probabilities cannot be applied throughout a circuit-breaker service life.

3.1.128
effectively earthed neutral system
system earthed through a sufficiently low impedance such that for all system conditions the ratio of the zero-sequence reactance to the positive-sequence reactance (X_0/X_1) is positive and less than 3, and the ratio of the zero-sequence resistance to the positive-sequence reactance (R_0/X_1) is positive and less than 1. Normally such systems are solidly earthed (neutral) systems or low impedance earthed (neutral) systems

NOTE For the correct assessment of the earthing conditions not only the physical earthing conditions around the relevant location but the total system is to be considered.

3.1.129
non-effectively earthed neutral system
system other than effectively earthed neutral system, not meeting the conditions given in 3.1.128. Normally such systems are isolated neutral systems, high impedance earthed (neutral) systems or resonant earthed (neutral) systems

NOTE For the correct assessment of the earthing conditions not only the physical earthing conditions around the relevant location but the total system is to be considered.

3.1.130
re-ignition (of an a.c. mechanical switching device)
[IEV 441-17-45]

3.1.131
restrike (of an a.c. mechanical switching device)

[EV 441-17-46]

3.1.132
cable system
system in which the TRV during breaking of terminal fault at 100 % of short-circuit breaking current does not exceed the two-parameter envelope derived from Table 1 of this standard

NOTE 1 This definition is restricted to systems of rated voltages higher than 1 kV and less than 100 kV.

NOTE 2 Circuit-breakers of indoor substations with cable connection are generally in cable-systems.

NOTE 3 A circuit-breaker in an outdoor substation is considered to be in a cable-system if the total length of cable (or equivalent length when capacitors are also present) connected on the supply side of the circuit-breaker is at least 100 m. However if in an actual case with an equivalent length of cable shorter than 100 m a calculation can show that the actual TRV is covered by the envelope defined from Table 1, then this system is considered as a cable system.

NOTE 4 The capacitance of cable-systems on the supply side of circuit-breakers is provided by cables and/or capacitors and/or insulated bus.

3.1.133
line system
system in which the TRV during breaking of terminal fault at 100 % of short-circuit breaking current is covered by the two-parameter envelope derived from Table 2 of this standard and exceeds the two-parameter envelope derived from Table 1 of this standard

NOTE 1 This definition is restricted to systems of rated voltages equal to or higher than 15 kV and less than 100 kV.

NOTE 2 In line-systems, no cable is connected on the supply side of the circuit-breaker, with the possible exception of a total length of cable less than 100 m between the circuit-breaker and the supply transformer(s).

NOTE 3 Systems with overhead lines directly connected to a busbar (without intervening cable connections) are typical examples of line-systems.

3.2 Assemblies

No particular definitions.

3.3 Parts of assemblies

No particular definitions.

3.4 Switching devices

3.4.101
switching device
[IEV 441-14-01]

3.4.102
mechanical switching device
[IEV 441-14-02]

3.4.103
circuit-breaker
[IEV 441-14-20]

3.4.104
dead tank circuit-breaker
[IEV 441-14-25]

3.4.105
live tank circuit-breaker
[IEV 441-14-26]

3.4.106
air circuit-breaker
[IEV 441-14-27]

3.4.107
oil circuit-breaker
[IEV 441-14-28]

3.4.108
vacuum circuit-breaker
[IEV 441-14-29]

3.4.109
gas-blast circuit-breaker
[IEV 441-14-30]

3.4.110
sulphur hexafluoride circuit-breaker
SF_6 circuit-breaker
[IEV 441-14-31]

3.4.111
air-blast circuit-breaker
[IEV 441-14-32]

3.4.112
circuit-breaker class E1
circuit-breaker with basic electrical endurance not falling into the category of class E2 as defined in 3.4.113

3.4.113
circuit-breaker class E2
circuit-breaker designed so as not to require maintenance of the interrupting parts of the main circuit during its expected operating life, and only minimal maintenance of its other parts (circuit-breaker with extended electrical endurance)

NOTE 1 Minimal maintenance may include lubrication, replenishment of gas and cleaning of external surfaces, where applicable.

NOTE 2 This definition is restricted to distribution circuit-breakers having a rated voltage above 1 kV, and up to and including 52 kV. See Annex G for rationale behind introduction of class E2.

3.4.114
circuit-breaker class C1
circuit-breaker with low probability of restrike during capacitive current breaking as demonstrated by specific type tests

3.4.115
circuit-breaker class C2
circuit-breaker with very low probability of restrike during capacitive current breaking as demonstrated by specific type tests

3.4.116
circuit-breaker class M1
circuit-breaker with normal mechanical endurance ~~(mechanically type tested for 2 000 operations) not falling into the category of class M2 as defined in 3.4.117~~ as demonstrated by specific type tests

3.4.117
circuit-breaker class M2
frequently operated circuit-breaker for special service requirements and designed so as to require only limited maintenance as demonstrated by specific type tests ~~(circuit-breaker with extended mechanical endurance, mechanically type tested for 10 000 operations)~~

~~NOTE A combination of the different classes of circuit-breakers with regard to electrical endurance, mechanical endurance and the restrike probability during capacitive current breaking is possible. For the designation of these circuit-breakers the notation of the different classes are combined following an alphabetical order, for example C1-M2.~~

3.4.118
self-tripping circuit-breaker
circuit-breaker which is tripped by a current in the main circuit without the aid of any form of auxiliary power

3.4.119
circuit-breaker class S1
circuit-breaker intended to be used in a cable system

3.4.120
circuit-breaker class S2

circuit-breaker intended to be used in a line-system, or in a cable-system with direct connection (without cable) to overhead lines

3.5 Parts of circuit-breakers

3.5.101
pole
[IEV 441-15-01]

3.5.102
main circuit
[IEV 441-15-02]

3.5.103
control circuit
[IEV 441-15-03]

3.5.104
auxiliary circuit
[IEV 441-15-04]

3.5.105
contact
[IEV 441-15-05]

3.5.106
contact piece
[IEV 441-15-06]

3.5.107
main contact
[IEV 441-15-07]

3.5.108
arcing contact
[IEV 441-15-08]

3.5.109
control contact
[IEV 441-15-09]

3.5.110
auxiliary contact
[IEV 441-15-10]

3.5.111
auxiliary switch
[IEV 441-15-11]

3.5.112
“a” contact;
make contact
[IEV 441-15-12]

3.5.113
“b” contact;
break contact
[IEV 441-15-13]

3.5.114
sliding contact
[IEV 441-15-15]

3.5.115
rolling contact
[IEV 441-15-16]

3.5.116
release
[IEV 441-15-17]

3.5.117
arc control device
[IEV 441-15-18]

3.5.118
position indicating device
[IEV 441-15-25]

3.5.119
connection (bolted or equivalent)
two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts or the equivalent

3.5.120
terminal
component provided for the connection of a device to external conductors

[IEV 151-01-03]

3.5.121
making (or breaking) unit
part of a circuit-breaker which in itself acts as a circuit-breaker and which, in series with one or more identical and simultaneously operated making or breaking units, forms the complete circuit-breaker

NOTE 1 Making units and breaking units may be separate or combined. Each unit may have several contacts.

NOTE 2 The means controlling the voltage distribution between units may differ from unit to unit.

3.5.122
module
assembly which generally comprises making or breaking units, post-insulators and mechanical parts and which is mechanically and electrically connected to other identical assemblies to form a pole of a circuit-breaker

3.5.123
enclosure
part of switchgear and controlgear providing a specified degree of protection (see IEC 60529) of equipment against external influences and a specified degree of protection against approach to or contact with live parts and against contact with moving parts

[IEV 441-13-01, modified]

3.5.124
operating mechanism
part of the circuit-breaker that actuates the main contacts

3.5.125
power kinematic chain
mechanical connecting system from and including the operating mechanism up to and including the moving contacts

NOTE See also A.3.5.111 of IEC 62271-102.

3.5.126
alternative operating mechanism
an alternative operating mechanism is obtained when a change in the power kinematic chain of the original operating mechanism or the use of an entirely different operating mechanism leads to the same mechanical characteristics.

NOTE 1 Mechanical characteristics are defined in 6.101.1.1. The use of mechanical characteristics and related requirements are described in Annex N.

NOTE 2 An alternative operating mechanism can utilise an operating principle different from the original one (for example the alternative mechanism can be spring-operated and the original hydraulic).

NOTE 3 A change in the secondary equipment does not lead to an alternative operating mechanism. However, it has to be checked that changes in the opening time/minimum clearing time does not entail different requirements for test-duty T100a (see 6.102.10).

3.6 Operation

3.6.101
operation
[IEV 441-16-01]

3.6.102
operating cycle
[IEV 441-16-02]

3.6.103
operating sequence
[IEV 441-16-03]

3.6.104
closing operation
[IEV 441-16-08]

3.6.105
opening operation
[IEV 441-16-09]

3.6.106
auto-reclosing
[IEV 441-16-10]

3.6.107
positive opening operation
[IEV 441-16-11]

3.6.108
positively driven operation
[IEV 441-16-12]

3.6.109
dependent manual operation

[IEV 441-16-13]

3.6.110
dependent power operation
[IEV 441-16-14]

3.6.111
stored energy operation
operation by means of energy stored in the mechanism itself prior to the switching operation and sufficient to complete the specified operating sequence under predetermined conditions

3.6.112
independent manual operation
[IEV 441-16-16]

3.6.113
closed position
[IEV 441-16-22]

3.6.114
open position
[IEV 441-16-23]

3.6.115
instantaneous release
[IEV 441-16-32]

3.6.116
making-current release
release which permits a circuit-breaker to open, without any intentional time delay, during a closing operation, if the making current exceeds a predetermined value, and which is rendered inoperative when the circuit-breaker is in the closed position

3.6.117
over-current release
[IEV 441-16-33]

3.6.118
definite time-delay over-current release
[IEV 441-16-34]

3.6.119
inverse time-delay over-current release
[IEV 441-16-35]

3.6.120
direct over-current release
[IEV 441-16-36]

3.6.121
indirect over-current release
[IEV 441-16-37]

3.6.122
shunt release
[IEV 441-16-41]

3.6.123
under-voltage release
[IEV 441-16-42]

3.6.124
reverse current release (d.c. only)
[IEV 441-16-43]

3.6.125
operating current (of an over-current release)
[IEV 441-16-45]

3.6.126
current setting (of an over-current release)
[IEV 441-16-46]

3.6.127
current setting range (of an over-current release)
[IEV 441-16-47]

3.6.128
anti-pumping device
[IEV 441-16-48]

3.6.129
interlocking device
[IEV 441-16-49]

3.6.130
circuit-breaker with lock-out preventing closing
[IEV 441-14-23]

3.7 Characteristic quantities

Figures 1 to 7 illustrate some definitions of this subclause.

Time quantities, see definitions 3.7.133 to 3.7.147, are expressed in milliseconds or in cycles. When expressed in cycles, the power frequency should be stated in brackets. In the case of circuit-breakers incorporating switching resistors, a distinction is made, where applicable, between time quantities associated with the contacts switching the full current and the contacts switching the current limited by switching resistors.

Unless otherwise stated, the time quantities referred to are associated with the contacts switching the full current.

3.7.101
rated value
quantity value assigned, generally by a manufacturer, for a specified operating condition of component, device or equipment

[IEV 151-04-03]

3.7.102
prospective current (of a circuit and with respect to a switching device or a fuse)
[IEV 441-17-01]

3.7.103
prospective peak current
peak value of the first major loop of the prospective current during the transient period following initiation

NOTE The definition assumes that the current is made by an ideal circuit-breaker, i.e. with instantaneous and simultaneous transition of its impedance across the terminals of each pole from infinity to zero. The peak value may differ from one pole to another; it depends on the instant of current initiation relative to the voltage wave across the terminals of each pole.

3.7.104
peak current
peak value of the first major loop of current during the transient period following initiation

3.7.105
prospective symmetrical current (of an a.c. circuit)
[IEV 441-17-03]

3.7.106
maximum prospective peak current (of an a.c. circuit)
[IEV 441-17-04]

3.7.107
prospective making current (for a pole of a switching device)
[IEV 441-17-05]

3.7.108
(peak) making current
peak value of the first major loop of the current in a pole of a circuit-breaker during the transient period following the initiation of current during a making operation

NOTE 1 The peak value may differ from one pole to another and from one operation to another as it depends on the instant of current initiation relative to the wave of the applied voltage.

NOTE 2 Where, for a polyphase circuit, a single value of (peak) making current is referred to, this is, unless otherwise stated, the highest value in any phase.

3.7.109
prospective breaking current (for a pole of a switching device)
prospective current evaluated at the instant corresponding to the initiation of the arc during breaking process

3.7.110
breaking current
[IEV 441-17-07]

3.7.111
critical (breaking) current
value of breaking current, less than rated short-circuit breaking current, at which the arcing time is a maximum and is significantly longer than at the rated short-circuit breaking current.

NOTE It will be assumed that this is the case if the minimum arcing times in any of the test-duties T10, T30 or T60 is one half-cycle or more longer than the minimum arcing times in the adjacent test-duties

3.7.112
breaking capacity
[IEV 441-17-08]

3.7.113
no-load line-charging breaking capacity
breaking capacity for which the specified conditions of use and behaviour include the opening of an overhead line operating at no-load

3.7.114
no-load cable-charging breaking capacity
breaking capacity for which the specified conditions of use and behaviour include the opening of an insulated cable operating at no-load

3.7.115
capacitor bank breaking capacity
breaking capacity for which the specified conditions of use and behaviour include the opening of a capacitor bank

3.7.116
making capacity
[IEV 441-17-09]

3.7.117
capacitor bank inrush making capacity
making capacity for which the specified conditions of use and behaviour include the closing onto a capacitor bank

3.7.118
out-of-phase (making or breaking) capacity
making or breaking capacity for which the specified conditions of use and behaviour include the loss or the lack of synchronism between the parts of an electrical system on either side of the circuit-breaker

3.7.119
short-circuit making capacity
[IEV 441-17-10]

3.7.120
short-circuit breaking capacity
[IEV 441-17-11]

3.7.121
short-time withstand current
[IEV 441-17-17]

3.7.122
peak withstand current
[IEV 441-17-18]

3.7.123
applied voltage
[IEV 441-17-24]

3.7.124
recovery voltage
[IEV 441-17-25]

3.7.125
transient recovery voltage (TRV)
[IEV 441-17-26]

3.7.126
prospective transient recovery voltage (of a circuit)
[IEV 441-17-29]

3.7.127
power frequency recovery voltage
[IEV 441-17-27]

3.7.128
peak arc voltage
[IEV 441-17-30]

3.7.129
clearance
[IEV 441-17-31]

3.7.130
clearance between poles
[IEV 441-17-32]

3.7.131
clearance to earth
[IEV 441-17-33]

3.7.132
clearance between open contacts
[IEV 441-17-34]

3.7.133
opening time
opening time of a circuit-breaker defined according to the tripping method as stated below and with any time delay device forming an integral part of the circuit-breaker adjusted to its minimum setting:

a) for a circuit-breaker tripped by any form of auxiliary power, the opening time is the interval of time between the instant of energising the opening release, the circuit-breaker being in the closed position, and the instant when the arcing contacts have separated in all poles;

b) for a self-tripping circuit-breaker, the opening time is the interval of time between the instant at which, the circuit-breaker being in the closed position, the current in the main circuit reaches the operating value of the overcurrent release and the instant when the arcing contacts have separated in all poles.

NOTE 1 The opening time may vary with the breaking current.

NOTE 2 For circuit-breakers with more than one interrupting unit per pole, the instant when the arcing contacts have separated in all poles is determined as the instant of contact separation in the first unit of the last pole.

NOTE 3 The opening time includes the operating time of any auxiliary equipment necessary to open the circuit-breaker and forming an integral part of the circuit-breaker.

3.7.134
arcing time (of a multipole switching device)
interval of time between the instant of the first initiation of an arc and the instant of final arc extinction in all poles

[IEV 441-17-38]

3.7.135
break time
interval of time between the beginning of the opening time of a mechanical switching device and the end of the arcing time

[IEV 441-17-39, modified]

3.7.136
closing time
interval of time between energising the closing circuit, the circuit-breaker being in the open position, and the instant when the contacts touch in all poles

NOTE The closing time includes the operating time of any auxiliary equipment necessary to close the circuit-breaker and forming an integral part of the circuit-breaker.

3.7.137
make time
interval of time between energising the closing circuit, the circuit-breaker being in the open position, and the instant when the current begins to flow in the first pole

[IEV 441-17-40, modified]

NOTE 1 The make time includes the operating time of any auxiliary equipment necessary to close the circuit-breaker and forming an integral part of the circuit-breaker.

NOTE 2 The make time may vary, e.g. due to the variation of the pre-arcing time.

3.7.138
pre-arcing time
interval of time between the initiation of current flow in the first pole during a closing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the contacts touch in the arcing pole for single-phase conditions

NOTE 1 The pre-arcing time depends on the instantaneous value of the applied voltage during a specific closing operation and therefore may vary considerably.

NOTE 2 This definition for pre-arcing time for a circuit-breaker should not be confused with the definition for pre-arcing time for a fuse.

3.7.139
open-close time (during auto-reclosing)
interval of time between the instant when the arcing contacts have separated in all poles and the instant when the contacts touch in the first pole during a reclosing cycle

3.7.140
dead time (during auto-reclosing)
interval of time between final arc extinction in all poles in the opening operation and the first re-establishment of current in any pole in the subsequent closing operation

NOTE The dead time may vary, e.g. due to the variation of the pre-arcing time.

3.7.141
reclosing time
interval of time between the beginning of the opening time and the instant when the contacts touch in all poles during a reclosing cycle

3.7.142
re-make time (during reclosing)
interval of time between the beginning of the opening time and the first re-establishment of current in any pole in the subsequent closing operation

NOTE The re-make time may vary, e.g. due to the variation of the pre-arcing time.

3.7.143
close-open time
interval of time between the instant when the contacts touch in the first pole during a closing operation and the instant when the arcing contacts have separated in all poles during the subsequent opening operation

[IEV 441-17-42, modified]

NOTE Unless otherwise stated, it is assumed that the opening release incorporated in the circuit-breaker is energised at the instant when the contacts touch in the first pole during closing. This represents the minimum close-open time.

3.7.144
make-break time
interval of time between the initiation of current flow in the first pole during a closing operation and the end of the arcing time during the subsequent opening operation

NOTE 1 Unless otherwise stated, it is assumed that the opening release of the circuit-breaker is energised one half-cycle after current begins to flow in the main circuit during making. It should be noted that the use of relays with shorter operating time may subject the circuit-breaker to asymmetrical currents that are in excess of those provided for in 6.106.5.

NOTE 2 The make-break time may vary due to the variation of the pre-arcing time.

3.7.145
pre-insertion time (of a closing resistor)
~~interval of time during a closing operation in any one pole between the instant of contact touch in the closing resistor element and the instant of contact touch in the main breaking unit of that pole~~

~~NOTE For circuit-breakers having series connected breaking units, the pre-insertion time is defined as the interval of time between the instant of the last contact touch in any closing resistor element and the instant of the last contact touch in any main breaking unit.~~

interval of time during a closing operation between the instant of contact touch of the resistor elements in any one pole and the instant of contact touch in the breaking unit of that pole

3.7.146
minimum trip duration
minimum time the auxiliary power is applied to the opening release to ensure complete opening of the circuit-breaker

3.7.147
minimum close duration
minimum time the auxiliary power is applied to the closing device to ensure complete closing of the circuit-breaker

3.7.150
normal current
current which the main circuit of a circuit-breaker is capable of carrying continuously under specified conditions of use and behaviour

3.7.151
peak factor (of the line transient voltage)
ratio between the maximum excursion and the initial value of the line transient voltage to earth of a phase of an overhead line after the interruption of a short-line fault current

NOTE The initial value of the transient voltage corresponds to the instant of arc extinction in the pole considered.

3.7.152
first-pole-to-clear factor (in a three-phase system)
when interrupting any symmetrical three-phase current the first-pole-to-clear factor is the ratio of the power frequency voltage across the first interrupting pole before current interruption in the other poles, to the power frequency voltage occurring across the pole or the poles after interruption in all three poles

3.7.153
amplitude factor
ratio between the maximum excursion of the transient recovery voltage to the crest value of the power frequency recovery voltage

3.7.154
insulation level
for a circuit-breaker, a characteristic defined by one or two values indicating the insulation withstand voltages

[IEV 604-03-47, modified]

3.7.155
power frequency withstand voltage
r.m.s. value of sinusoidal power frequency voltage that the circuit-breaker can withstand during tests made under specified conditions and for a specified time

[IEV 604-03-40, modified]

3.7.156
impulse withstand voltage
peak value of the standard impulse voltage wave which the insulation of the circuit-breaker withstands under specified test conditions

NOTE Depending on the shape of wave, the term may be qualified as "switching impulse withstand voltage" or "lightning impulse withstand voltage".

3.7.157
minimum functional pressure for operation
pressure, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa, which may be expressed in relative or absolute terms, at which and above which rated characteristics of a circuit-breaker are maintained and at which a replenishment of the operating device becomes necessary

NOTE This pressure is often designated as interlocking pressure (refer to 3.6.4.6 of IEC 62271-1).

3.7.158
minimum functional pressure for interruption and insulation
pressure for interruption and for insulation, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa, which may be expressed in relative or absolute terms, at which and above which rated characteristics of a circuit-breaker are maintained and at which a replenishment of the interrupting and/or insulating fluid becomes necessary

NOTE 1 See also 3.6.4.5 of IEC 62271-1.

NOTE 2 For circuit-breakers with a sealed pressure system (also termed sealed-for-life), the minimum functional pressure for interruption is the one at which the rated characteristics of the circuit-breaker are maintained taking into account the pressure drop at the end of the expected operating life.

3.7.159
minimum clearing time

sum of the minimum opening time, minimum relay time (0,5 cycle), and the minimum arcing time at current interruption after the minor loop of the first-pole-to-clear, during test duty T100a only, as declared by the manufacturer

NOTE This definition should be used only for the determination of the test parameters during short-circuit breaking tests according to test duty T100a.

3.7.160
insertion time (of an opening resistor)
interval of time during an opening operation between the instant of separation of the arcing contacts in the main interrupters of any one pole and the instant of contact separation in the resistor interrupters in that pole

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4 Ratings

The characteristics of a circuit-breaker, including its operating devices and auxiliary equipment, that shall be used to determine the ratings are the following:

Rated characteristics to be given for all circuit-breakers

a) rated voltage;

b) rated insulation level;

c) rated frequency;

d) rated normal current;

e) rated short-time withstand current;

f) rated peak withstand current;

g) rated duration of short-circuit;

h) rated supply voltage of closing and opening devices and of auxiliary circuits;

i) rated supply frequency of closing and opening devices and of auxiliary circuits;

j) rated pressures of compressed gas supply and/or of hydraulic supply for operation, interruption and insulation, as applicable;

k) rated short-circuit breaking current;

l) transient recovery voltage related to the rated short-circuit breaking current;

m) rated short-circuit making current;

n) rated operating sequence;

o) rated time quantities.

Rated characteristics to be given in the specific cases indicated below

p) characteristics for short-line faults related to the rated short-circuit breaking current, for circuit-breakers designed for direct connection to overhead lines, irrespective of the type of network on the source side, and rated at 15 kV and above and at more than 12,5 kA rated short-circuit breaking current;

q) rated line-charging breaking current, for three-pole circuit-breakers intended for switching over-head transmission lines (mandatory for circuit-breakers of rated voltages equal to or greater than 72,5 kV.

r) rated cable-charging breaking current, for three-pole circuit-breakers intended for switching cables (mandatory for circuit-breakers of rated voltages equal to or less than 52 kV).

Rated characteristics to be given on request

s) rated out-of-phase making and breaking current;

t) rated single capacitor bank breaking current;

u) rated back-to-back capacitor bank breaking current;

v) rated capacitor bank inrush making current;

w) rated back-to-back capacitor bank inrush making current.

The rated characteristics of the circuit-breaker are referred to the rated operating sequence.

4.1 Rated voltage (U_r)

Subclause 4.1 of IEC 62271-1 is applicable.

4.2 Rated insulation level

Subclause 4.2 of IEC 62271-1 is applicable with the following addition:

The standard values of rated withstand voltages across the open circuit-breaker are given in Tables 1a, 1b, 2a and 2b of IEC 62271-1.

However, for circuit-breakers with rated voltage of 300 kV and above intended for use in synchronisation operations simultaneously with a substantial transient or temporary overvoltage, the insulation of a standard circuit-breaker may be insufficient. In such cases it is suggested to use a standard circuit-breaker having a higher rated voltage or to use a special circuit-breaker, increasing the severity of the test with the circuit-breaker open. The test procedure for this test is described in 6.2.7.2. The standard values of rated power frequency and rated switching impulse withstand voltage across the open switching device are given in columns (3) and (6) of Tables 2a and 2b of IEC 62271-1.

For circuit-breakers with rated voltages 1 100 kV and 1 200 kV, Table 36 applies.

Table 36 – Rated insulation levels for rated voltages of 1 100 kV and 1 200 kV

Rated voltage U_r (kV r.m.s. value)	Rated short-duration power-frequency withstand voltage U_d kV (r.m.s. value)		Rated switching impulse withstand voltage U_s kV (peak value)			Rated lightning impulse withstand voltage U_p kV (peak value)	
	Phase-to-earth and between phases (Note 3)	**Across open switching device and/or isolating distance** (Notes 1 and 3)	**Phase-to-earth and across open switching device**	**Between phases** (Notes 3 and 4)	**Across isolating distance** (Notes 2 and 3)	**Phase-to-earth and between phases**	**Across open switching device and/or isolating distance** (Notes 2 and 3)
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
1 100	1 100 1 450	$\frac{1\,100\times 2}{\sqrt{3}}$	1 550	2 635	1 550 + (900)	2 250	2 250 + (630)
		1 100 + (635)	1 800	2 880		2 400	2 400 + (630)
1 200	1 200 1 600	$\frac{1\,200\times 2}{\sqrt{3}}$	1 800	2 970	1 675 + (980)	2 400	2 400 + (685)
		1 200 + (695)	1 950	3 120		2 550	2 550 + (685)
		1 200 + (695)	1 950	3 120		2 550	2 550 + (685)

NOTE 1 In column (3) the values in brackets are r.m.s. values.

NOTE 2 In column (6), values in brackets are the peak values of the power-frequency voltage $U_r \times \sqrt{2}/\sqrt{3}$ applied to the opposite terminal (combined voltage).

In column (8), values in brackets are the peak values of the power-frequency voltage 0,7 $U_r \times \sqrt{2}/\sqrt{3}$ applied to the opposite terminal (combined voltage).

NOTE 3 Values of column (2) are applicable as follows:

a) the smaller value is for type tests, phase-to-earth, the larger value is for the withstand voltage between phases;

b) the smaller value is for routine tests, phase-to-earth and across the open switching device.

The values of columns (3), (5), (6) and (8) are applicable for type tests only.

NOTE 4 These values are derived using the multiplying factors given in Table 3 of IEC 60071-1:2006.

4.3 Rated frequency (f_r)

Subclause 4.3 of IEC 62271-1 is applicable with the following modification:

The standard values for the rated frequency of high voltage circuit-breakers are 50 Hz and 60 Hz.

4.4 Rated normal current (I_r) and temperature rise

Subclause 4.4 of IEC 62271-1 is applicable.

If the circuit-breaker is fitted with a series connected accessory, such as a direct over-current release, the rated normal current of the accessory is the r.m.s. value of the current which the accessory shall be able to carry continuously without deterioration at its rated frequency, with a temperature rise not exceeding the values specified in Table 3 of IEC 62271-1.

4.5 Rated short-time withstand current (I_k)

Subclause 4.5 of IEC 62271-1 is applicable with the following addition:

The rated short-time withstand current is equal to the rated short-circuit breaking current (see 4.101).

4.6 Rated peak withstand current (I_p)

Subclause 4.6 of IEC 62271-1 is applicable with the following addition:

For circuit-breakers with rated voltages higher than 800 kV, the standard d.c. time constant is 120 ms and the rated peak withstand current equal to 2,7 times the rated short-time withstand current for 50 Hz and 60 Hz.

The rated peak withstand current is equal to the rated short-circuit making current (see 4.103).

4.7 Rated duration of short circuit (t_k)

Subclause 4.7 of IEC 62271-1 is applicable~~ with the following addition:~~.

~~A rated duration of a short-circuit need not be assigned to a self-tripping circuit-breaker provided that the following applies. When connected in a circuit the prospective breaking current of which is equal to its rated short-circuit breaking current, the circuit-breaker shall be capable of carrying the resulting current for the break-time required. This break time is that required by the circuit-breaker with the overcurrent release set for the maximum time lag when operating in accordance with its rated operating sequence.~~

~~NOTE Direct overcurrent releases include integrated tripping systems.~~

4.8 Rated supply voltage of closing and opening devices and of auxiliary and control circuits (U_a)

Subclause 4.8 of IEC 62271-1 is applicable.

4.9 Rated supply frequency of closing and opening devices and auxiliary circuits

Subclause 4.9 of IEC 62271-1 is applicable.

4.10 Rated pressures of compressed gas supply for insulation, operation and/or interruption

Subclause 4.10 of IEC 62271-1 is applicable.

4.101 Rated short-circuit breaking current (I_{sc})

The rated short-circuit breaking current is the highest short-circuit current which the circuit-breaker shall be capable of breaking under the conditions of use and behaviour prescribed in this standard. Such a current is found in a circuit having a power-frequency recovery voltage corresponding to the rated voltage of the circuit-breaker and having a transient recovery voltage equal to the value specified in 4.102. For three-pole circuit-breakers, the a.c. component relates to a three-phase short-circuit. Where applicable the provisions of 4.105 concerning short-line faults shall be taken into account.

The rated short-circuit breaking current is characterised by two values:

– the r.m.s. value of its a.c. component;

– the d.c. time constant of the rated short-circuit breaking current which results in a percentage of d.c. component at contact separation.

NOTE 1 If the percentage of d.c. component at contact separation does not exceed 20 %, the rated short-circuit breaking current is characterised only by the r.m.s. value of its a.c. component.

NOTE 2 The percentage of d.c. component is a function of the d.c. time constant of the rated short-circuit breaking current (see 4.101.2) and of the instant of initiation of the short-circuit current.

For determination of the a.c. and the percentage of d.c. component at any time following current initiation, see Figure 8.

The circuit-breaker shall be capable of breaking any short-circuit current up to its rated short-circuit breaking current containing any a.c. component up to the rated value and, associated with it, any percentage of d.c. component corresponding to the d.c. time constant up to that specified, under the conditions mentioned above.

The following applies to a standard circuit-breaker:

a) at voltages below and equal to the rated voltage, it shall be capable of breaking its rated short-circuit breaking current;

b) at voltages above the rated voltage, no short-circuit breaking current is guaranteed except to the extent provided for in 4.106.

4.101.1 AC component of the rated short-circuit breaking current

The standard value of the a.c. component of the rated short-circuit breaking current shall be selected from the R10 series specified in IEC 60059.

NOTE The R10 series comprises the numbers 1 – 1,25 – 1,6 – 2 – 2,5 – 3,15 – 4 – 5 – 6,3 – 8 and their products by 10^n.

4.101.2 DC time constant of the rated short-circuit breaking current

a) For circuit-breakers with rated voltages up to and including 800 kV

The standard d.c. time constant is 45 ms. The following are special case d.c. time constants, related to the rated voltage of the circuit-breaker:

– 120 ms for rated voltages up to and including 52 kV;

– 60 ms for rated voltages from 72,5 kV up to and including 420 kV;

– 75 ms for rated voltages 550 kV and ~~above~~ 800 kV.

These special case time constants recognise that the standard value may be inadequate in some systems. They are provided as unified values for such special system needs, taking into account the characteristics of the different ranges of rated voltage, for example their particular system structures, design of lines, etc.

NOTE 1 In addition, some applications may require even higher values, for example if a circuit-breaker is close to generators. In these circumstances the required d.c. time constant and any additional test requirements should be specified in the inquiry.

NOTE 2 More detailed information on the use of the standard time constant and the special case time constants is given in the explanatory Note I.2.1. The percentage of d.c. component against time for different time constants is shown in Figure 9.

NOTE 3 The percentage of d.c. component at contact separation as used in former editions of IEC 62271-100 or IEC 60056 can be derived by using the equation given in 6.106.5. The concept of percentage of d.c. component at contact separation for symmetrical test-duties is still used in this edition. For the asymmetrical test-duty T100a, such concept has been changed (see I.2.1 and Annexes P and Q).

b) For circuit-breakers with rated voltages higher than 800 kV

The standard d.c. time constant is 120 ms. Note 3 is also applicable in this case

4.102 Transient recovery voltage related to the rated short-circuit breaking current

The transient recovery voltage (TRV) related to the rated short-circuit breaking current in accordance with 4.101, is the reference voltage which constitutes the limit of the prospective transient recovery voltage of circuits which the circuit-breaker shall be capable of withstanding under fault conditions.

4.102.1 Representation of TRV waves

The waveform of transient recovery voltages varies according to the arrangement of actual circuits.

In some cases, particularly in systems with a voltage 100 kV and above, and where the short-circuit currents are relatively large in relation to the maximum short-circuit current at the point under consideration, the transient recovery voltage contains first a period of high rate of rise, followed by a later period of lower rate of rise. This waveform is generally adequately represented by an envelope consisting of three line segments defined by means of four parameters. Methods of drawing TRV envelopes are given in Annex E.

In other cases, particularly in systems with a voltage less than 100 kV, or in systems with a voltage greater than 100 kV in conditions where the short-circuit currents are relatively small in relation to the maximum short-circuit currents and fed through transformers, the transient recovery voltage approximates to a damped single frequency oscillation. This waveform is adequately represented by an envelope consisting of two line segments defined by means of two parameters. Methods of drawing TRV envelopes are given in Annex E.

Such a representation in terms of two parameters is a special case of representation in terms of four parameters.

The influence of local capacitance on the source side of the circuit-breaker produces a slower rate of rise of the voltage during the first few microseconds of the TRV. This is taken into account by introducing a time delay.

It appears that every part of the TRV wave may influence the interrupting capability of a circuit-breaker. The very beginning of the TRV may be of importance for some types of circuit-breakers. This part of the TRV, called initial TRV (ITRV), is caused by the initial oscillation of small amplitude due to reflections from the first major discontinuity along the busbar. The ITRV is mainly determined by the busbar and line bay configuration of the substation. The ITRV is a physical phenomenon which is very similar to the short-line fault. Compared with the short-line fault, the first voltage peak is rather low, but the time to the first peak is extremely short, that is, within the first microseconds after current zero. Therefore the thermal mode of interruption may be influenced.

~~If the circuit-breaker has a short-line fault rating, the ITRV requirements are considered to be covered if the short-line fault tests are carried out using a line with insignificant time delay (see 6.104.5.2 and 6.109.3) unless both terminals are not identical from an electrical point of view (for instance when an additional capacitance is used as mentioned in Note 4 of 6.109.3). In this case test circuits, which produce an equivalent TRV stress across the circuit-breaker may be used as an alternative.~~

~~Since the ITRV is proportional to the busbar surge impedance and to the current, the ITRV requirements can be neglected for all circuit-breakers with a rated short-circuit breaking current of less than 25 kA and for circuit-breakers with a rated voltage below 100 kV. In addition the ITRV requirements can be neglected for circuit-breakers installed in metal enclosed gas insulated switchgear (GIS) because of the low surge impedance.~~

If a circuit-breaker with a rated voltage equal to or less than 800 kV has a short-line fault rating, the ITRV requirements are covered if the short-line fault tests are carried out using a line with a time delay less than 100 ns (see 6.104.5.2 and 6.109.3) unless both terminals are not identical from an electrical point of view (for instance when an additional capacitance is used as mentioned in Note 4 of 6.109.3). When terminals are not identical from an electrical point of view, test circuits which produce an equivalent TRV stress across the circuit-breaker may be used.

For circuit-breakers with a rated voltage higher than 800 kV, the ITRV requirements are considered to be covered if the short-line fault tests are carried out using a line with a time delay less than 100 ns and a surge impedance of 450 Ω unless both terminals are not identical from an electrical point of view (for instance when an additional capacitance is used as mentioned in Note 4 of 6.109.3). When terminals are not identical from an electrical point of view, test circuits which produce an equivalent TRV stress across the circuit-breaker may be used.

Since the ITRV is proportional to the busbar surge impedance and to the current, the ITRV requirements can be neglected for all circuit-breakers with a rated short-circuit breaking current of less than 25 kA and for circuit-breakers with a rated voltage below 100 kV. In addition the ITRV requirements can be neglected for circuit-breakers installed in metal enclosed gas insulated switchgear (GIS) because of the low surge impedance. ITRV requirements can also be neglected for circuit-breakers directly connected to a busbar with a total source side capacitance of more than 800 pF.

4.102.2 Representation of TRV

The following parameters are used for the representation of TRV:

a) Four-parameter reference line (see Figure 10):

~~u_1 = first reference voltage, in kilovolts;~~

~~t_1 = time to reach u_1, in microseconds;~~

~~u_c = second reference voltage (TRV peak value), in kilovolts;~~

~~t_2 = time to reach u_c, in microseconds.~~

~~TRV parameters are defined as a function of the rated voltage (U_r), the first-pole-to-clear factor (k_{pp}) and the amplitude factor (k_{af}) as follows:~~

$$\cancel{u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}}$$

~~t_1 is derived from u_1 and the specified value of the rate of rise u_1/t_1 = RRRV;~~

~~t_1 for out-of-phase = 2 × t_1 (for terminal fault)~~

$\cancel{u_c = k_{af} \times k_{pp} U_r \sqrt{\frac{2}{3}}}$ ~~, where k_{af} is equal to:~~

~~– 1,4 for terminal fault and short-line fault,~~

~~– 1,25 for out-of-phase.~~

~~$t_2 = 4t_1$ for terminal fault and short-line fault;~~

~~t_2 for out-of-phase = between t_2 (for terminal fault) and $2 \times t_2$ (for terminal fault).~~

u_1 = first reference voltage, in kilovolts;

t_1 = time to reach u_1, in microseconds;

u_c = second reference voltage (TRV peak value), in kilovolts;

t_2 = time to reach u_c, in microseconds.

TRV parameters are defined as a function of the rated voltage (U_r), the first-pole-to-clear factor (k_{pp}) and the amplitude factor (k_{af}) as follows:

$$u_1 = 0{,}75 \times k_{pp} U_r \sqrt{\frac{2}{3}}$$

t_1 for terminal fault is derived from u_1 and the specified value of the rate of rise u_1/t_1 = RRRV;

t_1 for out-of-phase = $2 \times t_1$ (for terminal fault)

$$u_c = k_{af} \times k_{pp} U_r \sqrt{\frac{2}{3}}$$

1) For rated voltages up to and including 800 kV, k_{af} is equal to:
   - 1,4 for terminal fault and short-line fault;
   - 1,25 for out-of-phase.

   $t_2 = 4t_1$ for terminal fault and short-line fault;

   t_2 for out-of-phase = between t_2 (for terminal fault) and $2t_2$ (for terminal fault).

2) For rated voltages higher than 800 kV:

   A four-parameter reference line is specified for terminal fault and short-line fault test-duties and a two-parameter reference line (see b) and Figure 11) for out-of-phase test-duties. k_{af} is equal to:
   - 1,5 for terminal fault and short-line fault;
   - 1,25 for out-of-phase.

   $t_2 = 3t_1$ for test-duty T100 and for the supply side circuit for short-line fault.

   $t_2 = 4{,}5t_1$ for T60.

   For out-of-phase test duties OP1 and OP2, time t_3 is derived from u_c and a rate of rise of 1,54 kV/µs.

b) Two-parameter reference line (see Figure 11):

u_c = reference voltage (TRV peak value), in kV;

t_3 = time, in µs.

TRV parameters are defined as a function of the rated voltage (U_r), the first-pole-to-clear factor (k_{pp}) and the amplitude factor (k_{af}) as follows:

$$u_c = k_{af} \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$$

where k_{af} is equal to

1,4 for terminal fault in the case of cable systems;

1,54 for terminal fault and short-line fault, in the case of line systems;

1,25 for out-of-phase;

t_3 for the supply side circuit for short-line fault = t_3 (terminal fault).

t_3 for out-of-phase = 2 × t_3 (terminal fault).

c) Delay line of TRV (see Figures 10 and 11):

~~t_d = time delay, in microseconds;~~

~~u' = reference voltage, in kilovolts;~~

~~t' = time to reach u', in microseconds~~

~~The delay line starts on the time axis at the rated time delay and runs parallel to the first section of the reference line of rated TRV and terminates at the voltage u' (time co-ordinate t').~~

~~For rated voltages lower than 100 kV:~~

~~t_d = 0,15 × t_3, for terminal fault and out-of-phase in the case of cable systems;~~

~~t_d = 0,05 × t_3, for terminal fault and short-line-fault in the case of line systems;~~

~~t_d = 0,15 × t_3, for out-of-phase in the case of line systems;~~

~~$u' = u_c/3$;~~

~~t' is derived from t_d and t_3 according to Figure 11, $t' = t_d + t_3/3$.~~

~~For rated voltages equal or higher than 100 kV:~~

~~t_d = 2 µs for terminal fault and for the supply side circuit for short-line fault;~~

~~t_d = 2 µs to 0,1 × t_1 for out-of-phase;~~

~~$u' = u_1/2$;~~

~~t' is derived from u', u_1/t_1 (RRRV) and t_d according to Figure 10, $t' = t_d + u'$/RRRV.~~

t_d = time delay, in microseconds;

u' = reference voltage, in kilovolts;

t' = time to reach u', in microseconds.

The delay line starts on the time axis at the rated time delay and runs parallel to the first section of the reference line of rated TRV and terminates at the voltage u' (time co-ordinate t').

For rated voltages lower than 100 kV:

t_d = 0,15 × t_3, for terminal fault and out-of-phase in the case of cable systems;

t_d = 0,05 × t_3, for terminal fault and short-line-fault in the case of line systems;

t_d = 0,15 × t_3, for out-of-phase in the case of line systems;

$u' = u_c/3$;

t' is derived from t_d and t_3 according to Figure 11, $t' = t_d + t_3/3$.

For rated voltages from 100 kV up to and including 800 kV:

t_d = 2 µs for terminal fault and for the supply side circuit for short-line fault;

t_d = 2 µs to 0,1 × t_1 for out-of-phase;

$u' = u_1/2$;

t' is derived from u', u_1/t_1 (RRRV) and t_d according to Figure 10, $t' = t_d + u'$/RRRV.

For rated voltages higher than 800 kV:

t_d = 2 µs for terminal fault and for the supply side circuit for short-line fault;

$u' = u_1/2$;

t' is derived from u', u_1/t_1 (RRRV) and t_d according to Figure 10, $t' = t_d + u'$/RRRV.

t_d = 2 µs to 0,05 × t_3 for out-of-phase;

$u' = u_c/3$, t' is derived from u_c and a rate-of-rise of 1,54 kV/µs.

d) ITRV (see Figure 12):

u_i = reference voltage (ITRV peak), in kilovolts;

t_i = time to reach u_i, in microseconds.

The rate of rise of the ITRV is dependent on the interrupted short-circuit current and its amplitude depends upon the distance to the first discontinuity along the busbar. The ITRV is defined by the voltage u_i and the time t_i. The inherent waveshape shall follow a straight line drawn using the 20 % and the 80 % point of the ITRV peak voltage u_i and the required rate of rise of the ITRV.

4.102.3 Standard values of TRV related to the rated short-circuit breaking current

Standard values of TRV for three-pole circuit-breakers of rated voltages less than 100 kV make use of two parameters. Values are given in:

– Table 1, for cable systems;

– Table 2, for line systems.

~~For rated voltages of 100 kV and above, four parameters are used. Table 3 gives values for rated voltages of 100 kV up to 170 kV for effectively earthed systems. Table 4 gives values for rated voltages 100 kV up to 170 kV for non-effectively earthed systems. Table 5 gives values for rated voltages of 245 kV and above.~~

Table 3 gives values for rated voltages of 100 kV up to 170 kV for effectively earthed systems. Table 4 gives values for rated voltages of 100 kV up to 170 kV for non-effectively earthed systems. Table 5 gives values for rated voltages of 245 kV and above.

The TRV peak values given in Tables 1, 2, 3, 4, 5 and 37 shall be met. The values for the amplitude factor are given for information only.

The tables also indicate values of rate of rise, taken as u_c/t_3 and u_1/t_1, in the two-parameter and four-parameter cases, respectively, which together with TRV peak values u_c may be used for purposes of specification of TRV.

The values given in the tables are prospective values. They apply to circuit-breakers for general transmission and distribution in three-phase systems having service frequencies of 50 Hz or 60 Hz and consisting of transformers, overhead lines and cables.

In the case of single-phase systems or where circuit-breakers are for use in an installation having more severe conditions, the values may be different, particularly for the following cases:

a) circuit-breakers adjacent to generator circuits;

b) circuit-breakers directly connected to transformers without appreciable additional capacitance between the circuit-breaker and the transformer which provides approximately 50 % or more of the rated short-circuit breaking-current of the circuit-breaker. However the special case of circuit-breakers of rated voltage less than 100 kV with a connection of low capacitance to a transformer is covered in Annex M;

c) circuit-breakers in substations with series reactors (information is given in 8.103.7 and in Clause L.5 for circuit-breakers rated less than 100 kV);

d) circuit-breakers used for series compensated lines;

e) circuit-breakers in substations with capacitor banks.

The transient recovery voltage corresponding to the rated short-circuit breaking current when a terminal fault occurs, is used for testing at short-circuit breaking currents equal to the rated value. However, for testing with short-circuit breaking currents less than 100 % of the rated value, other values of transient recovery voltage are specified (see 6.104.5). Further additional requirements apply to circuit-breakers designed for direct connection to overhead lines, rated at 15 kV and above and having rated short-circuit breaking currents exceeding 12,5 kA, which may be operated in short-line fault conditions (see 4.105).

Table 1 – Standard values of transient recovery voltage for class S1 circuit-breakers – Rated voltage higher than 1 kV and less than 100 kV – Representation by two parameters

Rated voltage U_r kV	Type of test	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [a] u_c/t_3 kV/µs
3,6	Terminal fault	1,5	1,4	6,2	41	6	2,1	20	0,15
	Out-of-phase	2,5	1,25	9,2	82	12	3,1	40	0,11
4,76 [b]	Terminal fault	1,5	1,4	8,2	44	7	2,7	21	0,19
	Out-of-phase	2,5	1,25	12,1	88	13	4,0	43	0,14
7,2	Terminal fault	1,5	1,4	12,3	51	8	4,1	25	0,24
	Out-of-phase	2,5	1,25	18,4	102	15	6,1	49	0,18
8,25 [b]	Terminal fault	1,5	1,4	14,1	52	8	4,7	25	0,27
	Out-of-phase	2,5	1,25	21,1	104	16	7,0	50	0,20
12	Terminal fault	1,5	1,4	20,6	61	9	6,9	29	0,34
	Out-of-phase	2,5	1,25	30,6	122	18	10,2	59	0,25
15 [b]	Terminal fault	1,5	1,4	25,7	66	10	8,6	32	0,39
	Out-of-phase	2,5	1,25	38,3	132	20	12,8	64	0,29
17,5	Terminal fault	1,5	1,4	30	71	11	10,0	34	0,42
	Out-of-phase	2,5	1,25	44,7	142	21	14,9	69	0,31
24	Terminal fault	1,5	1,4	41,2	87	13	13,7	42	0,47
	Out-of-phase	2,5	1,25	61,2	174	26	20,4	84	0,35
25,8 [b]	Terminal fault	1,5	1,4	44,2	91	14	14,7	44	0,49
	Out-of-phase	2,5	1,25	65,8	182	27	21,9	88	0,36
36	Terminal fault	1,5	1,4	61,7	109	16	20,6	53	0,57
	Out-of-phase	2,5	1,25	91,9	218	33	30,6	105	0,42
38 [b]	Terminal fault	1,5	1,4	65,2	109	16	21,7	53	0,60
	Out-of-phase	2,5	1,25	97,0	218	33	32,3	105	0,45
48,3 [b]	Terminal fault	1,5	1,4	82,8	125	19	27,6	60	0,66
	Out-of-phase	2,5	1,25	123	250	38	41,1	121	0,49
52	Terminal fault	1,5	1,4	89,2	131	20	29,7	63	0,68
	Out-of-phase	2,5	1,25	133	262	39	44,2	127	0,51
72,5	Terminal fault	1,5	1,4	124	165	25	41,4	80	0,75
	Out-of-phase	2,5	1,25	185	330	50	61,7	160	0,56

[a] RRRV = rate of rise of recovery voltage.

[b] Used in North America.

Table 2 – Standard values of transient recovery voltage [c] for class S2 circuit-breakers – Rated voltage equal to or higher than 15 kV and less than 100 kV – Representation by two parameters

Rated voltage U_r kV	Type of test	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [a] u_c/t_3 kV/µs
15 [b]	Terminal fault	1,5	1,54	28,3	31	2	9,4	12	0,91
	Short-line fault	1	1,54	18,9	31	2	6,3	12	0,61
	Out-of-phase	2,5	1,25	38,3	62	9	12,8	30	0,62
17,5	Terminal fault	1,5	1,54	33,0	34	2	11,0	13	0,97
	Short-line fault	1	1,54	22,0	34	2	7,3	13	0,65
	Out-of-phase	2,5	1,25	45	68	10	14,9	33	0,65
24	Terminal fault	1,5	1,54	45,3	43	2	15,1	16	1,05
	Short-line fault	1	1,54	30,2	43	2	10,1	16	0,70
	Out-of-phase	2,5	1,25	61	86	13	20,4	42	0,71
25,8 [b]	Terminal fault	1,5	1,54	48,7	45	2	16,2	17	1,08
	Short-line fault	1	1,54	32,4	45	2	10,8	17	0,72
	Out-of-phase	2,5	1,25	66	90	14	21,9	44	0,73
36	Terminal fault	1,5	1,54	67,9	57	3	22,6	22	1,19
	Short-line fault	1	1,54	45,3	57	3	15,1	22	0,79
	Out-of-phase	2,5	1,25	92	114	17	30,6	55	0,81
38 [b]	Terminal fault	1,5	1,54	71,7	59	3	23,9	23	1,21
	Short-line fault	1	1,54	47,8	59	3	15,9	23	0,81
	Out-of-phase	2,5	1,25	97	118	18	32,3	57	0,82
48,3 [b]	Terminal fault	1,5	1,54	91,1	70	4	30,4	27	1,30
	Short-line fault	1	1,54	60,7	70	4	20,2	27	0,87
	Out-of-phase	2,5	1,25	123	140	21	41,1	68	0,88
52	Terminal fault	1,5	1,54	98,1	74	4	32,7	28	1,33
	Short-line fault	1	1,54	65,4	74	4	21,8	28	0,88
	Out-of-phase	2,5	1,25	133	148	22	44,2	72	0,90
72,5	Terminal fault	1,5	1,54	137	93	5	45,6	36	1,47
	Short-line fault	1	1,54	91,2	93	5	30,4	36	0,98
	Out-of-phase	2,5	1,25	185	186	28	61,7	90	0,99

[a] RRRV = rate of rise of recovery voltage.

[b] Used in North America.

[c] For short-line faults: transient recovery voltage and time quantities are those of the supply circuit. Short-line fault is only applicable for circuit-breakers designed for direct connection to overhead lines.

Table 3 – Standard values of transient recovery voltage [a] – Rated voltages of 100 kV to 170 kV for effectively earthed systems – Representation by four parameters

Rated voltage U_r kV	Test-duty	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	First reference voltage u_1 kV	Time t_1 µs	TRV peak value u_c kV	Time t_2 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [b] u_1/t_1 kV/µs
100	Terminal fault	1,3	1,40	80	40	149	160	2	40	22	2
	Short-line fault	1	1,40	61	31	114	124	2	31	17	2
	Out-of-phase	2	1,25	122	80	204	160-320	2-8	61	48	1,54
123	Terminal fault	1,3	1,40	98	49	183	196	2	49	26	2
	Short-line fault	1	1,40	75	38	141	152	2	38	21	2
	Out-of-phase	2	1,25	151	98	251	196-392	2-10	75	59	1,54
145	Terminal fault	1,3	1,40	115	58	215	232	2	58	31	2
	Short-line fault	1	1,40	89	44	166	176	2	44	24	2
	Out-of-phase	2	1,25	178	116	296	232-464	2-12	89	70	1,54
170	Terminal fault	1,3	1,40	135	68	253	272	2	68	36	2
	Short-line fault	1	1,40	104	52	194	208	2	52	28	2
	Out-of-phase	2	1,25	208	136	347	272-544	2-14	104	81	1,54

[a] In case of short-line faults, transient recovery voltage and time quantities are those of the supply circuit.

[b] RRRV = rate of rise of recovery voltage.

Table 4 – Standard values of transient recovery voltage [a] – Rated voltages of 100 kV to 170 kV for non-effectively earthed systems – Representation by four parameters

Rated voltage U_r kV	Test-duty	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	First reference voltage u_1 kV	Time t_1 µs	TRV peak value u_c kV	Time t_2 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [b] u_1/t_1 kV/µs)
100	Terminal fault	1,5	1,40	92	46	171	184	2	46	25	2
	Short-line fault	1	1,40	61	31	114	124	2	31	17	2
	Out-of-phase	2,5	1,25	153	92	255	184-368	2-9	77	55	1,67
123	Terminal fault	1,5	1,40	113	56	211	224	2	56	30	2
	Short-line fault	1	1,40	75	38	141	152	2	38	21	2
	Out-of-phase	2,5	1,25	188	112	314	224-448	2-11	94	67	1,67
145	Terminal fault	1,5	1,40	133	67	249	268	2	67	35	2
	Short-line fault	1	1,40	89	44	166	176	2	44	24	2
	Out-of-phase	2,5	1,25	222	134	370	268-536	2-13	111	79	1,67
170	Terminal fault	1,5	1,40	156	78	291	312	2	78	41	2
	Short-line fault	1	1,40	104	52	194	208	2	52	28	2
	Out-of-phase	2,5	1,25	260	156	434	312-624	2-16	130	94	1,67

[a] In case of short-line faults, transient recovery voltage and time quantities are those of the supply circuit.

[b] RRRV = rate of rise of recovery voltage.

In order to obtain the values of rate of rise of recovery voltage (RRRV) and u_c for the second and third clearing poles, a multiplier shall be applied to the values of RRRV and u_c of the first clearing pole at the relevant first-pole-to-clear factor. The values of these multipliers are given in Table 6.

RRRV multipliers are related to u_1/t_1; the times t_1 and t_2 are the same for the first, second and last clearing poles.

Table 5 – Standard values of transient recovery voltage [a] –
Rated voltages 245 kV and above for effectively earthed systems –
~~Representation by four parameters~~

Rated voltage	Test-duty	First-pole-to-clear factor	Amplitude factor	First reference voltage	Time	TRV peak value	Time	Time delay	Voltage	Time	RRRV [b]
U_r		k_{pp}	k_{af}	u_1	t_1	u_c	t_2	t_d	u'	t'	u_1/t_1
kV		p.u.	p.u.	kV	µs	KV	µs	µs	kV	µs	kV/µs
245	Terminal fault	1,3	1,40	195	98	364	392	2	98	51	2
	Short-line fault	1	1,40	150	75	280	300	2	75	40	2
	Out-of-phase	2	1,25	300	196	500	392-784	2-20	150	117	1,54
300	Terminal fault	1,3	1,40	239	119	446	476	2	119	62	2
	Short-line fault	1	1,40	184	92	343	368	2	92	48	2
	Out-of-phase	2	1,25	367	238	612	476-952	2-24	184	143	1,54
362	Terminal fault	1,3	1,40	288	144	538	576	2	144	74	2
	Short-line fault	1	1,40	222	111	414	444	2	111	57	2
	Out-of-phase	2	1,25	443	288	739	576-1152	2-29	222	173	1,54
420	Terminal fault	1,3	1,40	334	167	624	668	2	167	86	2
	Short-line fault	1	1,40	257	129	480	516	2	129	66	2
	Out-of-phase	2	1,25	514	334	857	668-1336	2-33	257	202	1,54
550	Terminal fault	1,3	1,40	438	219	817	876	2	219	111	2
	Short-line fault	1	1,40	337	168	629	672	2	168	86	2
	Out-of-phase	2	1,25	674	438	1 123	876-1752	2-44	337	263	1,54
800	Terminal fault	1,3	1,40	637	318	1 189	1 272	2	318	161	2
	Short-line fault	1	1,40	490	245	914	980	2	245	124	2
	Out-of-phase	2	1,25	980	636	1 633	1272-2544	2-64	490	382	1,54
1 100	Terminal fault	1,2	1,50	808	404	1 617	1 212	2	404	204	2
	Short-line fault	1	1,50	674	337	1 347	1 011	2	337	170	2
	Out-of-phase	2	1,25	-	-	2 245	1 458	2-73	748	559	1,54
1 200	Terminal fault	1,2	1,50	882	441	1 764	1 323	2	441	222	2
	Short-line fault	1	1,50	735	367	1 470	1 101	2	367	186	2
	Out-of-phase	2	1,25	-	-	2 449	1 590	2-80	816	610	1,54

[a] In case of short-line faults, transient recovery voltage and time quantities are those of the supply circuit.

[b] RRRV = rate of rise of recovery voltage.

Table 6 – Standard multipliers for transient recovery voltage values for second and third clearing poles for rated voltages above 1 kV

First-pole-to-clear factor k_{pp}	Multipliers			
	2nd clearing pole		3rd clearing pole	
	RRRV	u_c	RRRV	u_c
For effectively earthed systems				
1,2	0,95	0,95	0,83	0,83
1,3	0,95	0,98	0,70	0,77
For non-effectively earthed systems				
1,5	0,70	0,58	0,70	0,58

The multipliers of Table 6 have been calculated under the following assumptions:

– only three-phase earthed faults are considered;

– the rate of rise of recovery voltage (RRRV) at 100 % short-circuit currents is mainly determined by overhead lines and is calculated as the product of di/dt at current zero and the equivalent surge impedance;

– the equivalent surge impedance is calculated from the zero sequence (Z_0) and positive sequence (Z_1) surge impedances seen from the terminals of the circuit-breaker. For the relation of Z_0/Z_1 a value of approximately 2 has been chosen;

– the peak value of TRV (u_c) is proportional to the instantaneous value of power frequency recovery voltage at interruption.

See also Figures 13 and 14.

NOTE 1 This table is valid for test-duty T10, T30, T60, T100s and T100a. For test-duty T100a, the TRV reduction method should be applied as indicated in Annex P for the first clearing pole. For convenience of testing and with the consent of the manufacturer it is also possible not to apply the TRV reduction.

NOTE 2 The values are rounded values, depending on Z_0/Z_1 of the TRV circuits, the time constant of the system and the rated voltages.

4.102.4 Standard values of ITRV

Table 7 – Standard values of initial transient recovery voltage – Rated voltages 100 kV and above

Rated voltage U_r kV	**Multiplying factor to determine u_i as function of the r.m.s. value of the short-circuit breaking current I_{sc}*** $\cancel{E_i}$ f_i kV/ kA 50 Hz	 60 Hz	**Time** t_i µs
100	0,046	0,056	0,4
123	0,046	0,056	0,4
145	0,046	0,056	0,4
170	0,058	0,070	0,5
245	0,069	0,084	0,6
300	0,081	0,098	0,7
362	0,092	0,112	0,8
420	0,092	0,112	0,8
550	0,116	0,139	1,0
800	0,159	0,191	1,1
1 100	0,173	0,208	1,5
1 200	0,173	0,208	1,5

NOTE These values cover both three-phase and single-phase faults and are based on the assumption that the busbar, including the elements connected to it (supports, current and voltage transformers, disconnectors, etc.), can be roughly represented by a resulting surge impedance Z_i of about 260 Ω ~~in the case~~ with the exception of a rated voltage ~~lower than~~ 800 kV ~~and by a~~ for which the resulting surge impedance Z_i ~~of~~ is about 325 Ω ~~in the case of a rated voltage of 800 kV~~. The relation between f_i and t_i is then:

$$f_i = t_i \times Z_i \times \omega \times \sqrt{2}$$

where

$\omega = 2\pi f_r$ is the angular frequency corresponding to the rated frequency of the circuit-breaker.

* The actual initial peak voltages are obtained by multiplying the values in these columns by the r.m.s. value of the short-circuit ~~breaking~~ current.

4.103 Rated short-circuit making current

~~The rated short-circuit making current (see Figure 8) of a circuit-breaker having simultaneity of poles is that which corresponds to the rated voltage and the rated frequency. The following values apply:~~

- ~~for a rated frequency of 50 Hz and the standard value of the time constant of 45 ms (see 4.101.2) it is equal to 2,5 times the r.m.s. value of the a.c. component of its rated short-circuit breaking current (see 4.101);~~
- ~~for a rated frequency of 60 Hz and the standard value of the time constant of 45 ms (see 4.101.2) it is equal to 2,6 times the r.m.s. value of the a.c. component of its rated short-circuit breaking current (see 4.101);~~
- ~~for all special case time constants (see 4.101.2) it is equal to 2,7 times the r.m.s. value of the a.c. component of its rated short-circuit breaking current, independent of the rated frequency of the circuit-breaker (see 4.101).~~

The rated short-circuit making current (see Figure 8) of a circuit-breaker is related to:

– the a.c. component of the rated short-circuit current;

– the d.c. time constant of the rated short-circuit current;

– the rated frequency.

The rated short-circuit making current is obtained by multiplying the r.m.s. value of the a.c. component of the rated short-circuit breaking current (see 4.101) with the peak factor given in Table 37.

Table 37 – Peak factors for the rated short-circuit making current

Peak factor p.u.	**Frequency** Hz	**Time constant** ms
2,5	**50**	**45**
2,6	**60**	**45**
2,7	**50 or 60**	**> 45**

4.104 Rated operating sequence

The rated characteristics of the circuit-breaker are referred to the rated operating sequence. There are two alternative rated operating sequences as follows:

a) O – *t* – CO – *t*' – CO

Unless otherwise specified:

t = 3 min for circuit-breakers not intended for rapid auto-reclosing;

t = 0,3 s for circuit-breakers intended for rapid auto-reclosing (dead time);

t' = 3 min.

NOTE Instead of *t*' = 3 min, other values: *t*' = 15 s and *t*' = 1 min are also used for circuit-breakers intended for rapid auto-reclosing.

b) CO – *t*'' – CO

with:

t'' = 15 s for circuit-breakers not intended for rapid auto-reclosing

where

O represents an opening operation;

CO represents a closing operation followed immediately (that is, without any intentional delay) by an opening operation;

t, t' and *t*'' are time intervals between successive operations;

t and *t*' should always be expressed in minutes or in seconds and

t'' should always be expressed in seconds.

If the dead time is adjustable, the limits of adjustment shall be specified.

4.105 Characteristics for short-line faults

~~Characteristics for short-line faults are required for class S2 circuit-breakers having a rated voltage of 15 kV and above and a rated short-circuit breaking current exceeding 12,5 kA. Characteristics for short-line faults are also required for circuit-breakers having a rated voltage of 100 kV and above. These characteristics relate to the breaking of a single-phase earth fault in a system with solidly earthed neutral, where the first-pole-to-clear factor is equal to 1,0.~~

Characteristics for short-line faults tests are required for class S2 circuit-breakers designed for direct connection to overhead lines, irrespective of the type of network on the source side, having a rated voltage equal or higher than 15 kV and less than 100 kV and a rated short-circuit breaking current exceeding 12,5 kA. Characteristics for short-line faults are also required for all circuit-breakers designed for direct connection to overhead lines having a rated voltage of 100 kV and above and a rated short-circuit breaking current exceeding 12,5 kA.

NOTE In this standard, a single-phase test at phase-to-earth voltage covers all types of short-line fault (see ~~Table 8~~ L.3).

The short-line fault circuit is composed of a supply circuit on the source side of the circuit-breaker and a short-line on its load side (see Figure 15), with the following characteristics:

a) supply circuit characteristics:

- voltage equal to the phase-to-earth voltage $U_r/\sqrt{3}$ ~~corresponding to the rated voltage U_r~~ of the circuit-breaker;
- short-circuit current, in case of terminal fault, equal to the rated short-circuit breaking current of the circuit-breaker;
- prospective transient recovery voltage, in case of short-line fault, given by the standard values in
  - Table 2, for circuit-breakers in line systems with rated voltages from 15 kV and less than 100 kV;
  - Tables 3 and 4, for circuit-breakers with rated voltages from 100 kV up to and including 170 kV;
  - Table 5, for circuit-breakers with rated voltages 245 kV and above.
- ITRV characteristics for circuit-breakers of 100 kV and above derived from Table 7.

b) line characteristics:

- ~~standard values of the RRRV factor, based on a surge impedance Z of 450 Ω, the peak factor k and the line side time delay t_{dL} are given in Table 8. For determination of the line side time delay and the rate-of-rise of the line side voltage, see Figure 16;~~
- standard values of the RRRV factor, based on the line surge impedance Z, the peak factor k and the line side time delay t_{dL} that are given in Table 8. For determination of the line side time delay and the rate-of-rise of the line side voltage, see Figure 16;
- the method for calculation of transient recovery voltages from the characteristics is given in Annex A.

Table 8 – Standard values of line characteristics for short-line faults

~~Rated voltage~~ ~~U_r~~ ~~kV~~	~~Number of conductors per phase~~	~~Surge impedance~~ ~~Z~~ ~~Ω~~	~~Peak factor~~ ~~K~~	~~RRRV factor~~ ~~s*~~ ~~(kV/µs)/kA~~ ~~50 Hz~~	~~60 Hz~~	~~Time delay~~ ~~t_{dL}~~ ~~µs~~
~~$15 \leq U_r \leq 38$~~	~~1~~	~~450~~	~~1,6~~	~~0,200~~	~~0,240~~	~~0,1~~
~~$48,3 \leq U_r \leq 170$~~	~~1 to 4~~	~~450~~	~~1,6~~	~~0,200~~	~~0,240~~	~~0,2~~
~~$U_r \geq 245$~~	~~1 to 4~~	~~450~~	~~1,6~~	~~0,200~~	~~0,240~~	~~0,5~~

~~NOTE These values cover the short-line faults dealt with in this standard. For very short lines ($t_L < 5t_{dL}$) not all requirements as given in the table can be met. The procedures for approaching very short lines are given in CIGRE technical brochure 305 [4].~~

~~* For the RRRV factor s, see Annex A.~~

Rated voltage U_r kV	Surge impedance Z Ω	Peak factor k	RRRV factor s [b] (kV/µs)/kA 50 Hz	60 Hz	Time delay t_{dL} µs
$15 \leq U_r \leq 38$	450	1,6	0,200	0,240	0,1
$48,3 \leq U_r \leq 170$	450	1,6	0,200	0,240	0,2
$245 \leq U_r \leq 800$	450	1,6	0,200	0,240	0,5
$U_r > 800$	330 [a]	1,6	0,147	0,176	0,5

NOTE These values cover the short-line faults dealt with in this standard. For very short lines ($t_L < 5t_{dL}$) not all requirements as given in the table can be met. The procedures for approaching very short lines are given in IEC 62271-306 [4].

[a] As described in 4.102.1, a value of 450 Ω may be used during testing to cover ITRV requirements.

[b] For the RRRV factor s, see Annex A.

4.106 Rated out-of-phase making and breaking current

The rated out-of-phase breaking current is the maximum out-of-phase current that the circuit-breaker shall be capable of breaking under the conditions of use and behaviour prescribed in this standard in a circuit having a recovery voltage as specified below.

The specification of a rated out-of-phase making and breaking current is not mandatory. If a rated out-of-phase breaking current is assigned, the following applies:

a) the power frequency recovery voltage shall be 2,0/√3 times the rated voltage for effectively earthed neutral systems and 2,5/√3 times the rated voltage for other systems;

b) the transient recovery voltage shall be in accordance with:

   – Table 1, for circuit-breakers in cable systems with rated voltages less than 100 kV;

   – Table 2, for circuit-breakers in line systems with rated voltages less than 100 kV;

   – Table 3, for circuit-breakers with rated voltages of 100 kV up to and including 170 kV for effectively earthed systems;

   – Table 4, for circuit-breakers with rated voltages of 100 kV up to and including 170 kV for non-effectively earthed systems;

- Table 5, for circuit-breakers with rated voltages 245 kV and above.

c) the rated out-of-phase breaking current shall be 25 % of the rated short-circuit breaking current and the rated out-of-phase making current shall be the crest value of the rated out-of-phase breaking current, unless otherwise specified.

The standard conditions of use with respect to the rated out-of-phase making and breaking current are as follows:

- opening and closing operations carried out in conformity with the instructions given by the manufacturer for the operation and proper use of the circuit-breaker and its auxiliary equipment;
- earthing condition of the neutral for the power system corresponding to that for which the circuit-breaker has been tested;
- absence of a fault on either side of the circuit-breaker.

4.107 Rated capacitive switching currents

Capacitive switching currents may comprise part or all of the operating duty of a circuit-breaker such as the charging current of an unloaded transmission line or cable or the load current of a shunt capacitor bank.

The rating of a circuit-breaker for capacitive current switching shall include, where applicable:

- rated line-charging breaking current;
- rated cable-charging breaking current;
- rated single capacitor bank breaking current;
- rated back-to-back capacitor bank breaking current;
- rated single capacitor bank inrush making current;
- rated back-to-back capacitor bank inrush making current.

Preferred values of rated capacitive switching currents are given in Table 9.

The recovery voltage related to capacitive current switching depends on:

- the earthing of the system;
- the earthing of the capacitive load, for example screened cable, capacitor bank, transmission line;
- the mutual influence of adjacent phases of the capacitive load, for example belted cables, open air lines;
- the mutual influence of adjacent systems of overhead lines on the same route;
- the presence of single or two-phase earth faults.

Two classes of circuit-breakers are defined according to their restrike performances:

- class C1: low probability of restrike during capacitive current breaking;
- class C2: very low probability of restrike during capacitive current breaking.

NOTE 1 The probability is related to the performance during the series of type tests stated in 6.111.

NOTE 2 A circuit-breaker can be of class C2 for one kind of application (for example in effectively earthed neutral systems) and of class C1 for another kind of application where the recovery voltage stress is more severe (for example in non-effectively earthed neutral systems).

NOTE 3 Circuit-breakers with a restrike probability other than that of class C1 or class C2 are not covered by this standard.

4.107.1 Rated line-charging breaking current

The rated line-charging breaking current is the maximum line-charging current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard. The specification of a rated line-charging breaking current is mandatory for circuit-breakers of rated voltages equal to or greater than 72,5 kV.

4.107.2 Rated cable-charging breaking current

The rated cable-charging breaking current is the maximum cable-charging current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard. The specification of a rated cable-charging breaking current is not mandatory; it is required only for circuit-breakers to which class C1 or C2 for cable-charging current switching is assigned.

4.107.3 Rated single capacitor bank breaking current

The rated single capacitor bank breaking current is the maximum capacitor current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard. This breaking current refers to the switching of a shunt capacitor bank where no shunt capacitors are connected to the source side of the circuit-breaker.

Table 9 – Preferred values of rated capacitive switching currents

	Line	**Cable**	**Single capacitor bank**	**Back-to-back capacitor bank**		
Rated voltage U_r kV, r.m.s.	**Rated line-charging breaking current** I_l A, r.m.s.	**Rated cable-charging breaking** current I_c A, r.m.s.	**Rated single capacitor bank breaking current** I_{sb} A, r.m.s.	**Rated back-to-back capacitor bank breaking current** I_{bb} A, r.m.s.	**Rated back-to-back capacitor bank inrush making current** I_{bi} kA, peak	**Frequency of the inrush current** f_{bi} Hz
3,6	10	10	400	400	20	4 250
4,76	10	10	400	400	20	4 250
7,2	10	10	400	400	20	4 250
8,25	10	10	400	400	20	4 250
12	10	25	400	400	20	4 250
15	10	25	400	400	20	4 250
17,5	10	31,5	400	400	20	4 250
24	10	31,5	400	400	20	4 250
25,8	10	31,5	400	400	20	4 250
36	10	50	400	400	20	4 250
38	10	50	400	400	20	4 250
48,3	10	80	400	400	20	4 250
52	10	80	400	400	20	4 250
72,5	10	125	400	400	20	4 250
100	20	125	400	400	20	4 250
123	31,5	140	400	400	20	4 250
145	50	160	400	400	20	4 250
170	63	160	400	400	20	4 250
245	125	250	400	400	20	4 250
300	200	315	400	400	20	4 250

Table 9 *(continued)*

362	315	355	400	400	20	4 250
420	400	400	400	400	20	4 250
550	500	500	400	400	20	4 250
800	900					
1 100	1 200	-	-	-	-	-
1 200	1 300	-	-	-	-	-

NOTE 1 The values given in this table are chosen for standardisation purposes. They are preferred values and cover the majority of typical applications. If different values are needed, any appropriate value may be specified as rated value.

NOTE 2 For actual cases, the inrush currents can be calculated based on Annex H.

NOTE 3 If back-to-back capacitor switching tests are performed, single capacitor bank switching tests are not required.

NOTE 4 The peak of the inrush current and the inrush current frequency may be higher or lower than the preferred values stated in Table 9 depending on system conditions, for example whether or not current limiting reactors are used.

NOTE 5 Preferred values for rated voltages 1 100 kV and 1 200 kV are based on applications at 50 Hz. Higher values of current could be possible in the future in systems operated at 60 Hz, however experience shows that these higher currents would not lead to a higher stress for the circuit-breaker as the recovery voltage is generally the dominant factor for interruption.

4.107.4 Rated back-to-back capacitor bank breaking current

The rated back-to-back capacitor bank breaking current is the maximum capacitor current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard.

This breaking current refers to the switching of a shunt capacitor bank where one or several shunt capacitor banks are connected to the source side of the circuit-breaker giving an inrush making current equal to the rated back-to-back capacitor bank inrush making current.

NOTE Similar conditions could apply for switching at substations with cables.

4.107.5 Rated single capacitor bank inrush making current

No rating or preferred values are defined. This is because inrush currents associated with single capacitor banks are not considered critical.

4.107.6 Rated back-to-back capacitor bank inrush making current

The rated back-to-back capacitor bank inrush making current is the peak value of the current that the circuit-breaker shall be capable of making at its rated voltage and with a frequency of the inrush current appropriate to the service conditions (see Table 9).

4.108 Inductive load switching

No rating is assigned. See IEC 62271-110.

4.109 Rated time quantities

Refer to Figures 1, 2, 3, 4, 5, 6 and 7.

Rated values may be assigned to the following time quantities:

- opening time (no-load);
- break-time;
- closing time (no-load);
- open-close time (no-load);
- reclosing time (no-load);
- close-open time (no-load);
- pre-insertion time (no-load).

Rated time quantities are based on

- rated supply voltages of closing and opening devices and of auxiliary and control circuits (see 4.8);
- rated supply frequency of closing and opening devices and of auxiliary circuits (see 4.9);
- rated pressures of compressed gas supply for operation, for insulation and/or interruption, as applicable (see 4.10);
- rated pressure of hydraulic supply for operation;
- an ambient air temperature of 20 °C ± 5 °C.

NOTE Usually it is not practical to assign a rated value of make-time or of make-break time due to the variation of the arcing time and the pre-arcing time.

4.109.1 Rated break-time

~~The maximum break time determined during terminal fault test-duties T30, T60 and T100s of 6.106.2, 6.106.3 and 6.106.4 with the circuit-breaker operated at auxiliary supply voltage and frequency and pressures of pneumatic or hydraulic supply at their rated values and at an ambient air temperature of 20 °C ± 5 °C shall not exceed the rated break time.~~

~~NOTE 1 According to 6.102.3.1, the basic short-circuit test-duties, with the exception of T100a, should be carried out at minimum voltage and/or pressures for operation and/or interruption. In order to verify the rated break time during these test-duties, the recorded maximum break time should be amended to take account of the lower auxiliary supply voltage and pressure as follows:~~

$$\cancel{t_b \geq t_1 - (t_2 - t_3)}$$

~~where~~

~~t_b is the rated break time;~~

~~t_1 is the maximum recorded break time during test-duties T30, T60 and T100s;~~

~~t_2 is the maximum recorded opening time on no-load, with auxiliary supply voltage and pressures for operation and/or interruption as used during test-duties T30, T60 and T100s;~~

~~t_3 is the rated opening time.~~

~~If the break time determined according to this procedure exceeds the rated break time, the test-duty that has given the longest break time may be repeated with auxiliary supply voltage and frequency and pressure for operation and/or interruption at their rated values.~~

~~NOTE 2 For single-phase tests simulating a three-phase operation, the recorded break time, amended according to Note 1, may exceed the rated break time by one-tenth of a cycle because in these cases the current zeros occur less frequently than in the three-phase case.~~

~~NOTE 3 The break time during a make-break operating cycle of test-duty T100s should not exceed the rated break time by more than half-cycle of the power frequency.~~

The rated break time of a circuit-breaker is the maximum interval between the energizing of the trip circuit and the interruption of the current in the main circuit during test duties T30, T60 and T100s in all poles under the following conditions:

- rated auxiliary supply voltage and frequency;

– rated pressures for operation, insulation and interruption;

– an ambient air temperature of (20 ± 5) °C.

According to 6.102.3.1, the basic short-circuit test-duties, with the exception of T100a, should be carried out at the minimum auxiliary supply voltage and/or pressures for operation and/or interruption. For convenience of testing, the auxiliary supply voltage may be the rated or maximum value as long as it does not affect the making or breaking capability. (The operating times of some circuit-breakers may vary with the auxiliary supply voltage). In order to verify the rated break time during these test-duties, the maximum break time should be amended to take account of the lower auxiliary supply voltage and pressures as follows:

$$t_{bmax} = t_{bm} + t_w - (t_{om} - t_{or})$$

where

t_{bmax} is the maximum determined break time;

t_{bm} is the longest of the minimum recorded break times during test-duties T30, T60 and T100s;

Note that t_{bm} corresponds to the last pole-to-clear in case of a three-phase test.

t_w is the necessary arcing window expressed in ms;

– for single-phase tests in substitution for three-phase conditions
  - non-effectively earthed neutral systems: t_{we} = 150 – dα
  - effectively earthed neutral systems: t_{we} = 180 – dα

– for three-phase tests
  - t_{we} = 60 – dα

t_{we} is expressed in electrical degrees

$t_w = T \times t_{we}/360$

T period of power frequency (20 ms for 50 Hz, 16,7 ms for 60 Hz)

dα is the tripping impulse step in the search for the minimum arcing time, it is equal to18 electrical degrees

t_{om} is the maximum recorded opening time on no-load, with minimum auxiliary supply voltage and pressures for operation and/or interruption.

t_{or} is the maximum recorded opening time on no-load, with auxiliary supply voltage and pressures for operation with the rated condition.

If the maximum break time determined according to this procedure exceeds the rated break time, the test-duty that has given the longest break time may be repeated with auxiliary supply voltage and pressure for operation and interruption at their rated values.

The rated break time is defined based on the minimum arcing time because the longest recorded arcing time during the tests can be longer than under the actual field condition.

NOTE The break time during a make-break operation may be longer than that of a single break operation for some circuit-breaker designs. Such longer break times may impact system protection strategy and stability if the delay is longer than the relay time. Users should advise the manufacturer of the maximum allowable break time during make-break operations.

4.110 Number of mechanical operations

A circuit-breaker shall be able to perform the following number of operations taking into account the programme of maintenance specified by the manufacturer:

Standard circuit-breaker (normal mechanical endurance) **class M1**	2 000 operating sequences
Circuit-breaker for special service requirements (extended mechanical endurance) **class M2**	10 000 operating sequences

4.111 Classification of circuit-breakers as a function of electrical endurance

Circuit-breakers required to have an electrical endurance capability, intended for auto-reclosing duty, as usual for overhead line networks, and of rated voltages up to and including 52 kV, are classified class E2 as defined in 3.4.113 and tested to 6.112.2 and Table 33.

Circuit-breakers required to have an electrical endurance ability, but intended for use without auto-reclosing duty capability, for example in cable-connected networks, and of rated voltages up to and including 52 kV, are classified class E2 as defined in 3.4.113 and tested to 6.112.1.

Class E2 is termed extended electrical endurance.

Circuit-breakers not requiring this electrical endurance capability are classified class E1 as defined in 3.4.112, termed basic electrical endurance.

NOTE For circuit-breakers of rated voltages 72,5 kV and above guidance is given in IEC 62271-310 [5].

5 Design and construction

5.1 Requirements for liquids in circuit-breakers

Subclause 5.1 of IEC 62271-1 is applicable.

5.2 Requirements for gases in circuit-breakers

Subclause 5.2 of IEC 62271-1 is applicable.

5.3 Earthing of circuit-breakers

Subclause 5.3 of IEC 62271-1 is applicable.

5.4 Auxiliary equipment

Subclause 5.4 of IEC 62271-1 is applicable with the following additions:

– where shunt opening and closing releases are used, appropriate measures shall be taken in order to avoid damage on the releases when permanent orders for closing or opening are applied. For example, those measures may be the use of series control contacts arranged so that when the circuit-breaker is closed, the close release control contact ("b" contact or break contact) is open and the open release control contact ("a" contact or make contact) is closed, and when the circuit-breaker is open, the open release control contact is open and the close release control contact is closed;

NOTE 1 Systems other than contacts are possible and may be used.

– for shunt closing releases the protective measures for the shunt closing releases as mentioned in the first indent above shall operate no sooner than the minimum close duration (3.7.147) provided by the circuit-breaker and no later than the rated closing time;

NOTE 2 If the current of the shunt closing release is interrupted by the control contact, the closing command should be positively longer than the rated closing time.

– for shunt opening releases the protecting measures for the shunt opening releases as mentioned in the first indent above shall operate no sooner than the minimum trip duration (3.7.146) required by the circuit-breaker and no later than 20 ms after separation of the main contacts;
– for short close-open time requirements the protective measures for the shunt releases as mentioned in the first indent above shall operate no sooner than when main contacts close and no later than one half-cycle after main contacts close;
– where auxiliary switches are used as position indicators, they shall indicate the end position of the circuit-breaker at rest, open or closed. The signalling shall be sustained;
– connections shall withstand the stresses imposed by the circuit-breaker, especially those due to mechanical forces during operations;
– in the case of outdoor circuit-breakers, all auxiliary equipment including the wiring shall be adequately protected against rain and humidity;
– where special items of control equipment are used, they shall operate within the limits specified for supply voltages of auxiliary and control circuits, interrupting and/or insulating and operating media, and be able to switch the loads which are stated by the circuit-breaker manufacturer;
– special items of auxiliary equipment such as liquid indicators, pressure indicators, relief valves, filling and draining equipment, heating and interlock contacts shall operate within the limits specified for supply voltages of auxiliary and control circuits and/or within the limits of use of interrupting and/or insulating and operating media;
– the power consumption of heaters at rated voltage shall be within the tolerance of ± 10 % of the value stated by the manufacturer;
– where anti-pumping devices are part of the circuit-breaker control scheme, they shall act on each control circuit, if more than one is installed;
– where a control scheme of pole discrepancy is part of the circuit-breaker, the position of the poles shall be supervised, open or closed. Depending on the application, the delay time shall be adjustable between 0,1 s and 3 s.

5.5 Dependent power closing

Subclause 5.5 of IEC 62271-1 is applicable with the following addition:

– a circuit-breaker arranged for dependent power closing with external energy supply shall also be capable of opening immediately following the closing operation with the rated short-circuit making current.

5.6 Stored energy closing

Subclause 5.6 of IEC 62271-1 is applicable with the following addition to the first paragraph.

A circuit-breaker arranged for stored energy closing shall also be capable of opening immediately following the closing operation with the rated short-circuit making current.

5.7 Independent manual operation

Subclause 5.7 of IEC 62271-1 is not applicable for circuit-breakers.

5.8 Operation of releases

Subclause 5.8 of IEC 62271-1 is applicable with the following additions:

5.8.101 Over-current release

5.8.101.1 Operating current

An over-current release shall be marked with its rated normal current and its current setting range.

Within the current setting range, the over-current release shall always operate at currents of 110 % and above of the current setting, and shall never operate at currents of 90 % and below of this current setting.

5.8.101.2 Operating time

For an inverse time delay over-current release, the operating time shall be measured from the instant at which the over-current is established until the instant at which the release actuates the tripping mechanism of the circuit-breaker.

The manufacturer shall provide tables or curves, each with the applicable tolerances, showing the operating time as a function of current, between twice and six times the operating current. These tables or curves shall be provided for extreme current settings together with extreme settings of time delay.

5.8.101.3 Resetting current

If the current in the main circuit falls below a certain value, before the time delay of the overcurrent release has expired, the release shall not complete its operation and shall reset to its initial position.

The relevant information shall be given by the manufacturer.

5.8.102 Multiple releases

If a circuit-breaker is fitted with more than one release for the same function, a defect in one release shall not disturb the function in the others. Releases used for the same function shall be physically separated, i.e. magnetically decoupled.

For circuit-breakers rated at 72,5 kV and above accommodation should be made for one additional closing and one additional shunt opening release.

5.8.103 Operation limits of releases

For shunt opening releases the minimum trip duration and for shunt closing releases the minimum command duration at rated supply voltage shall not be less than 2 ms.

The minimum supply voltage for operation of shunt releases shall not be less than 20 % of the rated supply voltage.

5.8.104 Power consumption of releases

The power consumption of shunt closing or opening releases of a three-pole circuit-breaker should not exceed 1 200 VA. For certain circuit-breaker designs higher values may be required.

5.8.105 Integrated relays for self-tripping circuit-breakers

When an integrated relay is used for self-tripping circuit-breakers, it shall comply with IEC 60255-3. The input energising quantity is the current through the main contacts.

5.9 Low- and high-pressure interlocking devices

Subclause 5.9 of IEC 62271-1 is replaced by the following:

All circuit-breakers having an energy storage in gas receivers or hydraulic accumulators (see 5.6.1 of IEC 62271-1) and all circuit-breakers except sealed pressure devices, using compressed gas for interruption (see 5.103) shall be fitted with a low-pressure interlocking device, and can also be fitted with a high-pressure interlocking device, set to operate at, or within, the appropriate limits of pressure stated by the manufacturer.

5.10 Nameplates

Subclause 5.10 of IEC 62271-1 is applicable with the following additions: the nameplates of a circuit-breaker and its operating devices shall be marked in accordance with Table 10.

Coils of operating devices shall have a reference mark permitting the complete data to be obtained from the manufacturer.

Releases shall bear the appropriate data.

The nameplate shall be visible in the position of normal service and installation.

Table 10 – Nameplate information

	Abbrevi-ation	Unit	Circuit-breaker	Operating device	Condition: Marking only required if
1	2	3	4	5	6
Manufacturer			X	X	
Type designation and serial number			X	X	
Rated voltage	U_r	kV	X		
Rated lightning impulse withstand voltage	U_p	kV	X		
Rated switching impulse withstand voltage	U_S	kV	y		Rated voltage 300 kV and above
Rated frequency	f_r	Hz	y		Rating is not applicable at both 50 Hz and 60 Hz
Rated normal current	I_r	A	X		
Rated duration of short circuit	t_k	s	y		Different from 1 s
Rated short-circuit breaking current	I_{SC}	kA	X		
D.C. time constant of the rated short-circuit breaking current	τ	ms	y		Different from 45 ms
D.C. component of the rated short-circuit breaking current at contact separation corresponding to the d.c. time constant of the rated short-circuit breaking current	p_{CS}	%	y		More than 20 %
First pole-to-clear factor	k_{pp}		y		Different from 1,3 for rated voltages 100 kV to 170 kV
Rated out-of-phase breaking current	I_d	kA	(X)		
Rated line-charging breaking current	I_l	A	y		Rated voltage equal to or greater than 72,5 kV
Rated cable-charging breaking current	l_C	A	(X)		
Rated single capacitor bank-breaking current	I_{Sb}	A	(X)		
Rated back-to-back capacitor bank-breaking current	I_{bb}	A	(X)		
Rated back-to-back capacitor bank inrush making current	I_{bi}	kA	(X)		
Rated filling pressure for operation	p_{rm}	MPa		(X)	
Rated filling pressure for interruption	p_{re}	MPa	(X)		
Rated supply voltage of closing and opening devices	U_{op}	V		(X)	
Rated supply frequency of closing and opening devices		Hz		(X)	
Rated supply voltage of auxiliary circuits	U_a	V		(X)	
Rated supply frequency of auxiliary circuits		Hz		(X)	
Mass (including oil for oil circuit-breakers)	M	kg	y	y	More than 300 kg

Table 10 *(continued)*

	Abbrevi-ation	Unit	Circuit-breaker	Operating device	Condition: Marking only required if
1	2	3	4	5	6
Mass of fluid	*m*	kg	y		If contains fluid
Rated operating sequence			X		
Year of manufacture			X		
Temperature class			y	y	Different from – 5 °C indoor – 25 °C outdoor
Classification			y		If different from E1, M1, S1 for rated voltages less than 100 kV If different from E1, M1 for rated voltages 100 kV and above
Relevant standard with date of issue			X	X	
X = the marking of these values is mandatory; blanks indicate the value zero. (X) = the marking of these values is optional. y = the marking of these values to the conditions in column 6.					
NOTE The abbreviation in column 2 may be used instead of the terms in column 1. When terms in column 1 are used, the word “rated“ need not appear.					

5.11 Interlocking devices

Subclause 5.11 of IEC 62271-1 is applicable.

5.12 Position indication

Subclause 5.12 of IEC 62271-1 is applicable.

5.13 Degrees of protection by enclosures

Subclause 5.13 of IEC 62271-1 is applicable.

5.14 Creepage distances

Subclause 5.14 of IEC 62271-1 is applicable.

5.15 Gas and vacuum tightness

Subclause 5.15 of IEC 62271-1 is applicable.

5.16 Liquid tightness

Subclause 5.16 of IEC 62271-1 is applicable.

5.17 Fire hazard (flammability)

Subclause 5.17 of IEC 62271-1 is applicable.

5.18 Electromagnetic compatibility

Subclause 5.18 of IEC 62271-1 is applicable.

5.19 X-ray emission

Subclause 5.19 of IEC 62271-1 is applicable

5.20 Corrosion

Subclause 5.20 of IEC 62271-1 is applicable.

5.101 Requirements for simultaneity of poles during single closing and single opening operations

When no special requirement with respect to simultaneous operation of poles is stated, the maximum difference between the instants of contacts touching during closing in the individual poles shall not exceed a quarter of a cycle of rated frequency. If one pole consists of more than one interrupter unit connected in series, the maximum difference between the instants of contacts touching within these series connected interrupter units shall not exceed a sixth of a cycle of rated frequency. Where closing resistors are used, the maximum difference between the instants of contacts touching during closing in the individual closing resistors shall not exceed half a cycle of rated frequency. If on one pole more than one individual closing resistor is used, each assigned to one of the interrupter units which are connected in series, the maximum difference between the instants of contacts touching within these series connected closing resistors shall not exceed a third of a cycle of rated frequency

When no special requirement with respect to simultaneous operation of poles is stated, the maximum difference between the instants of contacts separating during opening shall not exceed a sixth of a cycle of rated frequency. If one pole consists of more than one interrupter unit connected in series, the maximum difference between the instants of contact separation within these series connected interrupter units shall not exceed an eighth of a cycle of rated frequency.

NOTE For a circuit-breaker having separate poles, the requirement is applicable when these operate in the same conditions; after a single-pole reclosing operation the conditions of operation for the three mechanisms may not be the same.

5.102 General requirement for operation

A circuit-breaker, including its operating devices, shall be capable of completing its rated operating sequence (4.104) in accordance with the relevant provisions of 5.5 to 5.9 and 5.103 for the whole range of ambient temperatures within its temperature class as defined in Clause 2 of IEC 62271-1.

This requirement is not applicable to auxiliary manual operating devices; where provided, these shall be used only for maintenance and for emergency operation on a dead circuit.

Circuit-breakers provided with heaters shall be designed to permit an opening operation at the minimum ambient temperature defined by the temperature class when the heaters are not operational for a minimum time of 2 h.

5.103 Pressure limits of fluids for operation

The manufacturer shall state the maximum and minimum pressures of the fluid for operation at which the circuit-breaker is capable of performing according to its ratings and at which the appropriate low- and high-pressure interlocking devices shall be set (see 5.9). The manufacturer shall state the minimum functional pressure for operation and interruption (see 3.7.157 and 3.7.158).

The manufacturer may specify pressure limits at which the circuit-breaker is capable of each of the following performances:

a) breaking its rated short-circuit breaking current, i.e. an "O" operation;
b) making its rated short-circuit making current immediately followed by breaking its rated short-circuit breaking current, i.e. a "CO" operating cycle;
c) for circuit-breakers intended for rapid auto-reclosing; breaking its rated short-circuit breaking current followed after a time interval *t* of the rated operating sequence (4.104) by making its rated short-circuit making current, immediately followed again by breaking its rated short-circuit breaking current, i.e. an "O – *t* – CO" operating sequence.

The circuit-breakers shall be provided with energy storage of sufficient capacity for satisfactory performance of the appropriate operations at the corresponding minimum pressures stated.

5.104 Vent outlets

Vent outlets are devices which allow a deliberate release of pressure in a circuit-breaker during operation.

NOTE This is applicable to air, air-blast and oil circuit-breakers.

Vent outlets of circuit-breakers shall be so situated that a discharge of oil or gas or both will not cause electrical breakdown and is directed away from any location where persons may be present. The necessary safety distance shall be stated by the manufacturer.

The construction shall be such that gas cannot collect at any point where ignition can be caused, during or after operation, by sparks arising from normal operation of the circuit-breaker or its auxiliary equipment.

6 Type tests

Clause 6 of 62271-1 is applicable with the following additions:

The type tests for circuit-breakers are listed in Table 11. The number of test samples is given in 6.1.1 and in 6.102.2. For the type tests, the tolerances on test quantities are given in Annex B.

The individual type tests shall, in principle, be performed on a circuit-breaker in a new and clean condition. In case of circuit-breakers using SF_6 for insulation, interruption and/or operation, the quality of the gas shall at least comply with the acceptance levels of IEC 60480.

The responsibility of the manufacturer is limited to the declared rated values and not to those values achieved during the type tests.

The uncertainty of each measurement by oscillograph or equivalent equipment (for example transient recorder), including associated equipment, of the quantities which determine the ratings (for example short-circuit current, applied voltage and recovery voltage) shall be within ±5 % (equal to a coverage factor of 2,0).

NOTE For the meaning of coverage factor, see ISO Guide to the expression of uncertainty in measurement (1995) [6].

Table 11 – Type tests

Mandatory type tests		**Subclauses**
Dielectric tests		6.2
Measurement of the resistance of the main circuit		6.4
Temperature-rise tests		6.5
Short-time withstand current and peak withstand current tests		6.6
Additional tests on auxiliary and control circuits		6.10
Mechanical operation test at ambient temperature		6.101.2.1 to 6.101.2.3
Short-circuit current making and breaking tests		6.102 to 6.106
Type tests dependant upon application, rating or design	**Condition requiring type test**	**Subclauses**
Radio interference voltage tests	$U_r \geq$ 123 kV	6.3
Verification of the degree of protection	Assigned IP class	6.7
Tightness test	Controlled, sealed or closed pressure systems	6.8
EMC tests	Electronic equipment or components are included in the secondary system	6.9
Extended mechanical endurance tests on circuit-breakers for special service conditions *#	Class M2 rating assigned	6.101.2.4
Low and high temperature tests	Assigned temperature class	6.101.3
Humidity test	Insulation subject to voltage stress and condensation	6.101.4
Static terminal load tests	Outdoor circuit-breaker with $U_r \geq$ 52kV	6.101.6
Critical current tests	Circuit-breaker performance against conditions in 6.107.1	6.107
Short-line fault tests *#	$U_r \geq$ 15kV and I_{sc} > 12,5 kA, in case of direct connection to overhead lines ~~in systems with solidly earthed neutral~~	6.109
Out-of-phase making and breaking tests *#	Out-of-phase rating assigned	6.110
Electrical endurance tests (only for $U_r \leq$ 52kV) *	Class E2 rating assigned	6.112
Test to prove operation under severe ice conditions *#	Outdoor circuit-breakers with rated ice thickness (10mm / 20mm)	6.101.5
Single-phase tests *#	Effectively earthed neutral systems	6.108
Double earth fault tests *#	Non-effectively earthed neutral systems	6.108
Capacitive current switching tests: – line-charging current breaking tests * – cable-charging current breaking tests *# – single capacitor bank switching tests *# – back-to-back capacitor bank switching tests *#	Relevant rating and classification (C1 or C2) assigned	6.111.5.1 6.111.5.1 6.111.5.2 6.111.5.2
Switching of shunt reactors and motors *#	Assigned switching rating	IEC 62271-110

NOTE 1 Mandatory type tests, shown in the upper part of the table, are required for all circuit-breakers regardless of rated voltage, design or intended use. Other type tests, shown in the lower part of the table, are required for all circuit-breakers where the associated rating is specified, e.g. out-of-phase switching, or where a specific condition is met, for example RIV is required only for rated voltages of 123 kV and above.

NOTE 2 In the lower part of the table some tests are marked by * or #. In the case of circuit-breakers with a rated voltage of up to and including 52 kV an * and for circuit-breakers with a rated voltage of 72,5 kV and above an # is used for the marking. For each marked test an additional test sample is allowed.

6.1 General

6.1.1 Grouping of tests

Subclause 6.1.1 of IEC 62271-1 is applicable.

6.1.2 Information for identification of specimens

Subclause 6.1.2 of IEC 62271-1 is applicable.

6.1.3 Information to be included in type test reports

Subclause 6.1.3 of IEC 62271-1 is applicable with the following addition:

Further details relating to records and reports of type tests for making, breaking and short-time current performance are given in Annex C.

6.1.101 Invalid tests

In the case of an invalid test, it may become necessary to perform a greater number of tests than are required by this standard. An invalid test is one where one or more of the test parameters demanded by the standard is not met. This includes, for example in the case of making, breaking or switching tests, current, voltage and time factors as well as point-on-wave requirements (if specified) and the additional features in synthetic testing such as correct auxiliary circuit-breaker operation and correct injection time.

The deviation from the standard could make the test less or more severe. Four different cases are considered in Table 12.

The invalid part of the test-duty may be repeated without reconditioning of the circuit-breaker. However, in the case of a failure of the circuit-breaker during such additional tests, or at the discretion of the manufacturer, the circuit-breaker may be reconditioned and the complete test-duty repeated. In the case where the circuit-breaker has not been reconditioned, the test report shall include reference to the invalid part of the test.

NOTE In a rapid, auto-reclosing duty cycle, the O – t – CO is regarded as one part, and an ensuing CO is regarded as another part.

A class E2 circuit-breaker may be reconditioned, but in this event the entire test series shall be repeated.

If any record of an individual operation cannot be produced for technical reasons, this individual operation is not considered invalid, provided that evidence can be given in another manner that the circuit-breaker did not fail and the required testing values were fulfilled.

Table 12 – Invalid tests

Test conditions related to standard	Circuit-breaker	
	Passes	**Fails**
More severe	Test valid, result accepted	Test to be repeated with correct parameters Modification of the design of the circuit-breaker not required
Less severe	Test to be repeated with correct parameters Modification of the design of the circuit-breaker not required	Circuit-breaker failed the test. Modification of the design of the circuit-breaker required, aiming for improvement of the performance Test-duty to be repeated on the modified circuit-breaker The modification may affect the results of already performed type tests

6.2 Dielectric tests

6.2.1 Ambient air conditions during tests

Subclause 6.2.1 of IEC 62271-1 is applicable.

6.2.2 Wet test procedure

Subclause 6.2.2 of IEC 62271-1 is applicable with the following note:

NOTE In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

6.2.3 Condition of circuit-breaker during dielectric tests

Subclause 6.2.3 of IEC 62271-1 is applicable.

6.2.4 Criteria to pass the test

Subclause 6.2.4 of IEC 62271-1 is applicable with the following addition:

If disruptive discharges occur and evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, the circuit-breaker shall be dismantled and inspected after the completion of the dielectric test series. If damage (for example tracking, puncture, etc.) to non-self-restoring insulation is observed, the circuit-breaker has failed the test.

NOTE 1 If the atmospheric correction factor K_t is less than 1,00 but greater than 0,95, it is permissible to follow the criteria stated in 6.2.4 of IEC 62271-1 if the correction factor is not applied during the tests. Then, if one or two disruptive discharges out of 15 impulses occur in the external insulation, the particular test series showing flashover(s) is repeated with the appropriate correction factor so that no external disruptive discharge occurs.

NOTE 2 For circuit-breakers of gas insulated switchgear tested with test bushings which are not part of the circuit-breaker, flashover across the test bushings should be disregarded.

6.2.5 Application of test voltage and test conditions

Subclause 6.2.5 of IEC 62271-1 is applicable.

6.2.6 Tests of circuit-breakers of $U_r \leq 245$ kV

Subclause 6.2.6 of IEC 62271-1 is applicable.

6.2.6.1 Power-frequency voltage tests

Subclause 6.2.6.1 of IEC 62271-1 is applicable with the following note:

NOTE In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

6.2.6.2 Lightning impulse voltage test

Subclause 6.2.6.2 of IEC 62271-1 is applicable.

6.2.7 Tests of circuit-breakers of $U_r > 245$ kV

Subclause 6.2.7 of IEC 62271-1 is applicable.

6.2.7.1 Power-frequency voltage tests

Subclause 6.2.7.1 of IEC 62271-1 is applicable with the following addition:

The test procedure following the alternative method is more severe than the test procedure following the preferred method.

6.2.7.2 Switching impulse voltage tests

Subclause 6.2.7.2 of IEC 62271-1 is applicable with the following addition:

For outdoor circuit-breakers dry tests shall be performed using voltage of positive polarity only. With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 9 of IEC 62271-1.

With the circuit-breaker open, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 9 of IEC 62271-1.

A second test series, with the test voltages according to column 6 of Tables 2a and 2b of IEC 62271-1, shall be performed for circuit-breakers intended for special applications as stated in 4.2. For each test condition of Table 11 of IEC 62271-1, one terminal shall be energised with switching impulse voltage and the opposite terminal with power-frequency voltage.

Subject to the manufacturer's approval, the test with the circuit-breaker open can be performed avoiding the use of the power-frequency voltage source. This test series consists of the application, to each terminal in turn, of impulses at a voltage equal to the sum of the switching impulse voltage and the peak value stated in column (6) of Tables 2a and 2b in IEC 62271-1, the opposite terminal being earthed.

Item b) of 6.2.5.2 of IEC 62271-1 shall be taken into account. In general, this test is more severe than that following the specified test procedure.

6.2.7.3 Lightning impulse voltage tests

Subclause 6.2.7.3 of IEC 62271-1 is applicable with the following addition:

With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 9 of IEC 62271-1.

With the circuit-breaker open, the test voltage equal to the rated withstand voltage across the open switching device shall be applied for each test condition of Table 11 of IEC 62271-1.

Subject to the manufacturer's approval, the test with the circuit-breaker open can be performed avoiding the use of the power-frequency voltage source. This test series applies to each terminal in turn (or on one terminal if the arrangement of the terminals is symmetrical with respect to the base), 15 consecutive impulses at a voltage equal to the sum of the rated lightning impulse withstand voltage and the peak value stated in column (8) of Tables 2a and 2b of IEC 62271-1, the opposite terminal being earthed. Item a) and item b) of 6.2.5.2 of IEC 62271-1 shall be taken into account. In general, this test is more severe than that following the specified test procedure.

6.2.8 Artificial pollution tests

Subclause 6.2.8 of IEC 62271-1 is applicable.

6.2.9 Partial discharge tests

Subclause 6.2.9 of IEC 62271-1 is applicable with the following addition:

Partial discharge tests are not normally required to be performed on the complete circuit-breaker. However, in the case of circuit-breakers using components for which a relevant IEC standard exists, including partial discharge measurements (for example, bushings, see IEC 60137), evidence shall be produced by the manufacturer showing that those components have passed the partial discharge tests as laid down in the relevant IEC standard.

6.2.10 Tests on auxiliary and control circuits

Subclause 6.2.10 of IEC 62271-1 is applicable.

6.2.11 Voltage test as a condition check

Subclause 6.2.11 of IEC 62271-1 is not applicable; the tests specified there are replaced with the following:

~~Where after mechanical or environmental tests (see 6.101.1.4) the insulating properties across open contacts of a circuit-breaker cannot be verified by visual inspection with sufficient reliability, a power-frequency withstand voltage test in dry condition according to 6.2.11 of IEC 62271-1 across the open circuit-breaker shall be applied as a condition check. In addition, a test to earth with the circuit-breaker in the closed position is required for dead tank and GIS circuit-breakers.~~

~~For gas enclosed vacuum circuit-breakers the voltage test as a condition check may not be sufficient. For such cases the vacuum integrity shall be demonstrated.~~

~~Where after making, breaking or switching tests (see 6.102.9) a voltage test is performed as a condition check, the following conditions shall apply:~~

~~For circuit-breakers with an asymmetrical current path, the connections shall be reversed. The complete tests shall be carried out once for each arrangement of the connections.~~

– ~~Circuit-breakers with~~ $\cancel{U_r \leq 72,5}$ ~~kV~~

~~A 1 min power-frequency voltage test shall be performed. The test voltage shall be 80 % of the value in Table 1a, column (2) of IEC 62271-1.~~

– ~~Circuit-breakers with~~ $\cancel{72,5 \text{ kV} < U_r \leq 245}$ ~~kV~~

~~An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 60 % of the highest relevant value in Table 1a, column (4) of IEC 62271-1.~~

~~– Circuit-breakers with 300 kV ≤ U_r ≤ 420 kV~~

~~An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in Table 2a of IEC 62271-1. In case of GIS circuit-breakers the crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in Table 103 of IEC 62271-203.~~

~~– Circuit-breakers with 550 kV ≤ U_r ≤ 800 kV~~

~~An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Table 2a of IEC 62271-1. In case of GIS circuit-breakers the crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Table 103 of IEC 62271-203.~~

~~Where an impulse voltage test shall be carried out, the waveshape of the impulse voltage shall be either a standard switching impulse or a waveshape according to the TRV specified for terminal fault test-duty T10. Five impulses of each polarity shall be applied. The circuit-breaker shall be considered to have passed the test if no disruptive discharge occurs. In the case that the synthetic testing equipment of the power laboratory is used, timing tolerances on the TRV waveshape of -10 % and +200 % on time t_3 are permitted.~~

~~NOTE 1 Comparative tests have shown that there are almost no differences in the behaviour of the circuit-breakers, both in new and in worn conditions, when testing is performed with standard switching impulses or with TRV impulses with a waveshape in accordance with terminal fault T10, respectively.~~

~~NOTE 2 If the tests are performed using the TRV impulse with a T10 waveshape, equivalence is maintained to the standard switching impulse if the following rules are applied:~~

~~– the damping of the TRV should be such that the second peak of the TRV oscillation is not higher than 80 % of the first one;~~

~~– about 2,5 ms after the peak, the actual value of the recovery voltage should be in the range of 50 % of the peak value.~~

Where after mechanical or environmental tests (see 6.101.1.4) the insulating properties across open contacts of a circuit-breaker cannot be verified by visual inspection with sufficient reliability, a power-frequency withstand voltage test in dry condition according to 6.2.11 of IEC 62271-1 across the open circuit-breaker shall be applied as a condition check. For GIS and dead tank circuit-breakers test conditions refer to Table 38.

For gas enclosed vacuum circuit-breakers the voltage test as a condition check may not be sufficient. For such cases the vacuum integrity shall be demonstrated.

Where after making, breaking or switching tests (see 6.102.9) a voltage test is performed as a condition check, the following conditions shall apply:

For circuit-breakers with an asymmetrical current path, the connections shall be reversed. The complete tests shall be carried out once for each arrangement of the connections. For dead tank and GIS circuit-breakers having a symmetrical current path, a test to earth is required with the circuit-breaker in closed position. When a test to earth is required, the rated insulation voltages across open contacts and to earth may be different. For such cases, each of the rated values corresponding to the test condition shall be used as the reference value for the determination of the test voltage. These requirements are summarised in Table 38.

– Circuit-breakers with U_r ≤ 72,5 kV

A 1 min power-frequency voltage test shall be performed. The test voltage shall be 80 % of the value in Tables 1a or 1b, column (2) of IEC 62271-1.

– Circuit-breakers with 72,5 kV < U_r ≤ 245 kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 60 % of the highest relevant value in Tables 1a or 1b, column (4) of IEC 62271-1.

– Circuit-breakers with 300 kV ≤ U_r ≤ 420 kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in Tables 2a or 2b of IEC 62271-1. In case of GIS circuit-breakers the crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in Table 103 of IEC 62271-203.

– Circuit-breakers with 550 kV ≤ U_r ≤ 800 kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Tables 2a or 2b of IEC 62271-1. In case of GIS circuit-breakers the crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Table 103 of IEC 62271-203.

– Circuit-breakers with U_r > 800 kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Tables 2a of IEC 62271-1. In case of GIS circuit-breakers the crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage. Examples of rated switching impulse withstand voltage values for GIS equipment are given in Table G.1 of IEC 62271-203.

Where an impulse voltage test shall be carried out, the waveshape of the impulse voltage shall be either a standard switching impulse or a waveshape according to the TRV specified for terminal fault test-duty T10. Five impulses of each polarity shall be applied. The circuit-breaker shall be considered to have passed the test if no disruptive discharge occurs. In the case that a T10 waveshape is used, timing tolerances on the TRV waveshape of -10 % and +200 % on time t_3 are permitted.

NOTE 1 Comparative tests have shown that there are almost no differences in the behaviour of the circuit-breakers, both in new and in worn conditions, when testing is performed with standard switching impulses or with TRV impulses with a waveshape in accordance with terminal fault T10, respectively.

NOTE 2 If the tests are performed using the TRV impulse with a T10 waveshape, equivalence is maintained to the standard switching impulse if the following rules are applied:

– the damping of the TRV should be such that the second peak of the TRV oscillation is not higher than 80 % of the first one;

– the voltage should be in the range of 50 % of its peak value 2,5 ms after time to peak.

Table 38 – Test requirements for voltage tests as condition check for GIS and dead tank circuit-breakers

No. of series connected breaks	Arrangement of the current path	Circuit-breaker position		
		Open (one side)	Open (other side)	Closed
Single	Symmetrical	Y	N	Y
	Asymmetrical	Y	Y	N
Multi	Symmetrical	Y	N	Y
	Asymmetrical	Y	Y	Y
Y: necessary to apply voltage. N: not necessary to apply voltage.				

6.3 Radio interference voltage (r.i.v.) tests

Subclause 6.3 of IEC 62271-1 is applicable with the following addition:

Tests may be performed on one pole of the circuit-breaker in both closed and open position. During the tests the circuit-breaker shall be equipped with all accessories such as grading capacitors, corona rings, HV connectors, etc., which may influence the radio interference voltage performance.

6.4 Measurement of the resistance of the main circuit

Subclause 6.4 of IEC 62271-1 is applicable.

6.5 Temperature-rise tests

6.5.1 Conditions of the circuit-breaker to be tested

Subclause 6.5.1 of IEC 62271-1 is applicable.

6.5.2 Arrangement of the equipment

Subclause 6.5.2 of IEC 62271-1 is applicable with the following additions:

For a circuit-breaker not fitted with series connected accessories, the test shall be made with the rated normal current of the circuit-breaker.

For a circuit-breaker fitted with series connected accessories having a range of rated normal currents, the following tests shall be made:

a) a test of the circuit-breaker fitted with the series connected accessories having a rated normal current equal to that of the circuit-breaker, and made at the rated normal current of the circuit-breaker;

b) a series of tests of the circuit-breaker fitted with the intended accessories, and made with currents equal to the rated normal current of each accessory.

NOTE If the accessories can be removed from the circuit-breaker, and if it is evident that the temperature rise of the circuit-breaker and of the accessories do not appreciably influence each other, test b) above may be replaced by a series of tests on the accessories alone.

6.5.3 Measurement of the temperature and the temperature rise

Subclause 6.5.3 of IEC 62271-1 is applicable.

6.5.4 Ambient air temperature

Subclause 6.5.4 of IEC 62271-1 is applicable.

6.5.5 Temperature-rise tests of the auxiliary and control equipment

Subclause 6.5.5 of IEC 62271-1 is applicable.

6.5.6 Interpretation of the temperature-rise tests

Subclause 6.5.6 of IEC 62271-1 is applicable.

6.6 Short-time withstand current and peak withstand current tests

Subclause 6.6 of IEC 62271-1 is applicable.

6.6.1 Arrangement of the circuit-breaker and of the test circuit

Subclause 6.6.1 of IEC 62271-1 is applicable with the following addition:

If the circuit-breaker is fitted with direct over-current releases, these shall be arranged for test with the coil of the minimum operating current set to operate at the maximum current and maximum time delay; the coil shall be connected to the source side of the test circuit. If the circuit-breaker can be used without direct over-current releases, it shall also be tested without them.

For other self-tripping circuit-breakers, the over-current release shall be arranged for test with the settings to operate at the maximum current and maximum delay time. If the circuit-breaker can be used without the release, it shall also be tested without it.

6.6.2 Test current and duration

Subclause 6.6.2 of IEC 62271-1 is applicable~~ with the following addition:~~.

~~For self-tripping circuit-breakers, the rated operating sequence confined to opening operations only shall be performed. The average of the r.m.s. values of the a.c. components of the breaking current in all phases and operations shall be considered as the r.m.s. value of the short-time current except that where the test is made at rated voltage, prospective current values may be used.~~

6.6.3 Behaviour of the circuit-breaker during test

Subclause 6.6.3 of IEC 62271-1 is applicable.

6.6.4 Conditions of the circuit-breaker after test

Subclause 6.6.4 of IEC 62271-1 is applicable with the following addition:

After the tests of self-tripping circuit-breakers, the conditions of the circuit-breaker shall comply with 6.102.9, and it shall be demonstrated that the over-current release is still in order to operate correctly. A primary injection test at 110 % of the minimum tripping current and in the conditions (single-phase or three-phase), as declared by the manufacturer, is a satisfactory demonstration.

6.7 Verification of the degree of protection

6.7.1 Verification of the IP coding

Subclause 6.7.1 of IEC 62271-1 is applicable to all parts of circuit-breakers which are accessible in normal service.

6.7.2 Mechanical impact test

Subclause 6.7.2 of IEC 62271-1 is applicable.

6.8 Tightness tests

Subclause 6.8 of IEC 62271-1 is applicable.

In the case of a vacuum circuit-breaker, the tightness verification of the vacuum insulation shall be carried out by means of a power frequency test according to 6.2.11 or an equivalent test.

6.9 Electromagnetic compatibility (EMC) tests

Subclause 6.9 of IEC 62271-1 is applicable.

6.9.3.1 Ripple on d.c. input power port immunity test

Subclause 6.9.3.1 of IEC 62271-1 is applicable with the following addition:

If no electronic components are used in the control unit and the mechanical operation test at ambient air temperature in accordance with 6.101.2 is performed on the complete circuit-breaker equipped with its entire control unit, the ripple on d.c. input power port immunity test according to subclause 6.9.3.1 of IEC 62271-1 is regarded as covered and additional tests shall be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 6.101.1.2 are acceptable.

Where electronic components are used, tests according to subclause 6.9.3.1 of IEC 62271-1 on the individual components are sufficient.

NOTE This subclause is applicable to both, complete electronic boards (e.g. control modules) and devices containing at least one electronic component (e.g. electronic timing relays).

6.9.3.2 Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests

Subclause 6.9.3.2 of IEC 62271-1 is applicable.

6.10 Additional tests on auxiliary and control circuits

6.10.1 General

Subclause 6.10.1 of IEC 62271-1 is applicable.

6.10.2 Functional tests

Subclause 6.10.2 of IEC 62271-1 is applicable with the following addition:

If the mechanical operation test at ambient air temperature in accordance with 6.101.2 is performed on the complete circuit-breaker equipped with its entire control unit, the functional tests according to subclause 6.10.2 of IEC 62271-1 are regarded as covered and additional tests shall be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 6.101.1.2 are acceptable.

6.10.3 Electrical continuity of earthed metallic parts test

Subclause 6.10.3 of IEC 62271-1 is applicable.

6.10.4 Verification of the operational characteristics of auxiliary contacts

Subclause 6.10.4 of IEC 62271-1 is applicable.

6.10.5 Environmental tests

Subclause 6.10.5 of IEC 62271-1 is applicable with the following addition:

If the mechanical operation test at ambient air temperature in accordance with 6.101.2, the low and high temperature tests in accordance with 6.101.3 and, if applicable, the humidity test in accordance with 6.101.4 are performed on the complete circuit-breaker equipped with its entire control unit or in case of the humidity test on the control equipment respectively, the environmental tests according to subclause 6.10.5 of IEC 62271-1 is regarded as covered and additional tests can be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 6.101.1.2 are acceptable.

NOTE Seismic tests are not covered. If a seismic test is requested, it should be performed by agreement between manufacturer and user.

6.101 Mechanical and environmental tests

6.101.1 Miscellaneous provisions for mechanical and environmental tests

6.101.1.1 Mechanical characteristics

At the beginning of the type tests, the mechanical characteristics of the circuit-breaker shall be established, for example, by recording no-load travel curves. This may be done also by the use of characteristic parameters, for example, momentary speed at a certain stroke, etc. The mechanical characteristics will serve as the reference for the purpose of characterising the mechanical behaviour of the circuit-breaker. Furthermore, the mechanical characteristics shall be used to confirm that the different test samples used during the mechanical, making, breaking and switching type tests behave mechanically in a similar way. The test in which this reference is gained is referred to as reference no-load test and the curves or other parameters resulting from it as reference mechanical characteristics. The reference no-load test may be taken from any appropriate no-load test being part of an individual type test.

The following operating characteristics shall be recorded:

– mechanical characteristics for opening and closing operation;
– closing time;
– opening time.

The mechanical characteristics shall be produced during a no-load test made with a single O operation and a single C operation at rated supply voltage of operating devices and of auxiliary and control circuits, rated functional pressure for operation and, for convenience of testing, at the minimum functional pressure for interruption.

The opening time and the closing time recorded in the reference no-load test shall be used as reference closing and reference opening time. The allowable deviations from these reference times correspond to the tolerances given by the manufacturer when performed under the same conditions as used for the procedure to produce the reference mechanical characteristics.

Annex N gives requirements and explanation on the use of mechanical characteristics.

6.101.1.2 Component tests

When testing of a complete circuit-breaker is not practicable, component tests may be accepted as type tests. The manufacturer should determine the components which are suitable for testing.

Components are separate functional sub-assemblies which can be operated independently of the complete circuit-breaker (for example, pole, breaking unit, operating mechanism).

When component tests are made, the manufacturer shall prove that the mechanical and environmental stresses on the component during the tests are not less than those applied to the same component when the complete circuit-breaker is tested. Component tests shall cover all different types of components of the complete circuit-breaker, provided that the particular test is applicable to the component. The conditions for the component type tests shall be the same as those which could be employed for the complete circuit-breaker.

Parts of auxiliary and control equipment which have been manufactured in accordance with relevant standards shall comply with these standards. The proper function of such parts in connection with the function of the other parts of the circuit-breaker shall be verified.

6.101.1.3 Characteristics and settings of the circuit-breaker to be recorded before and after the tests

Before and after the tests, the following operating characteristics or settings shall be recorded and evaluated:

a) closing time;
b) opening time;
c) time spread between units of one pole;
d) time spread between poles (if multi-pole tested);
e) recharging time of the operating device;
f) consumption of the control circuit;
g) consumption of the tripping devices, possible recording of the current of the releases;
h) duration of opening and closing command impulse;
i) tightness, if applicable;
j) gas densities or pressures, if applicable;
k) resistance of the main circuit;
l) time-travel chart;
m) other important characteristics or settings as specified by the manufacturer.

The above operating characteristics shall be recorded at

– rated supply voltage and rated filling pressure for operation;
– maximum supply voltage and maximum filling pressure for operation;
– maximum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and maximum filling pressure for operation.

6.101.1.4 Condition of the circuit-breaker during and after the tests

During and after the tests, the circuit-breaker shall be in such a condition that it is capable of operating normally, carrying its rated normal current, making and breaking its rated short-circuit current and withstanding the voltage values according to its rated insulation level.

In general, these requirements are fulfilled if

– during the tests, the circuit-breaker operates on command and does not operate without command;
– after the tests, the characteristics measured according to 6.101.1.3 are within the tolerances given by the manufacturer;
– after the tests, all parts, including contacts, do not show undue wear;
– after the tests, coated contacts are such that a layer of coating material remains at the contact area. If this is not the case, the contacts shall be regarded as bare and the test requirements are fulfilled only if the temperature rise of the contacts during the temperature-rise test (according to 6.5) does not exceed the value permitted for bare contacts;
– during and after the tests, any distortion of mechanical parts is not such that it adversely affects the operation of the circuit-breaker or prevents the proper fitting of any replacement part;

– after the tests the insulating properties of the circuit-breaker in the open position shall be in essentially the same condition as before the tests. Visual inspection of the circuit-breaker after the tests is usually sufficient for verification of the insulating properties. In the case of circuit-breakers with sealed-for-life interrupter units, a voltage test as a condition check in accordance with 6.2.11 may be necessary.

6.101.1.5 Condition of the auxiliary and control equipment during and after the tests

During and after the tests, the following conditions for the auxiliary and control equipment shall be fulfilled:

– during the tests, care should be taken to prevent undue heating;
– during the tests, a set of contacts (both make and break auxiliary contacts) shall be arranged to switch the current of the circuits to be controlled (see 5.4);
– during and after the tests, the auxiliary and control equipment shall fulfil its functions;
– during and after the tests, capability of the auxiliary circuits of the auxiliary switches and of the control equipment shall not be impaired. In case of doubt, the tests according to 6.2.10 of IEC 62271-1 shall be performed;
– during and after the tests, the contact resistance of the auxiliary switches shall not be affected adversely. The temperature rise when carrying the rated current shall not exceed the specified values (see Table 3 of IEC 62271-1).

6.101.2 Mechanical operation test at ambient air temperature

6.101.2.1 General

The mechanical operation test shall be made at the ambient air temperature of the test location. The ambient air temperature should be recorded in the test report. Auxiliary equipment forming part of the operating devices shall be included.

The mechanical operation test shall consist of 2 000 operating sequences.

Except for circuit-breakers fitted with over-current releases the test shall be made without voltage on or current in the main circuit.

For circuit-breakers fitted with over-current releases, approximately 10 % of the operating sequences shall be performed with the opening device energised by the current in the main circuit. The current shall be the minimum current necessary to operate the over-current release. For these tests, the current through over-current releases may be supplied from a suitable low-voltage source.

During the test, lubrication is allowed in accordance with the manufacturer's instructions, but no mechanical adjustment or other kind of maintenance is allowed.

NOTE A circuit-breaker design may be fitted with several variants of auxiliary equipment (shunt releases and motors) in order to accommodate the various rated control voltages and frequencies as stated in 4.8 and 4.9. These variants do not need to be tested if they are of similar designs and if the resulting no-load mechanical characteristics are within the tolerance given in Annex N.

6.101.2.2 Condition of the circuit-breaker before the test

The circuit-breaker for test shall be mounted on its own support and its operating mechanism shall be operated in the specified manner. It shall be tested according to its type as follows:

A multipole circuit-breaker actuated by a single operating device and/or with all poles mounted on a common frame shall be tested as a complete unit.

Tests shall be conducted at the rated filling pressure for interruption according to 6.101.1.3, item j).

A multipole circuit-breaker in which each pole or even each column is actuated by a separate operating device should be tested preferably as a complete multipole circuit-breaker. However, for convenience, or owing to limitations of the dimensions of the test bay, one single-pole unit of the circuit-breaker may be tested, provided that it is equivalent to, or not in a more favourable condition than, the complete multipole circuit-breaker over the range of tests, for example in respect of

– reference mechanical travel characteristics;
– power and strength of closing and opening mechanism;
– rigidity of structure.

6.101.2.3 Description of the test on class M1 circuit-breakers

The circuit-breaker shall be tested in accordance with Table 13.

Table 13 – Number of operating sequences

Operating sequence	Supply voltage and operating pressure	Number of operating sequences	
		Circuit-breakers for auto-reclosing	Circuit-breakers not for auto-reclosing
C – t_a – O – t_a	Minimum	500	500
	Rated	500	500
	Maximum	500	500
O – t – CO – t_a – C – t_a	Rated	250	–
CO – t_a	Rated	–	500

O = opening;

C = closing;

CO = a closing operation followed immediately (i.e., without any intentional time-delay) by an opening operation;

t_a = time between two operations which is necessary to restore the initial conditions and/or to prevent undue heating of parts of the circuit-breaker (this time can be different according to the type of operation);

t = 0,3 s for circuit-breakers intended for rapid auto-reclosing, if not otherwise specified.

6.101.2.4 Extended mechanical endurance tests on class M2 circuit-breakers for special service requirements

For special service requirements in the case of frequently operated circuit-breakers, extended mechanical endurance tests may be carried out, as follows.

The tests shall be made according to 6.101.1, 6.101.2.1, 6.101.2.2 and 6.101.2.3 with the following addition:

– the tests shall consist of 10 000 operating sequences comprising five times the relevant test series specified in Table 13;
– between the test series specified, some maintenance, such as lubrication and mechanical adjustment, is allowed, and shall be performed in accordance with the manufacturer's instructions. Change of contacts is not permitted;
– the programme of maintenance during the tests shall be defined by the manufacturer before the tests and recorded in the test report.

6.101.2.5 Acceptance criteria for the mechanical operation tests

The criteria given below apply for mechanical operation tests on class M1 and class M2 circuit-breakers.

a) Before and after the total test programme, the following operations shall be performed:
   – five close-open operating cycles at the rated supply voltage of closing and opening devices and of auxiliary and control circuits and/or the rated pressure for operation;
   – five close-open operating cycles at the minimum supply voltage of closing and opening devices and of auxiliary and control circuits and/or the minimum pressure for operation;
   – five close-open operating cycles at the maximum supply voltage of closing and opening devices and of auxiliary and control circuits and/or the maximum pressure for operation.

   During these operating cycles, the operating characteristics (see 6.101.1.3) shall be recorded and evaluated. It is not necessary to publish all the oscillograms recorded. However, at least one oscillogram for each set of conditions given above shall be included in the test report.

In addition, the following checks and measurements shall be performed (see 10.2.102):

   – measurements of characteristic operating fluid pressures and consumption during operations, if applicable;
   – verification of the rated operating sequence;
   – checks of certain specific operations, if applicable.

   The variation between the mean values of each parameter measured before and after the extended mechanical endurance tests shall be within the tolerances given by the manufacturer.

b) After each series of 2 000 operating sequences, the operating characteristics a), b), c), d), e) and l) in 6.101.1.3 shall be recorded.

c) After the total test programme the condition of the circuit-breaker shall be in accordance with 6.101.1.4.

6.101.3 Low and high temperature tests

6.101.3.1 General

The two tests need not be performed in succession, and the order in which they are made is arbitrary. For class –5 °C indoor circuit-breakers and for class –10 °C outdoor circuit-breakers, no low temperature test is required.

For single enclosure circuit-breakers or multi-enclosure circuit-breakers with a common operating device, three-pole tests shall be made. For multi-enclosure circuit-breakers with independent poles, testing of one complete pole is permitted.

Owing to limitations of the test facilities, multi-enclosure type circuit-breakers may be tested using one or more of the following alternatives provided that the circuit-breaker in its testing arrangement is not in a more favourable condition than normal condition for mechanical operation (see 6.101.2.2):

a) reduced length of phase-to-earth insulation;
b) reduced pole spacing;
c) reduced number of modules.

If heat sources are required, they shall be in operation.

Liquid or gas supplies for circuit-breaker operation are to be at the test air temperature unless the circuit-breaker design requires a heat source for these supplies.

No maintenance, replacement of parts, lubrication or readjustment of the circuit-breaker is permissible during the tests.

NOTE 1 In order to determine the material temperature characteristics, ageing, etc., tests of longer duration than those specified in the following subclauses may be necessary.

As an alternative approach to the methods in this standard, a manufacturer may establish compliance with performance requirements for an established circuit-breaker family by documenting satisfactory circuit-breaker field experience in at least one location with ambient air temperatures frequently at or above the specified maximum ambient air temperature of 40 °C, and at least one location with satisfactory field experience in specified minimum ambient air temperature depending on the class of the circuit-breaker (see Clause 2 of IEC 62271-1).

The circuit-breaker has passed the test if the conditions stated in 6.101.1.4 and 6.101.1.5 are fulfilled. Furthermore, the conditions in 6.101.3.3 and 6.101.3.4 shall be fulfilled and the leakage rates recorded shall not exceed the limits given in Table 13 of IEC 62271-1. In the test report the testing conditions and the condition of the circuit-breaker before, during and after the test shall be reported. The recorded quantities shall be presented in an appropriate way and the oscillograms taken shall be shown. To reduce the number of oscillograms in the test report, it is allowed to show a single representative oscillogram of every relevant type of operation under each specified testing condition.

Vacuum circuit-breakers are excluded from the tightness verification tests during the high and low temperature tests. The integrity of the vacuum will be verified by a power frequency voltage (or equivalent) test after the high and low temperature tests. However, if the vacuum circuit-breaker is used in an enclosure filled with an insulating gas, for example SF_6, the tightness verification tests during the high and low temperature tests shall be performed on this enclosure.

NOTE 2 A circuit-breaker design may be fitted with several variants of auxiliary equipment (shunt releases and motors) in order to accommodate the various rated control voltages and frequencies as stated in 4.8 and 4.9. These variants do not need to be tested if they are of similar designs and if the resulting no-load mechanical characteristics are within the tolerance given in 6.101.1.1.

6.101.3.2 Measurement of ambient air temperature

The ambient air temperature of the immediate test environment shall be measured at half the height of the circuit-breaker and at a distance of 1 m from the circuit-breaker.

The maximum temperature deviation over the height of the circuit-breaker shall not exceed 5 K.

6.101.3.3 Low temperature test

The diagram of the test sequences and identification of the application points for the tests specified are given in Figure 17a.

If the low temperature test is performed immediately after the high temperature test, the low temperature test can proceed after completion of item u) of the high temperature test. In this case items a) and b) are omitted.

a) The test circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.
b) Characteristics and settings of the circuit-breaker shall be recorded in accordance with 6.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C (T_A). The tightness test (if applicable) shall be performed according to 6.8.

c) With the circuit-breaker in the closed position, the air temperature shall be decreased to the appropriate, minimum ambient air temperature (T_L), according to the class of the circuit-breaker as given in 2.1.1, 2.1.2 and 2.2.3 of IEC 62271-1. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at T_L.

d) During the 24 h period with the circuit-breaker in the closed position at temperature T_L, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table ~~12~~ 13 of IEC 62271-1.

NOTE 1 A tightness test is applicable if gases are used for operation, interruption and/or insulation. In case of vacuum circuit-breakers no tightness test is required. However, if the vacuum circuit-breaker is used in an enclosure filled with an insulating gas, for example SF_6, the tightness verification tests have to be performed on this enclosure.

e) After 24 h at temperature T_L, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The opening time and the closing time shall be recorded to establish low temperature operating characteristics. Contact velocity should be recorded if feasible.

f) The low temperature behaviour of the circuit-breaker and its alarms and lock-out systems shall be verified by disconnecting the supply of all heating devices, including also the anti-condensation heating elements, for a duration t_x. During this interval, occurrence of the alarm is acceptable but lock-out is not. At the end of the interval t_x, an opening order, at rated values of supply voltage and operating pressure, shall be given. The circuit-breaker shall then open. The opening time shall be recorded (and the mechanical travel characteristics measured, if feasible) to allow assessment of the interrupting capability.

   The manufacturer shall state the value of t_x (not less than 2 h) up to which the circuit-breaker is still operable without auxiliary power to the heaters. In the absence of such a statement, the preferred value shall be equal to 2 h.

   NOTE 2 The measurement of the mechanical characteristics is feasible if a location is accessible for the travel sensor to be used.

g) The circuit-breaker shall be left in the open position for 24 h.

h) During the 24 h period with the circuit-breaker in the open position at temperature T_L, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table ~~12~~ 13 of IEC 62271-1.

i) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at temperature T_L. At least a 3 min interval shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded to establish low temperature operating characteristics. Contact velocity should be recorded if feasible. Following the first closing operation (C) and the first opening operation (O) three CO operating cycles (no intentional time delay) shall be performed. The additional operations shall be made by performing C – t_a – O – t_a operating sequences (t_a is defined in Table 13).

j) After completing the 50 opening and 50 closing operations, the air temperature shall be increased to ambient air temperature T_A at a rate of change of approximately 10 K per hour.

   During the temperature transition period the circuit-breaker shall be subjected to alternate C – t_a – O – t_a – C and O – t_a – C – t_a – O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in open and closed positions for 30 min periods between the operating sequences.

k) After the circuit-breaker has stabilised thermally at ambient air temperature T_A, a recheck shall be made of the circuit-breaker settings, operating characteristics and tightness as in Items a) and b) for comparison with the initial characteristics.

The accumulated leakage during the complete low temperature test sequence from item b) to item j) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).

6.101.3.4 High-temperature test

The diagram of the test sequence and identification of the application points for the tests specified are given in Figure 17b.

If the high temperature test is performed immediately after the low temperature test, the high temperature test can proceed after completion of item j) of the low temperature test. In this case, items l) and m) below are omitted.

l) The test circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.

m) Characteristics and settings of the circuit-breaker shall be recorded in accordance with 6.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C (T_A). The tightness test (if applicable) shall be performed according to 6.8.

n) With the circuit-breaker in the closed position, the air temperature shall be increased to the appropriate, maximum ambient air temperature (T_H), according to the upper limit of ambient air temperature as given in 2.1.1, 2.1.2 and 2.2.3 of IEC 62271-1. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at T_H.

NOTE 1 The influence of solar radiation is not considered.

o) During the 24 h period with the circuit-breaker in the closed position at the temperature T_H, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 13 of IEC 62271-1.

NOTE 2 A tightness test is applicable if gases are used for operation, interruption and/or insulation. In case of vacuum circuit-breakers no tightness test is required. However, if the vacuum circuit-breaker is used in an enclosure filled with an insulating gas, for example SF_6, the tightness verification tests have to be performed on this enclosure.

p) After 24 h at the temperature T_H, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The opening time and the closing time shall be recorded to establish high temperature operating characteristics. Contact velocity should be recorded if feasible.

NOTE 3 The measurement of the mechanical characteristics is feasible if a location is accessible for the travel sensor to be used.

q) The circuit-breaker shall be opened and left open for 24 h at the temperature T_H.

r) During the 24 h period with the circuit-breaker in the open position at the temperature T_H, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table ~~12~~ 13 of IEC 62271-1.

s) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at the temperature T_H. An interval of at least 3 min shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded to establish high temperature operating characteristics. Contact velocity should be recorded if feasible.

Following the first closing operation (C) and the first opening operation (O) three CO operation cycles (no intentional time delay) shall be performed. The additional operations shall be made by performing C – t_a – O – t_a operating sequences (t_a is defined in Table 13).

t) After completing the 50 opening and 50 closing operations, the air temperature shall be decreased to ambient air temperature T_A, at a rate of change of approximately 10 K/h.

During the temperature transition period, the circuit-breaker shall be subjected to alternate C – t_a – O – t_a – C and O – t_a – C – t_a – O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at

30 min intervals so that the circuit-breaker will be in the open and closed positions for 30 min periods between the operating sequences.

u) After the circuit-breaker has stabilised thermally at ambient air temperature T_A, a recheck shall be made of the circuit-breaker settings, operating characteristics and tightness as in items l) and m) for comparison with the initial characteristics.

The accumulated leakage during the complete high temperature test sequence from item l) to item t) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).

6.101.4 Humidity test

6.101.4.1 General

The humidity test shall not be applied on equipment which is designed to be directly exposed to precipitation, for example primary parts of outdoor circuit-breakers. The test shall be performed on circuit-breakers or circuit-breaker components, where due to sudden changes of the temperature condensation may occur on insulating surfaces which are continuously stressed by voltage. This is mainly the insulation of the secondary wiring of indoor installed circuit-breakers. It is also not necessary where effective means against condensation are provided, for example control cubicles with anti-condensation heaters.

Applying the test procedure described in 6.101.4.2, the withstand of the test object, primarily circuit-breaker components, to humidity effects, which may produce condensation on the surface of the test specimen, is determined in an accelerated manner.

6.101.4.2 Test procedure

The test object shall be arranged in a test chamber containing circulating air and in which the temperature and humidity shall follow the cycle given below:

During about half of the cycle the surfaces of the test object shall be wet, and dry during the other half. To obtain this result the test cycle consists of a period t_4 with low air temperature (T_{min} = 25 °C ± 3 °C) and a period t_2 with high air temperature (T_{max} = 40 °C ± 2 °C) inside the test chamber. Both periods shall be equal in time. The generation of fog shall be maintained for that half of the cycle (see Figure 18) in which the low air temperature is applied.

The beginning of fog generation coincides in principle with the beginning of the low air temperature period. However, to wet the vertical surfaces of materials with a high thermal time constant, it may be necessary to start the fog generation later within the low air temperature period.

The duration of the test cycle depends on the thermal characteristics of the test objects, and shall be sufficiently long, both at high and low temperature, to cause wetting and drying of all insulation surfaces. In order to obtain these conditions, steam should be injected directly into the test chamber or heated water should be atomised; the rise from 25 °C to 40 °C may be obtained with the provision of heat coming from the steam or atomised water or, if necessary, by additional heaters. Preliminary cycles shall be carried out with the test object placed in the test chamber in order to observe and to check these conditions.

NOTE For low-voltage components of high-voltage circuit-breakers, usually having time constants smaller than 10 min, the duration of the time intervals given in Figure 18 are: t_1 = 10 min, t_2 = 20 min, t_3 = 10 min and t_4 = 20 min.

The fog is obtained by the continuous or periodical atomisation of 0,2 l to 0,4 l of water (with the resistivity characteristics given below) per hour and per cubic metre of test chamber volume. The diameter of the droplets shall be less than 10 µm; such a fog may be obtained by mechanical atomisers. The direction of the spraying shall be such that the surfaces of the test object are not directly sprayed. No water shall drop from the ceiling upon the test object.

During the fog generation the test chamber shall be closed and no additional forced air-circulation is permitted.

The water used to create the humidity shall be such that the water collected in the test chamber has a resistivity equal to or greater than 100 Ωm and contains neither salt (NaCl) nor any corrosive element.

The temperature and the relative humidity of the air in the test chamber shall be measured in the immediate vicinity of the test object and shall be recorded for the whole duration of the test. No value of relative humidity is specified during the drop in temperature; however, the humidity shall be above 80 % during the period when the temperature is maintained at 25 °C. The air shall be circulated in order to obtain uniform distribution of the humidity in the test chamber.

The number of cycles shall be 350.

During and after the test, the operating characteristics of the test objects shall not be affected. The auxiliary and control circuits shall withstand a power frequency voltage of 1 500 V for 1 min. The degree of corrosion, if any, should be indicated in the test report.

6.101.5 Test to prove the operation under severe ice conditions

The test under severe ice conditions is applicable only to outdoor circuit-breakers having moving external parts and for which a class of 10 mm or 20 mm of ice thickness is specified. The test shall be performed under the conditions described in IEC 62271-102.

6.101.6 Static terminal load test

6.101.6.1 General

The static terminal load test is applicable only to outdoor circuit-breakers.

If the manufacturer can demonstrate by means of calculations that the circuit-breaker can withstand the specified stresses, then tests need not be performed.

The static terminal load test is performed to demonstrate that the circuit-breaker operates correctly when loaded by stresses resulting from ice, wind and connected conductors.

Ice coating and wind pressure on the circuit-breaker shall be in accordance with 2.1.2 of IEC 62271-1.

~~Some examples of forces due to flexible and tubular connected conductors (not including wind or ice load or the dynamic loads on the circuit-breaker itself) are given as a guidance in Table 14.~~

Some examples of forces due to wind, ice and weight on flexible and tubular connected conductors (not including wind or ice load or the dynamic loads on the circuit-breaker itself) are given as a guidance in Table 14.

The tensile force due to the connected conductors is assumed to act at the outermost end of the circuit-breaker terminal.

For simultaneous action of ice, wind and connected conductors, the resultant terminal forces F_{sr1}, F_{sr2}, F_{sr3} and F_{sr4} (see Figure 19) are defined as rated static terminal loads.

6.101.6.2 Tests

The tests shall be made at the ambient air temperature of the test room.

The tests should be performed on at least one complete pole of the circuit-breaker. If the manufacturer can demonstrate that there is no interaction between different columns in the pole, it is sufficient to test only one column. For circuit-breakers which are symmetrical to the pole unit vertical centreline, only one terminal need be tested with the rated static terminal load. For circuit-breakers which are not symmetrical, each terminal shall be tested.

Two testing methods are available:

a) The tests shall be carried out with the resultant forces F_{sr1}, F_{sr2}, F_{sr3} and F_{sr4} of the 3 components: vertical, longitudinal and transversal (as defined in Figure 20). The following tests shall be performed:
   - Test 1 with: $F_{\mathrm{sr1}} = F_{\mathrm{th\ A}} + F_{\mathrm{th\ B1}} + F_{\mathrm{tv\ C2}} + F_{\mathrm{wh}}$
   - Test 2 with: $F_{\mathrm{sr2}} = F_{\mathrm{th\ A}} + F_{\mathrm{th\ B1}} + F_{\mathrm{tv\ C1}} + F_{\mathrm{wh}}$
   - Test 3 with: $F_{\mathrm{sr3}} = F_{\mathrm{th\ A}} + F_{\mathrm{th\ B2}} + F_{\mathrm{tv\ C2}} + F_{\mathrm{wh}}$
   - Test 4 with: $F_{\mathrm{sr4}} = F_{\mathrm{th\ A}} + F_{\mathrm{th\ B2}} + F_{\mathrm{tv\ C1}} + F_{\mathrm{wh}}$

For convenience of testing, the order of the individual tests is arbitrary. If the structure of the circuit-breaker is symmetrical to the longitudinal axis of its interrupter units, either tests number 2 and 4 or tests number 1 and 3 may be omitted.

b) As an alternative, the tests may be made separately, applying the forces subsequently as follows:
   - with a horizontal force, F_{shA}, applied in longitudinal axis of the terminal (directions A_1 and A_2 in Figure 20);
   - with a horizontal force, F_{shB}, applied in two directions successively at 90° from the longitudinal axis of the terminals (directions B_1 and B_2 in Figure 20);
   - with a vertical force, F_{sv} applied in two directions successively (directions C_1 and C_2 in Figure 20).

In case of a three-pole circuit-breaker with a common base frame, the middle pole should be tested.

To avoid the need to apply a special force representing the force of wind acting at the circuit-breaker's centre of application of pressure, this wind load may be applied at the terminal (see Figure 19) and reduced in magnitude in proportion to the longer lever arm (the bending moment at the lowest part of the circuit-breaker should be the same).

Before and after each of the individual terminal load tests two operating cycles (CO operation) shall be performed. For this purpose the circuit-breaker may need to be pressurized. For safety reasons the pressure may be at any appropriate value.

The test is considered to be satisfactory if the circuit-breaker operates normally when the mechanical load is applied. This is fulfilled if the travel of the contact, the opening and the closing time after the series of tests show no significant change from the values recorded before the tests; the rules given in 6.101.1.1 and Annex N shall be applied accordingly.

NOTE As the pressure in the circuit-breaker for the static terminal load tests may deviate from the value prescribed for the test specified in 6.101.1.1 and in Annex N, a direct comparison of the mechanical parameters recorded during the static terminal load tests with the reference mechanical characteristics is not practicable. However, the rules given in 6.101.1.1 and Annex N may be applied in an adapted way.

After the tests, no leakage or deterioration of the seals shall have occurred.

Table 14 – Examples of static horizontal and vertical forces for static terminal load test

Rated voltage range U_r kV	Rated current range I_r A	Static horizontal force F_{th} Longitudinal F_{thA} N	Static horizontal force F_{th} Transversal F_{thB} N	Static vertical force (vertical axis-upward and downward) F_{tv} N
< 100	800 – 1 250	500	400	500
< 100	1 600 – 2 500	750	500	750
100 – 170	1 250 – 2 000	1 000	750	750
100 – 170	2 500 – 4 000	1 250	750	1 000
245 – 362	1 600 – 4 000	1 250	1 000	1 250
420 – 800	2 000 – 4 000	1 750	1 250	1 500
1 100 – 1 200	4 000 – 6 300	3 500	3 000	2 500

6.102 Miscellaneous provisions for making and breaking tests

The following subclauses are applicable to all making and breaking tests unless otherwise specified in the relevant clauses.

Where applicable, prior to the commencement of the tests, the manufacturer shall declare the values of

– minimum conditions of the operating mechanism guaranteeing the rated operating sequence (for example the minimum functional pressure for operation in case of a hydraulic operating mechanism);

– minimum conditions of the interrupting device guaranteeing the rated operating sequence (for example the minimum functional pressure for interruption in case of a SF_6 circuit-breaker).

6.102.1 General

Circuit-breakers shall be capable of making and breaking all short-circuit currents, symmetrical and asymmetrical, up to and including the rated short-circuit breaking currents: this is demonstrated, when the circuit-breakers make and break the specified three-phase symmetrical and asymmetrical currents between 10 % (or such lower currents as specified in 6.107.2 if 6.107.1 is applicable) and 100 % of the rated short-circuit breaking current at rated voltage.

In addition, circuit-breakers intended to be used in an effectively earthed neutral system or for single-pole operation shall make and break single-phase short-circuit currents between 10 % (or such lower currents as specified in 6.107.2 if 6.107.1 is applicable) and 100 % of the rated short-circuit breaking current at phase-to-earth voltage ($U_r/\sqrt{3}$). Furthermore, circuit-breakers shall be capable of breaking short-circuit currents in case of double earth faults (see 6.108).

Circuit-breakers to which any capacitive current switching rating has been assigned shall be capable of switching capacitive currents up to and including the rated capacitive switching current at a voltage level up to and including the specified one (see 6.111.7). This is demonstrated when the circuit-breakers switch the rated capacitive switching current at the specified test voltage.

Three-phase making and breaking requirements should preferably be proved in three-phase circuits.

If the tests are carried out in a laboratory, the applied voltage, current, transient and power-frequency recovery voltages may all be obtained from a single power source (direct tests) or from several sources where all of the current, or a major portion of it, is obtained from one source, and the transient recovery voltage is obtained wholly or in part from one or more separate sources (synthetic tests).

If, due to limitations of the testing facilities, the short-circuit performance of the circuit-breaker cannot be proved in the above way, several methods employing either direct or synthetic test methods may be used either singly or in combination, depending on the circuit-breaker type:

a) single-pole testing (see 6.102.4.1);
b) unit testing (see 6.102.4.2);
c) multi-part testing (see 6.102.4.3).

The operating time of some circuit-breakers may vary when the supply voltage to the coils is at the minimum value specified in 5.8 of IEC 62271-1, while the operating times are reasonably constant at their rated supply voltages. Performing a test duty with correct arcing times can be difficult to achieve in such a case, especially where steps of 18 electrical degrees need to be made to prove the arcing window. Additionally, the scattering of the closing time may prevent the possibility to perform the making test with the rated short-circuit making current.

For circuit-breakers where the operation of the coils does not affect contact travel characteristics, it is permitted to increase the supply voltage of the coils from the minimum value to 110 % of the rated supply voltage. No-load operations performed at the rated and minimum supply voltage shall be included in the test report to show that the contact travel characteristics are not affected by the increased voltage of the coil.

At least one making and one breaking operation shall be performed for test-duty T100s with minimum supply voltage to prove the ability of the circuit-breaker to operate correctly up to its rated short-circuit current under minimum control voltage conditions.

6.102.2 Number of test specimens

Subclause 6.1.1 of IEC 62271-1 is applicable with the following addition:

As a recommended practice for the performance of short-circuit making and breaking tests and of switching tests (including terminal fault, short-line fault, out-of-phase and capacitive current switching tests where applicable), a unique test specimen should be used. Where required, maintenance is allowed and should be performed as permitted, between each individual test-duty in the case of short-circuit tests and between each test series in the case of other than short-circuit tests. The manufacturer shall provide a statement to the testing laboratory of those parts that may be renewed during the tests.

It is, however, recognised that in the case of several test-duties being carried out in the same testing station during one occupation, the restrictions given in the previous paragraph may cause economic constraints. Under these circumstances, it is allowed to use up to two test specimens for the performance of all the above-mentioned tests. In such a case, full identification of the two test specimens according to 6.1.2 of IEC 62271-1 shall be carried out; in addition, the mechanical travel characteristics of the two specimens shall be within the tolerances given in 6.101.1.1.

As a further allowance limited to circuit-breakers having independent operating mechanisms for each pole, tested single-phase and full pole, in addition to the two test specimens, supplementary interrupting units of up to two poles may be used.

If tests are carried out as unit tests on one or more units of a pole, the total number of units involved in the individual test, taking the provisions of 6.102.4.2.3 into account, is considered as one test specimen. In this case, two test specimens with their associated operating mechanisms and up to two additional test specimens (appropriate interrupting units) may be used.

In Figure 21 the permitted number of test specimens for making, breaking and switching tests is illustrated, and in Figure 22 the definition of a test specimen in accordance with 3.2.1 of IEC 62271-1 is illustrated.

The additional allowance is permitted, provided that inspection of the equipment after the tests shows that there is no undue damage to the non-renewable parts which could impair the capability of the circuit-breaker to withstand the complete series of type tests without change of its non-renewable parts. Should this not be the case, the tests shall be repeated using the same specimen with only replacement of the renewable parts as declared by the manufacturer.

Where additional non-mandatory tests are performed, the use of additional test specimens, exceeding the number specified above, is allowed (see Table 11).

6.102.3 Arrangement of circuit-breaker for tests

6.102.3.1 General

The circuit-breaker under test shall be mounted on its own support or on an equivalent support. A circuit-breaker supplied as an integral part of an enclosed unit shall be assembled on its own supporting structure and enclosure, complete with any disconnecting features, with vent outlets forming part of the unit and, where practicable, with main connections and busbars.

Its operating device shall be operated in the manner specified and in particular, if it is electrically or spring operated, closing solenoid or shunt closing releases and shunt opening releases shall be supplied at their respective minimum voltages guaranteeing successful operation (85 % of the rated voltage for the closing solenoid or shunt closing releases, 85 % of the rated voltage if a.c. or 70 % if d.c. for the opening release). To facilitate consistent control of the opening and closing operation, the releases shall be supplied at the maximum operating voltage for test-duty T100a, capacitive current switching tests, small inductive current switching tests and the single-phase test specified in 6.108. Operating devices having a minimum operating condition (i.e. pressure, energy, etc.) shall be operated at the minimum condition for operation at the commencement of the rated operating sequence, as per 4.104, unless otherwise specified in the relevant clauses. In cases where test duty or test stations limitations allow for operating sequences consisting of separate O operations, CO and O – t – CO operating sequences, the following procedure applies to pneumatically and hydraulically operating devices:

a) before performing making, breaking and switching tests and starting from the minimum functional pressure for operation as per 3.7.157, all the pressures during the rated operating sequence carried out at no-load shall be recorded;
b) the recorded values shall be compared with the minimum values declared by the manufacturer as guaranteeing successful operations as separate O, CO and O – t – CO;
c) tests shall be carried out at the pressure for operation set at the minimum value resulting from a) and b) above, whatever is the lower, for the corresponding operation in the test-duty; the pressure values shall be reported in the test report.

Interlocking devices associated with pressure interlocks shall be made inoperative during the tests, if they interfere with the intent of the test.

It shall be shown that the circuit-breaker will operate satisfactorily under the above conditions at no-load as specified in 6.102.6. The pressure of the compressed gas for interruption, if any, shall be set at its minimum functional value according to 3.7.158.

The circuit-breaker shall be tested according to its type as specified in 6.102.3.2 and 6.102.3.3.

6.102.3.2 Common enclosure type

A three-pole circuit-breaker having all its arcing contacts supported within a common enclosure shall be tested as a complete three-pole circuit-breaker in three-phase circuits, taking Annex O into account.

The reasons are as follows:

– possibility of disruptive discharge between poles or to earth due to the influence of exhaust gases;
– possible differences in the conditions of the extinguishing medium (pressures, temperatures, pollution levels, etc.);
– greater influence between phases due to electrodynamic forces in the case of a three-phase fault;
– possible different stresses on the operating mechanism.

6.102.3.3 Multi-enclosure type

A three-pole circuit-breaker consisting of three independent single-pole switching devices can be tested single-phase according to 6.102.4.1. The manufacturer shall give testing evidence to show compliance with 5.101.

A three-pole circuit-breaker not having completely independent switching devices should be tested as a complete three-pole circuit-breaker. However, owing to limitation of available testing facilities, one single pole of the circuit-breaker may be tested, provided that it is with regard to the mechanical and electrical conditions applied during the tests equivalent to, or not in a more favourable condition than, the complete three-pole circuit-breaker over the range of tests in respect of

– mechanical travel characteristics in a making operation (for the evaluation method, see 6.102.4.1);
– mechanical travel characteristics in a breaking operation (for the evaluation method, see 6.102.4.1);
– availability of arc-extinguishing medium;
– power and strength of closing and opening devices;
– rigidity of structure.

6.102.3.4 Self-tripping circuit-breakers

For self-tripping circuit-breakers, subject to the provisions of 6.103.4, the over-current release shall be inoperative during making, breaking and switching tests and the over-current release or the current transformers shall be connected to the live side of the test circuit.

6.102.4 General considerations concerning testing methods

6.102.4.1 Single-phase testing of a single pole of a three-pole circuit-breaker

According to this method, a single pole of a three-pole circuit-breaker is tested single-phase, applying to the pole the same current and substantially the same power-frequency voltage which would be impressed upon the most highly stressed pole during three-phase making and breaking by the complete three-pole circuit-breaker under corresponding conditions.

In those cases where the circuit-breaker design permits single-pole testing to simulate three-phase conditions and the circuit-breaker is equipped with one operating mechanism for all poles a complete three-pole assembly shall be supplied for the tests.

For short-circuit tests in order to establish whether the circuit-breaker permits single-phase tests to simulate three-phase conditions, verification tests consisting of an asymmetrical and a symmetrical making operation and a breaking operation shall be performed. Furthermore, it shall be checked that the operating characteristics of the circuit-breaker to be single-phase tested correspond to the provisions of 6.101.1.1.

The verification test for breaking consists of performing a three-phase short-circuit breaking test at the same current level as prescribed for test-duty T100s, without TRV with any convenient test voltage, and with the longest expected arcing time in the last-pole-to-clear.

The verification test for making consists of two three-phase making operations under the same conditions as given in 6.104.2. In one making operation full symmetrical current and the maximum prearcing time shall be achieved in one pole. In the other making operation the maximum asymmetry shall be achieved in one pole; in this case the making operation may be performed at a convenient reduced voltage.

During these verification tests for making and breaking, the course of the contact travel is recorded. It shall be used as a reference for the following procedure (see Figure 23a). The sensor for picking up the course of the contact travel shall be mounted at a suitable location making it possible for providing the course of the contact travel at best, either directly or indirectly.

From this reference course, two envelope curves shall be drawn from the instant of contact separation to the end of the contact travel, in the case of a breaking operation, and from the beginning of the contact travel to the instant of contact touch, in the case of a making operation. The distance of the two envelopes from the original course shall be ±5 % of the total travel evaluated from the three-phase verification test (see Figure 23b).

During a single-phase test under the same conditions (test-duty T100s with the longest arcing time and the longest pre-arcing time) the course of the contact travel shall be recorded. If the course of the contact travel in the single-phase test is within the envelopes of the mechanical travel characteristics from the instant of contact separation to the end of the contact travel in the case of a breaking operation and from the beginning of the contact travel to the instant of contact touch in the case of a making operation of the three-phase tests, single-phase tests for representing three-phase conditions are valid.

The envelopes can be moved in the vertical direction until one of the curves covers the reference curve. This gives maximum tolerances over the reference contact travel curve of –0 %, +10 % and +0 %, –10 % respectively (see Figures 23c and 23d). The displacement of the envelope can be done only once for the complete procedure in order to get a maximum total deviation from the reference curve of 10 %.

NOTE To achieve the correct contact travel characteristics of the individual poles, depending on the design (single-phase or three-phase operated), it may be necessary to make adjustments, for example by using transfer functions.

Special attention should be paid to the emission of arc products. If it is considered that such emission would, for example, be likely to impair the insulation distance to adjacent poles, then this shall be checked, using earthed metallic screens (see 6.102.8).

6.102.4.2 Unit testing

Certain circuit-breakers are constructed by assembling identical breaking or making units in series, the voltage distribution between the units of each pole often being improved by the use of parallel impedances.

This type of design enables the breaking or making performance of a circuit-breaker to be tested by carrying out tests on one or more units.

The requirements of 6.101.1.1, 6.102.3 and 6.102.4.1 also apply for unit testing. Since therefore at least a complete pole assembly has to be made available for the verification tests on one or more units, the test results relate only to this specific pole design.

The following situations can be distinguished:

a) The circuit-breaker pole consists of units (or assemblies of units) which are separately operated and which have no mutual connections for the arc extinguishing medium.

   In this case unit testing is acceptable. However, the mutual influence through the electrodynamic forces of the current on the units and the arc in the units should be taken into account (see Figure 24). This may be done by substitution of the second interrupter unit by a conductor with equivalent shape.

b) The circuit-breaker pole consists of units (or assemblies of units) which are separately operated but which have a mutual connection for the arc extinguishing medium.

   In this case, unit testing is only acceptable if the units not under test arc during the test (e.g. used as auxiliary circuit-breaker in synthetic tests).

c) The circuit-breaker pole consists of units (or assemblies of units) which are not separately operated.

   ~~In this case, unit testing is only acceptable if the mechanical travel characteristics for the single-unit testing and for full-pole testing are the same. The procedure as given in 6.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly. Moreover, the influence of electrodynamic forces (see also item a) above) shall be covered.~~

   ~~However, if the units not under test arc during the test (for example, used as auxiliary circuit-breaker in synthetic tests), the requirements related to the mechanical travel characteristics are considered to be covered. In this case, the requirement for circuit-breakers, which have mutual connections for the extinguishing medium between units (see also item b) above) is covered at the same time.~~

   In this case, unit testing is only acceptable if the mechanical characteristics for the single-unit testing and for full-pole testing are the same. The procedure as given in 6.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly. Moreover, the influence of electrodynamic forces (see also item a) above) shall be covered.

   However, if the units not under test arc during the test (for example, used as auxiliary circuit-breaker in synthetic tests), the requirements related to the mechanical characteristics are considered to be covered. In this case, the requirement for circuit-breakers, which have mutual connections for the extinguishing medium between units (see also item b) above) is covered at the same time.

d) For test currents equal to or less than 60 % of the rated short-circuit current, single-unit testing is permissible if the arc extinguishing medium volume of the single unit under test is proportional to the applicable part of one assembly of units having the same arc extinguishing medium.

   ~~The mechanical travel characteristics for single-unit testing and for full-pole testing shall be the same. The procedure given in 6.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly.~~

   The mechanical characteristics under no-load conditions for single-unit testing and for full-pole testing shall be the same. The procedure for comparison of mechanical characteristics given in 6.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly. The mutual influence through the electrodynamic forces of the current and the arc in the units is considered to be negligible for test currents equal or less than 60 % of the rated short-circuit current.

When carrying out unit tests it is essential that the units are identical and that the static voltage distribution for the type of test (for example terminal faults, short-line fault, out-of-phase, etc.) is known.

For unit testing of GIS and dead tank circuit-breakers, see Annex O.

6.102.4.2.1 Identical nature of the units

The units of the circuit-breaker shall be identical in their shape, in their dimensions and in their operating conditions; only the devices for controlling the voltage distribution among units may be different. In particular, the following conditions shall be fulfilled.

a) *Operation of contacts*

The opening, in breaking tests, or the closing, in making tests, of the contacts of one pole shall be such that the time interval between the opening or closing of the contacts of the unit which is first to operate and the contacts of the unit which is last to operate is not more than one-eighth of a cycle of rated frequency. Rated operating pressures and voltages shall be used to determine this time interval.

b) *Supply of the arc-extinguishing medium*

For a circuit-breaker using a supply of arc-extinguishing medium from a source external to the units, the supply to each unit shall, for all practical purposes, be independent of the supply to the other units, and the arrangement of the supply pipes shall be such as to ensure that all units are fed essentially together and in an identical manner.

6.102.4.2.2 Voltage distribution

The test voltage is determined by analysing the voltage distribution between the units of the pole.

The voltage distribution between units of a pole, as affected by the influence of earth, shall be determined for the relevant test conditions laid down for tests on one pole:

– for terminal fault conditions see items c) and d) of 6.103.3 and Figures 27a, 27b, 28a and 28b;

NOTE 1 The test circuit shown in Figures 27b and 28b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex O of this standard and in IEC 62271-101.

– for short-line fault conditions see 6.109.3;

– for out-of-phase conditions see 6.110.1 and Figures 51, 52 and 53;

– for capacitive current switching conditions see 6.111.3, 6.111.4 and 6.111.5.

Where the units are not symmetrically arranged, the voltage distribution shall be determined also with reverse connections.

The voltage distribution is determined either by measurement or by calculation. Values used in the calculations shall be supported by measurements of the stray capacitances of the circuit-breaker. Such calculations and supporting measurements verifying the assumptions used in the calculations are the responsibility of the manufacturer.

If the circuit-breaker is fitted with parallel resistors, the voltage distribution shall be calculated or measured statically at the equivalent frequency involved in the TRV.

NOTE 2 The equivalent frequency is considered to be $1/(2t_1)$ in the case of four parameters or $1/(2t_3)$ in the case of two parameters (see Figures 39 and 40).

For short-line fault unit tests, the voltage distribution shall be calculated or measured statically on the basis of a voltage on the line side at the fundamental frequency of the line oscillation and a voltage on the source side at the equivalent frequency of the TRV for terminal faults, the common point of the two voltages being at earth potential.

If only capacitors are used, the voltage distribution may be calculated or measured at power frequency.

The manufacturing tolerances for resistors and capacitors shall be taken into account. The manufacturer shall state the value of these tolerances.

NOTE 3 It may be taken into account that the voltage distribution is more favourable during the out-of-phase and capacitive current breaking tests than during the terminal or short-line fault tests. This also applies when, in exceptional cases, tests have to be performed under the conditions of unearthed faults in effectively earthed neutral systems.

NOTE 4 The influence of pollution is not considered in determining voltage distribution. In some cases, pollution may affect this voltage distribution.

6.102.4.2.3 Requirements for unit testing

When testing a single unit, the test voltage shall be the voltage of the most highly stressed unit of the complete pole of the circuit-breaker, determined in accordance with 6.102.4.2.2. For short-line fault conditions, the unit referred to is that most highly stressed at the specified time of the first peak of the line side transient voltage.

When testing a group of units, the voltage appearing at the terminals of the most highly stressed unit of the group shall be equal to the voltage of the most highly stressed unit of the pole, both determined in accordance with 6.102.4.2.2.

During unit testing, the insulation to earth is not stressed with the full voltage occurring during a breaking operation of the complete circuit-breaker. For certain types of circuit-breakers, such as circuit-breakers in metal enclosures, it is therefore necessary to prove that the insulation to earth is capable of withstanding this full voltage, after interruption of the rated short-circuit current in all units with maximum arcing time. The influence of exhaust gases should also be taken into account.

Additional guidance is given in Annex O of this standard. IEC 62271-101 shall be taken into account.

6.102.4.3 Multi-part testing

If all TRV requirements for the given test-duty cannot be met simultaneously, the test may be carried out in two successive parts, as illustrated in Figure 43.

In the first part the initial portion of the TRV shall not cross the straight line defining the delay time and shall meet the specified reference line up to the voltage u_1 and the time t_1.

In the second part, the voltage u_c and the time t_2 shall be attained.

The number of tests for each part shall be the same as the number required for the test-duty, and the arcing times for each part shall meet the requirements of 6.102.10. The arcing times in separate tests forming part of one multi-part test shall be the same with a margin of ±1 ms. Moreover if the minimum arcing time in one part differs from that established in the other part by more than 1 ms then the maximum arcing time associated with the longer of the two minimum arcing times shall be used for both parts.

The circuit-breaker may be re-conditioned between the first part and the second part in accordance with 6.102.9.5.

In rare cases, it may be necessary to perform the test in more than two parts. In such cases, the principles stated above shall be applied.

6.102.5 Synthetic tests

Synthetic testing methods can be applied for making, breaking and switching tests as required in 6.106 to 6.111. Synthetic testing techniques and methods are described in IEC 62271-101.

6.102.6 No-load operations before tests

Before commencing making and breaking tests, no-load operations and no-load operating sequences (O, CO and O – *t* – CO) shall be made and details of the operating characteristics of the circuit-breaker recorded. Details such as closing time and opening time shall be recorded.

In addition, it shall be demonstrated that the mechanical behaviour of the circuit-breaker, or sample under test, conforms to that of the reference mechanical travel characteristics required in 6.101.1.1. For this test the operational conditions stated in 6.101.1.1 apply. After a change of contacts or any kind of maintenance, these mechanical travel characteristics shall be reconfirmed by repeating these no-load tests.

For a circuit-breaker fitted with a making current release, it shall be shown that this does not operate on no-load.

The pressure of the fluid for interruption shall be set at its minimum functional value according to 3.7.158.

For electrically or spring-operated circuit-breakers, operations shall be made with the closing solenoid or shunt-closing releases energised at 100 % and 85 % of the rated supply voltage of the closing device and with the shunt-opening release energised at 100 % and 85 % in the case of a.c., and 100 % and 70 % in the case of d.c. of the rated supply voltage.

For pneumatic or hydraulic operating devices, the operations shall be made under the following conditions:

a) pressure of the fluid for operation set at its minimum functional value as per 3.7.157 with the shunt opening releases energised at 85 % in case of a.c., 70 % in case of d.c. and with the shunt closing releases energised at 85 % of the rated supply voltage;
b) pressure of the fluid for operation set at its rated value as per 4.10 with the shunt releases energised at the rated supply voltage.

6.102.7 Alternative operating mechanisms

For a circuit-breaker equipped with an alternative operating mechanism, repetition of the type tests under short-circuit and out-of-phase conditions and of the capacitive current switching type tests is not necessary.

NOTE 1 In this subclause, it is considered that one version of the circuit-breaker using a certain operating mechanism, is completely type-tested in accordance with this standard; this version is referred to as the completely tested circuit-breaker. The other versions, differing only in the operating mechanisms (see definition in 3.5.124), are referred to as circuit-breakers with alternative operating mechanisms.

The tests to be performed are limited to the following:

a) On each of the circuit-breakers (the completely tested circuit-breaker and the circuit-breakers with alternative operating mechanisms) the mechanical characteristics shall be recorded and compared in accordance with 6.101.1.1 (The use of mechanical characteristics and related requirements are described in Annex N.).
b) On each of the circuit-breakers (the completely tested circuit-breaker and the circuit-breakers with alternative operating mechanisms) test-duty T100s shall be performed. In addition the mechanical characteristics during the breaking operations with the longest arcing time shall be evaluated according to the method prescribed in 6.101.1.1. (The use of mechanical characteristics and related requirements are described in Annex N.).
c) In the particular case where the variation in opening times of the alternative operating mechanism causes the circuit-breaker to fall into a different category of minimum clearing time (see 3.7.159), test duty T100a shall be performed on the circuit-breaker with alternative operating mechanism.

If requirements a), b) and c) are met, the reference mechanical characteristics of the completely tested circuit-breaker shall apply also for the circuit-breakers with alternative operating mechanisms.

6.102.8 Behaviour of circuit-breaker during tests

During making and breaking tests, the circuit-breaker shall not

– show signs of distress;
– show harmful interaction between poles and to earth;
– show harmful interaction with adjacent laboratory equipment;
– exhibit behaviour which could endanger an operator.

For circuit-breakers which are designed to have discharge of interrupting medium to atmosphere during the making and breaking tests, the above requirements are considered to have been met, provided

– for oil circuit-breakers, there is no outward emission of flame, and the gases produced, together with the oil carried with the gases, shall be conducted from the circuit-breaker and directed away from all live conductors and locations where persons may be present;
– for other types of circuit-breakers, such as air blast or air break, there is an outward emission of flame, gas and/or metallic particles. If such emissions are appreciable it may be required that the tests shall be made with metallic screens placed in the vicinity of the live parts and separated from them by a safety clearance distance which the manufacturer shall specify. The screens shall be insulated from earth but connected thereto by a suitable device to indicate any significant leakage current to earth. There shall be no indication of significant leakage currents to the circuit-breaker earthed structure, or screens when fitted, during the tests.

NOTE 1 If no other devices are available, the earthed parts, etc. should be connected to earth through a fuse consisting of a copper wire of 0,1 mm diameter and 5 cm long. No significant leakage is assumed to have occurred if this fuse wire is intact after the test.

If faults occur which are neither persistent nor due to defect in design, but rather are due to errors in assembly or maintenance, the faults can be rectified and the circuit-breaker subjected to the repeated test-duty concerned. In those cases, the test report shall include reference to the invalid tests.

NSDDs may occur during the recovery voltage period following a breaking operation. However, their occurrence is not a sign of distress of the switching device under test. Therefore, their number is of no significance to interpreting the performance of the device under test. They shall be reported in the test report in order to differentiate them from restrikes.

NOTE 2 It is not the intent to require the installation of special measuring circuits to detect NSDDs. They should only be reported when seen on an oscillogram.

6.102.9 Condition of circuit-breaker after tests

6.102.9.1 General

The circuit-breaker may be inspected after any test-duty. Its mechanical parts and insulators shall be in essentially the same condition as before the test-duty. Visual inspection is usually sufficient for verification of the insulating properties. In case of doubt, the condition checking test according to 6.2.11 is sufficient to prove the insulation properties.

For circuit-breakers with sealed-for-life interrupter units, the condition checking test is mandatory, except as stated in 6.102.9.4.

6.102.9.2 Condition after a short-circuit test-duty

After each short-circuit test-duty, the circuit-breaker shall be capable of making and breaking its rated normal current at the rated voltage, although its short-circuit making and breaking performance may be impaired. After test-duty L_{90} a condition checking test according to 6.2.11 shall be performed. If test-duty L_{90} is not performed, the condition checking test shall be carried out after test-duty T100s.

If interrupter units are placed in an insulating fluid with different characteristics, that also might withstand the test voltages when replacing the original arc extinguishing medium (for example a vacuum interrupter unit in an enclosure filled with SF_6) the condition checking test, as requested in 6.2.11 may not be adequate to verify the integrity of the device. In such cases a short-circuit breaking test shall be made in addition. If more than one test-duty is carried out without reconditioning this additional test shall be made before or after the no-load tests subsequent to the short-circuit test-duties as follows:

– if performed three-phase, a circuit which supplies at least 10 % of the rated short-circuit breaking current and at least 50 % of the rated voltage shall be used with both the source side neutral and the short-circuit point earthed;
– if performed single-phase, the same procedure applies and the test has to be repeated on each pole.

The requirements mentioned above also apply to synthetic tests.

A successful interruption in each pole is evidence that the interrupter integrity is maintained.

For other than sealed for life interrupter units, visual inspection is usually sufficient for verification of the capability of the circuit-breaker to carry the rated normal current and to make and break its rated normal current at the rated voltage.

The main contacts shall be in such a condition, in particular with regard to wear, contact area, pressure and freedom of movement, that they are capable of carrying the rated normal current of the circuit-breaker without their temperature rise exceeding by more than 10 K the values specified for them in Table 3 of IEC 62271-1.

NOTE Experience shows that an increase of the voltage drop across the circuit-breaker cannot alone be considered as reliable evidence of an increase in temperature rise.

Contacts shall be considered as "silver-faced" only if there is still a layer of silver at the contact points after any of the short-circuit test-duties; otherwise, they shall be treated as "not silver-faced" (see 4.4.3, point 6 of IEC 62271-1).

In order to check the operation of the circuit-breaker after testing, no-load operations shall be made, if change of contacts or other kinds of maintenance are intended to be performed after the test-duty. These shall be compared with the corresponding operations made in accordance with 6.102.6 and shall show no significant change.

6.102.9.3 Condition after a short-circuit test series

In order to check the operation of the circuit-breaker after test, a no-load closing and a no-load opening operation shall be made at the completion of the entire series of short-circuit tests. These operations shall be carried out under the same conditions as one of the corresponding operations before the tests. The no-load operations after the test series shall be compared with the corresponding operations made in accordance with 6.102.6 and shall show no significant change. The requirements of 6.101.1.1 and of Annex N shall be fulfilled. The circuit-breaker shall close and latch satisfactorily.

It is recognised that the rated short-circuit current making, breaking and carrying capability will have been impaired, but degradation of the components in the current-carrying path shall not reduce the integrity of the insulating or the mechanically supporting components of the circuit-breaker. With regard to the main contacts the relevant provisions of 6.102.9.2 apply.

No criteria can be given for the acceptable level of degradation for the fluid insulation (gas, oil, air etc.) as their required strength is linked to the design criteria of each individual type of circuit-breaker.

6.102.9.4 Condition after a capacitive current switching test series

The circuit-breaker shall, after performing the line-charging, cable-charging and capacitor bank current switching test series specified in 6.111.9, and before reconditioning, be capable of operating satisfactorily at any making and breaking current up to its rated short-circuit making and breaking current at rated voltage.

In addition, the circuit-breaker shall be capable of carrying its rated normal current with a temperature rise not in excess of the temperature rise permitted by Table 3 of IEC 62271-1. In case of class C2 circuit-breakers the temperature rise shall not exceed the values permitted by Table 3 of IEC 62271-1 by more than 10 K.

For other than sealed for life interrupter units, visual inspection is usually sufficient for verification of the capability of the circuit-breaker to carry the rated normal current and to make and break at any current up to its rated short-circuit making and breaking current at the rated voltage.

There shall be no evidence of puncture, flashover or tracking of the internal insulating materials, except that moderate wear of the parts of arc control devices exposed to the arc is permissible.

Degradation of the components in the current carrying path shall not reduce the integrity of the normal current carrying path.

If, during the capacitive current switching tests, one or more restrikes occurred, the dielectric condition checking test according to 6.2.11 shall be performed before visual inspection, provided that the tested peak recovery voltage during the capacitive current switching tests is lower than the peak voltage of the specified dielectric condition checking test. The subsequent visual inspection shall demonstrate that the restrike occurred between the arcing contacts only. There shall be no evidence of puncture, flashover or permanent tracking of internal insulating materials. Wear of the parts of arc control devices exposed to the arc is permissible as long as it does not impair the breaking capability. Moreover, the inspection of the insulating gap between the main contacts, if they are different from the arcing contacts, shall not show any trace of a restrike.

If no restrike occurred during the capacitive current switching tests visual inspection is sufficient. The dielectric condition checking test according to 6.2.11 shall not be performed.

Where further tests are performed on the same pole, the dielectric condition checking test shall be performed after the capacitive current switching test. If no restrike occurred during the capacitive current switching test, this dielectric condition checking test need not be performed, and the condition checking test may be performed after the additional tests.

NOTE If the circuit-breaker fails during the additional tests, this procedure may make the capacitive current switching tests invalid.

For circuit-breakers with sealed-for-life interrupter units, the dielectric condition checking test according to 6.2.11 shall be performed, whether a restrike occurs during testing or not, provided that the tested peak recovery voltage during the capacitive current switching tests is lower than the peak voltage of the specified dielectric condition checking test.

6.102.9.5 Reconditioning after a short-circuit test-duty and other test series

It may be necessary to carry out maintenance work on the circuit-breaker after performing a short-circuit test-duty or other test series in order to restore it to the original condition specified by the manufacturer. For example, it may be necessary to

a) repair or replace the arcing contacts and any other renewable parts recommended by the manufacturer;
b) renew or filter of the oil, or any other extinguishing medium, and add any quantity of the medium necessary to restore its normal level or density;
c) remove deposit, caused by the decomposition of the extinguishing medium, from internal insulation.

A class E2 circuit-breaker shall not be reconditioned during the basic short-circuit test-duties, given in 6.106.

6.102.10 Demonstration of arcing times

It is preferred that the sequence for performing the three valid breaking operations is such that the last breaking operation results in a medium arcing time. The procedures described in this subclause are relevant for the adjustment of prospective arcing times. The actual arcing times may vary from the prospective ones. Tests are valid as long as the actual arcing times are within the tolerances given in Annex B.

For circuit-breakers with the rated operating sequence CO – t'' – CO, one CO shall demonstrate the minimum arcing time and the other one shall demonstrate the maximum arcing time.

The terminal fault tests T100a in 6.102.10.1.2, 6.102.10.2.1.2 and 6.102.10.2.2.2 consist of three valid operations independent of the rated operating sequence. After the number of operations provided for in accordance with the rated operating sequence the circuit-breaker may be reconditioned in accordance with 6.102.9.5.

NOTE The arcing times prescribed in this subclause are adequate to cover the effect of the unintentional non-simultaneity of the circuit-breaker poles.

6.102.10.1 Three-phase tests

The procedures given below are for direct tests. Where synthetic tests are performed it is necessary to establish the minimum arcing time for the first phase to clear before starting the sequence. The method of establishing this minimum arcing time is given in 6.102.10.2.

6.102.10.1.1 Test-duty T10, T30, T60, T100s, T100s(b), OP1 and OP2

For these tests the tripping impulse shall be advanced by 40 electrical degrees (40°) between each opening operation. For T100s(b), see note in 6.106.

~~A graphical representation of the three valid breaking operations for the first-pole-to-clear factor 1,5 is given in Figure 29 and for the first-pole-to-clear factor 1,3 in Figure 30.~~

Examples of a graphical representation of the three valid breaking operations for the first-pole-to-clear factor 1,5 are given in Figure 29 and for the first-pole-to-clear factor 1,3 in Figure 30.

6.102.10.1.2 Test-duty T100a

Since the severity of the tests for this test-duty can vary widely depending on the moment of contact separation, a procedure has been developed in order to arrive at realistic stresses on the circuit-breaker under test. The initiation of the short-circuit changes 60° between tests in order to transfer the required asymmetry criteria from phase to phase.

The intention is to achieve a series of three valid tests and the duty is considered satisfactory if the following conditions are met:

a) One operation where in the first pole-to-clear arc extinction occurs at the end of a major current loop with the longest possible arc duration and with the required asymmetry criteria as given in 6.106.6 in order to comply with the TRV requirements.

NOTE Some circuit-breakers will not clear at the end of a major loop. Arcing then continues during the subsequent minor current loop and becomes a last pole-to-clear. However, this test is considered valid if during a subsequent test it is proven that the longest possible arc-duration was achieved.

b) One operation where in one of the last poles-to-clear arc-extinction occurs at the end of a major extended current loop with the longest possible arc-duration and with the required asymmetry criteria as given in 6.106.6.

   A test where the circuit-breaker clears at the end of a reduced major current loop or a minor loop in the phase meeting the asymmetry criteria is invalid (with the exception of the situation described in the note to a) above.

c) One operation with the required asymmetry criteria as given in 6.106.6 to prove the validity of test conditions outlined in a) and b) above.

The sequence of the tests is of no consequence as long as the series of tests fulfils the test conditions mentioned in a), b) and c).

If it is not possible to achieve the above requirements because of the characteristics of the circuit-breaker, the number of operations should be extended to prove that, in this particular case, the most severe test conditions have been achieved. The circuit-breaker should not be subjected to more than six opening operations when attempting to meet the above requirements.

The circuit-breaker may be reconditioned with renewable parts before the extended operations (see 6.102.9.5). An additional test sample can also be used for the extended operations.

The recommended procedure is as follows.

For the first valid operation, the initiation of short-circuit and the setting of the control of the tripping impulse shall be such that

– the required asymmetry criteria are obtained in one phase;
- arc extinction occurs in the phase with the required asymmetry criteria after a major loop (or the greatest possible part of that loop) in case of the first phase-to-clear or after a major extended loop (or the greatest possible part of that loop) in case of one of the last phases-to-clear.

For the second valid operation, the initiation of short-circuit should be advanced by 60° and the setting of the control of the tripping impulse shall be as follows:

– if the first operation was valid because the arc extinction occurred in the phase with the required asymmetry criteria after a major loop, the setting of the control of the tripping impulse shall be advanced by approximately 130° with respect to the first valid operation;

– if the first operation was valid because the arc extinction occurred in the phase with the required asymmetry criteria after a major extended loop, then the setting of the control of the tripping impulse shall be advanced by approximately 25° with respect to the first valid operation.

For the third operation, the procedure for the second operation may be repeated. The initiation of short-circuit shall be advanced by 60° with respect to the second operation and the setting of the control of the tripping impulse shall be as follows:

– if the second operation was valid because the arc extinction occurred in the phase with the required asymmetry criteria after a major loop, the setting of the control of the tripping impulse shall be advanced by approximately 130° with respect to the second operation;
– if the second operation was valid because the arc extinction occurred in the phase with the required asymmetry criteria after a major extended loop, the setting of the control of the tripping impulse shall be advanced by approximately 25° with respect to the second operation.

If the characteristics of the circuit-breaker are not constant it may be necessary to use other procedures to achieve the three valid operations described above.

This test procedure is applicable to non-effectively earthed neutral systems (first-pole-to-clear factor 1,5) and to effectively earthed neutral systems (first-pole-to-clear factor 1,3).

Figures 31 and 32 give graphical examples of the three valid breaking operations.

6.102.10.2 Single-phase tests in substitution for three-phase conditions

The procedures given below are partly derived from synthetic test methods. Where direct tests are performed the procedure for establishing a minimum arcing time might result in a valid test with maximum arcing time or with an arcing time in excess of the maximum arcing time.

The aim of the following single-phase tests is to satisfy the conditions of the first-pole-to-clear and the last pole-to-clear for each test-duty in one test circuit.

The following procedures are applicable if all operations of the rated operating sequence fulfil the requirements of 5.101. If not, caution shall be exercised when using the following Tables 15 through 22.

6.102.10.2.1 Non-effectively earthed neutral systems

6.102.10.2.1.1 Test-duties T10, T30, T60, T100s and T100s(b), OP1 and OP2

The first valid breaking operation shall demonstrate interruption with an arcing time as small as possible. The resultant arcing time is known as the minimum arcing time ($t_{\text{arc min}}$). This is established when any extra delay in the contact separation with respect to the current waveform results in interruption at the next current zero. This minimum arcing time is found by changing the setting of the tripping impulse by steps of 18° (dα).

The second valid breaking operation shall demonstrate interruption with the maximum arcing time. The required maximum arcing time is known as $t_{\text{arc max}}$ and is determined by:

$$t_{\text{arc max}} \geq t_{\text{arc min}} + T\,\frac{150^{\circ} - \mathrm{d}\alpha}{360^{\circ}}$$

where

$t_{\text{arc min}}$ is the minimum arcing time obtained from the first valid operation;

$\mathrm{d}\alpha$ = 18°;

T is one period of the power frequency.

This is normally achieved by setting the tripping impulse at least (150° – dα) earlier than that of the first valid breaking operation.

The third valid breaking operation shall demonstrate interruption with an arcing time which is approximately equal to the average value of those of the first and second valid breaking operations. This arcing time is known as the medium arcing time ($t_{\text{arc med}}$) and is determined by

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

The tripping impulse for the third valid breaking operation shall be delayed by 75° (± 18°) from that of the second valid breaking operation.

Figure 33 gives a graphical representation of the three valid breaking operations.

6.102.10.2.1.2 Test-duty T100a

a) Arcing times

The first valid breaking operation shall demonstrate interruption at the end of the minor loop with an arc duration as small as possible. The resultant arc duration is known in this standard as the minimum arcing time ($t_{\text{arc min}}$). This is established when any extra delay in the contact separation with respect to the current waveform results in interruption at the next current zero which will be at the end of a major loop. This minimum arc duration is found by changing the setting of the tripping impulse by steps of approximately 18° (dα).

NOTE 1 With some circuit-breakers, the minimum arcing time for the minor loop may be so long that the circuit-breaker will be able to clear the preceding major loop at the same moment of contact separation. In such cases, the minimum arcing time is demonstrated at the end of a major loop, and no test on the minor loop is required.

The minimum arcing time obtained ($t_{\text{arc min major loop}}$) is used to calculate the minimum clearing time and to determine the major loop parameters for all the operations (parameters in Tables 15 through 22). For the second valid breaking operation with the maximum arcing time, the minimum arcing time ($t_{\text{arc min}}$), to be used in the equation is $t_{\text{arc min}} = t_{\text{arc min major loop}} + \Delta t_2$.

If additional tests are necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

The second valid breaking operation shall demonstrate interruption with the maximum arcing time. The required maximum arcing time is known in this standard as $t_{\text{arc max}}$ and is determined by

$$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times \frac{30^{\mathrm{o}} + \mathrm{d}\alpha}{360^{\mathrm{o}}}$$

where the time interval Δt_1 is the duration of the major loop given in Tables 15 through 22.

The time interval Δt_1 is a function of the d.c. time constant (τ), the rated frequency of the system, the opening time and the minimum arcing time of the circuit-breaker. The time interval Δt_1 is equal to the duration (rounded) of the subsequent major loop (on the appropriate asymmetrical current waveform) which will occur after the minimum clearing time. Interruption shall occur after a major loop or after the subsequent minor loop if the circuit-breaker failed to interrupt after the required major loop. This is achieved by setting the tripping impulse later than that of the first valid breaking operation.

Tables 15 through 22 consider a relay time of 0,5 cycle of the rated frequency (10 ms at 50 Hz and 8,3 ms at 60 Hz). If the circuit-breaker fails to interrupt after the required major loop and interrupts after the subsequent minor loop, the required maximum arcing time is extended by the duration of the appropriate minor loop (Δt_2) given in Tables 15 through 22.

NOTE 2 In a direct test circuit, any delay of the tripping impulse after the test at $t_{\text{arc min}}$ will result in a subsequent major loop with an arc duration of:

$$t_{\text{arc max}} = t_{\text{arc min}} + \Delta t_1 - T \times \frac{\mathrm{d}\alpha}{360^{\mathrm{o}}}$$

Therefore only an arcing window of 180° can be demonstrated in a single-phase test circuit. This condition may lead to overstress the circuit-breaker. If that is the case, for non-effectively earthed neutral applications only, it is permissible to further delay the tripping impulse in order to obtain the required maximum arcing time.

The third valid breaking operation shall demonstrate interruption with an arcing time that is approximately equal to the average value of those of the first and second valid breaking operations. This arcing time is known in this standard as the medium arcing time ($t_{\text{arc med}}$) and is determined by:

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

This interruption shall also occur after a major loop or after the subsequent minor loop if the circuit-breaker failed to interrupt after the required major loop.

NOTE 3 In the specific cases where a circuit-breaker interrupts after a minor current loop during the maximum arcing time test, the medium arcing time should be determined by using the prospective maximum arcing time considering an interruption following a major current loop.

The tripping impulse for the third valid breaking operation shall be delayed from that of the second valid breaking operation in order to achieve this arcing time.

Figure 34 gives a graphical example of the three valid breaking operations.

b) Short-circuit current during arcing interval

The breaking operations are valid if the following conditions are met:

– the peak short-circuit current during the last loop prior to the interruption is between 90 % and 110 % of the required value and

– the duration of the short-circuit current loop prior to the interruption is between 90 % and 110 % of the required value.

or if the above tolerances cannot be fulfilled:

– the product "$I \times t$", "I" being the required peak value of the last short-circuit current loop and "t" being the required duration of the last short-circuit current loop, is between 81 % and 121 % of the required values.

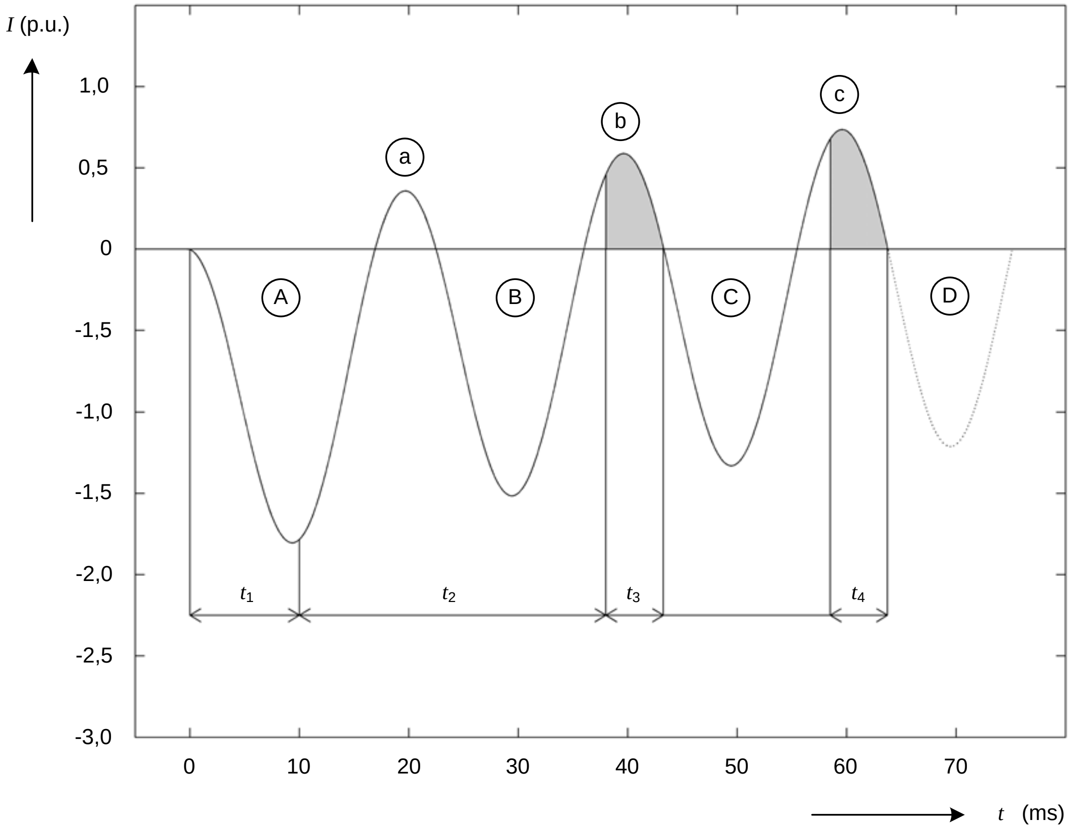
Tables 15 through 22 give required values of the peak short-circuit current and loop duration that should be attained by the last loop prior to the interruption. The required product "$I \times t$" can also be derived from these tables.

NOTE 4 For direct tests, these conditions apply to the prospective short-circuit current only provided that the instant of current initiation is within ±10° of that obtained during the prospective current calibration test.

NOTE 5 For circuits breakers having relatively high arc voltages, the procedure to obtain the required current loop amplitude and duration during synthetic tests is explained in IEC 62271-101.

NOTE 6 The corresponding di/dt values given in Tables 15 through 22 are only applicable to the first-pole-to-clear. For the second and third pole-to-clear, the di/dt can be approximated as the di/dt of the second and third pole-to-clear in case of a symmetrical fault current. See Table 6 for corresponding TRV values.

If, during the tests, the minimum arcing time is such that the circuit-breaker cannot clear at the intended minor loop (b in Figure 57) without exceeding the declared minimum clearing time window, the single-phase procedure shall be repeated at the next minor loop (c in Figure 57). If during these tests the minimum arcing time is such that the minimum clearing time would fit inside the original clearing time window again, the major loop in between the two minor loops (C in Figure 57) shall be tested. The medium and maximum arcing times of the third major loop shall be based on the minimum arcing time of the third minor loop.



Key

A	First major loop	t_1	t_{relay}
B	Second major loop	t_2	$t_{open\ min}$
C	Third major loop	t_3	$t_{arc\ 1}$
D	Fourth major loop	t_4	$t_{arc\ 2}$
a	First minor loop		
b	Second minor loop		
c	Third minor loop		

$t_{arc\ 1} = t_{arc\ min\ minor\ loop\ b} - 18°$

$t_{arc\ 2} = t_{arc\ min\ minor\ loop\ c}$

If $t_{arc\ 2} \leq t_{arc\ 1}$ → testing of major loop C

If $t_{arc\ 2} > t_{arc\ 1}$ → testing of major loop D

Figure 57 – Determination of the major loop to be tested

Table 15 – Last current loop parameters for 50 Hz operation in relation with short-circuit test-duty T100a τ = 45 ms

τ = 45 ms	Major loop				Minor loop			
Minimum clearing time	$\hat{I}$	Δt_1	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)	$\hat{I}$	Δt_2	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)
ms	p.u.	ms	%	%	p.u.	ms	%	%
10,0 < t ≤ 22,5	1,52	13,5	44,6	92,7	0,36	5,5	60,2	75,6
22,5 < t ≤ 43,5	1,33	12,0	28,9	97,8	0,59	7,5	37,9	89,9
43,5 < t ≤ 64,0	1,21	11,5	18,7	99,6	0,74	8,5	24,1	95,3
64,0 < t ≤ 84,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
84,5 < t ≤ 104,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

$\hat{I}$: p.u. value of the peak current related to the peak value of the symmetrical short-circuit current
Δt_1: duration of major loop (rounded to 0,5 ms)
Δt_2: duration of minor loop (rounded to 0,5 ms)
τ: system circuit time constant

[a] Test duty T100a is not applicable, d.c. component lower than 20 % for both current loops.

All values in this table have been calculated with a protection relay time of 10 ms.

~~NOTE 1 The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.~~

NOTE ~~2~~ If the minimum arcing time obtained during test is different from the value declared by the manufacturer and if the real minimum arcing time leads to another minimum clearing time class (interruption to another current loop) then it could be necessary to repeat the test with the appropriate current loop values. If a repetition is necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

Table 16 – Last current loop parameters for 50 Hz operation in relation with short-circuit test-duty T100a τ = 60 ms

τ = 60 ms	Major loop				Minor loop			
Minimum clearing time	$\hat{I}$	Δt_1	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)	$\hat{I}$	Δt_2	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)
ms	p.u.	ms	%	%	p.u.	ms	%	%
10,0 < t ≤ 22,5	1,61	14,0	54,2	86,9	0,28	5,0	68,7	69,0
22,5 < t ≤ 43,0	1,44	13,0	39,2	94,1	0,49	6,5	48,6	84,8
43,0 < t ≤ 63,5	1,31	12,0	28,3	97,4	0,63	7,5	34,5	92,0
63,5 < t ≤ 84,0	1,22	11,5	20,3	99,0	0,74	8,5	24,6	95,6
84,0 < t ≤ 104,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

$\hat{I}$: p.u. value of the peak current related to the peak value of the symmetrical short-circuit current
Δt_1: duration of major loop (rounded to 0,5 ms)
Δt_2: duration of minor loop (rounded to 0,5 ms)
τ: system circuit time constant

[a] Test duty T100a is not applicable, d.c. component lower than 20 % for both current loops.

All values in this table have been calculated with a protection relay time of 10 ms.

~~NOTE 1 The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.~~

NOTE ~~2~~ If the minimum arcing time obtained during test is different from the value declared by the manufacturer and if the real minimum arcing time leads to another minimum clearing time class (interruption to another current loop) then it could be necessary to repeat the test with the appropriate current loop values. If a repetition is necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

Table 17 – Last current loop parameters for 50 Hz operation in relation with short-circuit test-duty T100a τ = 75 ms

τ = 75 ms	Major loop				Minor loop			
Minimum clearing time	$\hat{I}$	Δt_1	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)	$\hat{I}$	Δt_2	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)
ms	p.u.	ms	%	%	p.u.	ms	%	%
10,0 < t ≤ 22,0	1,67	15,0	61,0	81,8	0,23	4,5	74,3	63,8
22,0 < t ≤ 43,0	1,51	13,5	47,1	90,2	0,41	6,0	56,4	80,2
43,0 < t ≤ 63,5	1,39	12,5	36,3	94,7	0,55	7,0	42,9	88,5
63,5 < t ≤ 84,0	1,30	12,0	27,9	97,2	0,66	8,0	32,7	93,1
84,0 < t ≤ 104,0	1,23	11,5	21,4	98,6	0,74	8,5	25,0	95,8

$\hat{I}$: p.u. value of the peak current related to the peak value of the symmetrical short-circuit current
Δt_1: duration of major loop (rounded to 0,5 ms)
$\Delta t2$: duration of minor loop (rounded to 0,5 ms)
τ: system circuit time constant

All values in this table have been calculated with a protection relay time of 10 ms.

~~NOTE 1 The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.~~

NOTE ~~2~~ If the minimum arcing time obtained during test is different from the value declared by the manufacturer and if the real minimum arcing time leads to another minimum clearing time class (interruption to another current loop) then it could be necessary to repeat the test with the appropriate current loop values. If a repetition is necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

Table 18 – Last current loop parameters for 50 Hz operation in relation with short-circuit test-duty T100a τ = 120 ms

τ = 120 ms	Major loop				Minor loop			
Minimum clearing time	$\hat{I}$	Δt_1	**Percentage of d.c. component at current zero**	**Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)**	$\hat{I}$	Δt_2	**Percentage of d.c. component at current zero**	**Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)**
ms	p.u.	ms	%	%	p.u.	ms	%	%
10,0 < t ≤ 22,0	1,78	15,5	73,1	70,2	0,15	3,5	83,4	53,0
22,0 < t ≤ 42,5	1,66	14,5	62,1	80,0	0,28	5,0	70,2	69,4
42,5 < t ≤ 63,0	1,56	14,0	52,8	86,3	0,39	6,0	59,2	79,0
63,0 < t ≤ 83,5	1,47	13,0	44,8	90,6	0,49	6,5	50,0	85,3
83,5 < t ≤ 103,5	1,40	12,5	38,0	93,5	0,57	7,0	42,2	89,5

$\hat{I}$: p.u. value of the peak current related to the peak value of the symmetrical short-circuit current
Δt_1: duration of major loop (rounded to 0,5 ms)
Δt_2: duration of minor loop (rounded to 0,5 ms)
τ: system circuit time constant

All values in this table have been calculated with a protection relay time of 10 ms.

~~NOTE 1 The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.~~

NOTE ~~2~~ If the minimum arcing time obtained during test is different from the value declared by the manufacturer and if the real minimum arcing time leads to another minimum clearing time class (interruption to another current loop) then it could be necessary to repeat the test with the appropriate current loop values. If a repetition is necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

Table 19 – Last current loop parameters for 60 Hz operation in relation with short-circuit test-duty T100a τ = 45 ms

τ = 45 ms	Major loop				Minor loop			
Minimum clearing time ms	$\hat{I}$ p.u.	Δt_1 ms	Percentage of d.c. component at current zero %	Corresponding d*i*/d*t* at current zero (percentage of the d*i*/d*t* of the rated symmetrical current) %	$\hat{I}$ p.u.	Δt_2 ms	Percentage of d.c. component at current zero %	Corresponding d*i*/d*t* at current zero (percentage of the d*i*/d*t* of the rated symmetrical current) %
8,5 < t ≤ 19,0	1,58	11,5	50,8	89,1	0,31	4,5	65,8	71,4
19,0 < t ≤ 36,0	1,40	10,5	35,4	95,6	0,52	5,5	44,8	86,8
36,0 < t ≤ 53,0	1,27	10,0	24,6	98,4	0,67	6,5	30,6	93,4
53,0 < t ≤ 70,0	1,19	9,5	17,1	99,5	0,77	7,0	21,0	96,5
70,0 < t ≤ 87,0	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
87,0 < t ≤ 103,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

$\hat{I}$: p.u. value of the peak current related to the peak value of the symmetrical short-circuit current
Δt_1: duration of major loop (rounded to 0,5 ms)
Δt_2: duration of minor loop (rounded to 0,5 ms)
τ: system circuit time constant

[a] Test duty T100a is not applicable, d.c. component lower than 20 % for both current loops.

All values in this table have been calculated with a protection relay time of 8,3 ms.

~~NOTE 1 The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.~~

NOTE ~~2~~ If the minimum arcing time obtained during test is different from the value declared by the manufacturer and if the real minimum arcing time leads to another minimum clearing time class (interruption to another current loop) then it could be necessary to repeat the test with the appropriate current loop values. If a repetition is necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

Table 20 – Last current loop parameters for 60 Hz operation in relation with short-circuit test-duty T100a τ = 60 ms

τ = 60 ms	Major loop				Minor loop			
Minimum clearing time ms	$\hat{I}$ p.u.	Δt_1 ms	**Percentage of d.c. component at current zero** %	**Corresponding d*i*/d*t* at current zero (percentage of the d*i*/d*t* of the rated symmetrical current)** %	$\hat{I}$ p.u.	Δt_2 ms	**Percentage of d.c. component at current zero** %	**Corresponding d*i*/d*t* at current zero (percentage of the d*i*/d*t* of the rated symmetrical current)** %
$8,5 < t \leq 18,5$	1,66	12,0	59,8	82,8	0,24	4,0	73,3	64,8
$18,5 < t \leq 36,0$	1,50	11,0	45,7	91,0	0,43	5,0	55,0	81,1
$36,0 < t \leq 53,0$	1,38	10,5	34,8	95,3	0,57	6,0	41,4	89,2
$53,0 < t \leq 70,0$	1,29	10,0	26,4	97,6	0,67	6,5	31,2	93,6
$70,0 < t \leq 87,0$	1,22	9,5	20,1	98,8	0,75	7,0	23,5	96,2
$87,0 < t \leq 103,5$	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

$\hat{I}$: p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt_1: duration of major loop (rounded to 0,5 ms)

Δt_2: duration of minor loop (rounded to 0,5 ms)

τ: system circuit time constant

[a] Test duty T100a is not applicable, d.c. component lower than 20 % for both current loops.

All values in this table have been calculated with a protection relay time of 8,3 ms.

~~NOTE 1 The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.~~

NOTE ~~2~~ If the minimum arcing time obtained during test is different from the value declared by the manufacturer and if the real minimum arcing time leads to another minimum clearing time class (interruption to another current loop) then it could be necessary to repeat the test with the appropriate current loop values. If a repetition is necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

Table 21 – Last current loop parameters for 60 Hz operation in relation with short-circuit test-duty T100a τ = 75 ms

τ = 75 ms	Major loop				Minor loop			
Minimum clearing time	$\hat{I}$	Δt_1	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)	$\hat{I}$	Δt_2	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)
ms	p.u.	ms	%	%	p.u.	ms	%	%
8,5 < t ≤ 18,5	1,72	12,5	66,1	77,4	0,20	3,5	78,2	59,6
18,5 < t ≤ 35,5	1,57	11,5	53,2	86,6	0,36	4,5	62,1	76,2
35,5 < t ≤ 52,5	1,46	11,0	42,8	91,9	0,49	6,0	49,5	85,1
52,5 < t ≤ 69,5	1,37	10,5	34,4	95,1	0,59	6,0	39,5	90,5
69,5 < t ≤ 86,5	1,30	10,0	27,6	97,1	0,67	6,5	31,5	93,8
86,5 < t ≤ 103,5	1,24	9,5	22,2	98,3	0,74	7,0	25,2	95,9

$\hat{I}$: p.u. value of the peak current related to the peak value of the symmetrical short-circuit current
Δt_1: duration of major loop (rounded to 0,5 ms)
Δt_2: duration of minor loop (rounded to 0,5 ms)
τ: system circuit time constant

All values in this table have been calculated with a protection relay time of 8,3 ms.

~~NOTE 1 The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.~~

NOTE ~~2~~ If the minimum arcing time obtained during test is different from the value declared by the manufacturer and if the real minimum arcing time leads to another minimum clearing time class (interruption to another current loop) then it could be necessary to repeat the test with the appropriate current loop values. If a repetition is necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

Table 22 – Last current loop parameters for 60 Hz operation in relation with short-circuit test-duty T100a τ = 120 ms

τ = 120 ms	Major loop				Minor loop			
Minimum clearing time	$\hat{I}$	Δt_1	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)	$\hat{I}$	Δt_2	Percentage of d.c. component at current zero	Corresponding di/dt at current zero (percentage of the di/dt of the rated symmetrical current)
ms	p.u.	ms	%	%	p.u.	ms	%	%
8,5 < t ≤ 18,0	1,81	13,5	77,0	65,5	0,13	2,5	86,0	49,1
18,0 < t ≤ 35,0	1,71	12,5	67,2	75,5	0,24	4,0	74,6	64,9
35,0 < t ≤ 52,0	1,62	12,0	58,6	82,3	0,34	4,5	64,7	74,8
52,0 < t ≤ 69,0	1,54	11,5	51,1	87,1	0,43	5,0	56,2	81,5
69,0 < t ≤ 86,0	1,47	11,0	44,6	90,5	0,50	5,5	48,8	86,2
86,0 < t ≤ 103,0	1,41	10,5	38,8	93,0	0,57	6,0	42,4	89,6

$\hat{I}$: p.u. value of the peak current related to the peak value of the symmetrical short-circuit current
Δt_1: duration of major loop (rounded to 0,5 ms)
Δt_2: duration of minor loop (rounded to 0,5 ms)
τ: system circuit time constant

All values in this table have been calculated with a protection relay time of 8,3 ms.

~~NOTE 1 The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.~~

NOTE ~~2~~ If the minimum arcing time obtained during test is different from the value declared by the manufacturer and if the real minimum arcing time leads to another minimum clearing time class (interruption to another current loop) then it could be necessary to repeat the test with the appropriate current loop values. If a repetition is necessary, reconditioning of the circuit-breaker according to 6.102.9.5 or the use of an additional test sample according to 6.102.2 are permitted.

6.102.10.2.2 Effectively earthed neutral systems including short-line fault tests

6.102.10.2.2.1 Test-duties T10, T30, T60, T100s and T100s(b), OP1 and OP2, L_{90}, L_{75} and L_{60}

The procedure to obtain the three valid breaking operations is the same as the one described for non-effectively earthed neutral systems, with the following modifications:

The required maximum arcing time shall be:

$$t_{\text{arc max}} \geq t_{\text{arc min}} + T\,\frac{180^{\circ} - \mathrm{d}\alpha}{360^{\circ}}$$

This is normally achieved by having the tripping impulse at least (180° – dα) earlier than that of the first valid breaking operation.

The third valid breaking operation shall demonstrate interruption with an arcing time which is approximately equal to the average value of those of the first and second valid breaking operations. This arcing time is determined by

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

The third valid breaking operation is achieved by having the tripping impulse 90° (±18°) later than that of the second valid breaking operation.

Figure 35 gives the graphical representation of the three valid breaking operations.

6.102.10.2.2.2 Test-duty T100a

The procedure to obtain the three valid breaking operations is the same as the one described for non-effectively earthed neutral systems, with the following modifications:

The required maximum arcing time shall be:

$$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times \frac{\mathrm{d}\alpha}{360^{\circ}}$$

where Δt_1 is given in Tables 15 through 22.

Figure 36 gives a graphical example of the three valid breaking operations.

6.102.10.2.3 Modified procedure in cases where the circuit-breaker failed to interrupt during a test with a medium arcing time

6.102.10.2.3.1 Breaking test with symmetrical current

If the circuit-breaker does not interrupt at the expected current zero during a breaking test with symmetrical current with a medium arcing time then it is necessary to perform one or two additional tests.

a) Direct tests

   Two cases shall be considered:

   – For k_{pp} = 1,3 (systems with effectively earthed neutral)

     If the circuit-breaker does not interrupt with the prospective medium arcing time but at a subsequent current zero, the arcing time on such a test would be known as the "ultimate maximum arcing time" $t_{\text{arc ult max}}$. This test is valid if the circuit-breaker is able to interrupt during an additional test with the "new minimum arcing time", which shall be 18° longer than the prospective medium arcing time. In this case this single additional test is sufficient with the setting of the tripping impulse advanced by 18°.

– For k_{pp} = 1,5 (systems with non-effectively earthed neutral)

  If the circuit-breaker has not interrupted with the prospective medium arcing time and at the subsequent current zero, two additional tests are necessary:

  i) one with the "new minimum arcing time" $t_{arc\ new\ min}$, which shall be 18°longer than the prospective medium arcing time,

  ii) another one with the "new maximum arcing time", which shall be 150° longer than the "new minimum arcing time". This test may necessitate a forced re-ignition circuit at the preceding current zero crossing.

b) Synthetic tests

The first valid additional test shall demonstrate interruption at the "new minimum arcing time" $t_{arc\ new\ min}$. This is found when any extra advancement in contact separation with respect to the current waveform from that for the test at medium arcing time results in a successful interruption. The "new minimum arcing time" is found by changing the setting of the tripping impulse by steps of 18° (dα).

The second valid breaking operation shall demonstrate interruption with the "ultimate maximum arcing time" $t_{arc\ ult\ max}$ which is:

$$t_{\text{arc ult max}} \geq t_{\text{arc new min}} + T\,\frac{150° - \mathrm{d}\alpha}{360°} \quad \text{if } k_{pp} = 1{,}5$$

$$t_{\text{arc ult max}} \geq t_{\text{arc new min}} + T\,\frac{180° - \mathrm{d}\alpha}{360°} \quad \text{if } k_{pp} = 1{,}3,\ 1{,}2 \text{ or } 1{,}0$$

where

$t_{arc\ new\ min}$ is the "new" minimum arcing time;

$t_{arc\ ult\ max}$ is the "ultimate" maximum arcing time;

dα = 18°.

If the circuit-breaker fails during the second additional test, it is permissible to carry out maintenance work on the circuit-breaker according to 6.102.9.5 and repeat the test-duty by starting with a minimum arcing time which is greater than the failed medium arcing time.

6.102.10.2.3.2 Breaking test with asymmetrical current

If the circuit-breaker does not interrupt at the expected current zero after a major loop, during a breaking test with asymmetrical current (test-duty T100a) and with a medium arcing time, then it shall interrupt after the subsequent minor loop.

6.102.10.2.4 Tests combining the conditions for effectively and non-effectively earthed neutral systems

Both conditions, non-effectively earthed neutral systems (6.102.10.2.1) and effectively earthed neutral systems (6.102.10.2.2), may be combined in one test series. The transient and power frequency voltages to be used shall be those applicable to a non-effectively earthed neutral system and the arcing times shall be those applicable to an effectively earthed neutral system.

6.102.10.2.5 Splitting of test-duties in test series taking into account the associated TRV for each pole-to-clear

It is recognised that single-phase tests in substitution of three-phase conditions are more severe than three-phase tests because the arcing time of the last-pole-to-clear is used together with the TRV of the first-pole-to-clear. As an alternative, the manufacturer may choose to split each test-duty into two or three separate test series, each test series demonstrating a successful interruption with the minimum, maximum and medium arcing time for each pole-to-clear with its associated TRV. The standard multipliers for the TRV values for the second and third clearing poles for rated voltages above 72,5 kV are given in Table 6.

Reconditioning of the circuit-breaker after each test series is permitted and shall comply with the requirements of 6.102.9.5.

Assuming that the simultaneity of poles during all operations of the rated operating sequence is within the tolerances of 5.101, for tests with symmetrical current the interrupting window for each phase is within the band stated in Table 23, if the instant of interruption for the first clearing pole with the minimum arcing time is taken as reference. A graphical representation of the interrupting window and the voltage factor k_p, determining the TRV of the individual pole, is given in Figure 37 and Figure 58 for systems with a first-pole-to-clear factor of 1,2 and 1,3 and in Figure 38 for systems with a first-pole-to-clear factor of 1,5.

Table 23 – Interrupting window for tests with symmetrical current

First-pole-to-clear factor	First clearing pole °	Second clearing pole °	Third clearing pole °
1,5	0 – 42	90 – 132	90 – 132
1,3	0 – 42	77 – 119	120 – 162
1,2	0 – 42	71 – 113	120 – 162

6.103 Test circuits for short-circuit making and breaking tests

6.103.1 Power factor

The power factor in each phase shall be determined in accordance with one of the methods described in Annex D.

The power factor of a three-phase circuit shall be taken as the average of the power factors in each phase.

During the tests, this average value shall not exceed 0,15.

The power factor of any phase shall not vary from the average by more than 25 % of the average.

6.103.2 Frequency

Circuit-breakers shall be tested at rated frequency with a tolerance of ±8 %.

However, for convenience of testing, some deviations from the above tolerance are allowable; for example, when circuit-breakers rated at 50 Hz are tested at 60 Hz and vice versa, care should be exercised in the interpretation of the results, taking into account all significant facts such as the type of the circuit-breaker and the type of test performed.

6.103.3 Earthing of test circuit

The connections to earth of the test circuit for short-circuit making and breaking tests shall be in accordance with the following requirements and shall, in all cases, be indicated in the diagram of the test circuit included in the test report (see item g) of C.2.4).

a) Three-phase tests of a three-pole circuit-breaker, first-pole-to-clear factor 1,5:

The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply isolated and the short-circuit point earthed as shown in Figure 25a, or vice versa as shown in Figure 25b, if the test can only be made in the latter way.

These test circuits give a first-pole-to-clear factor of 1,5.

In accordance with Figure 25a, the neutral of the supply source may be earthed through a resistor, the resistance of which is as high as possible and, expressed in ohms, in no case less than $U/10$, where U is the numerical value in volts of the voltage between lines of the test circuit.

When a test circuit according to Figure 25b is used, it is recognised that in case of an earth fault at one terminal of the test circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through an appropriate impedance.

b) Three-phase tests of a three-pole circuit-breaker, first-pole-to-clear factor 1,3:

The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply connected to earth by an appropriate impedance and the short-circuit point earthed as shown in Figure 26a, or vice versa as shown in Figure 26b, if the test can only be made in the latter way.

The impedance in the neutral connection shall be selected appropriate to a first-pole-to-clear factor of 1,3. Assuming $Z_0 = 3,25 \times Z_1$ the appropriate value of the impedance in the neutral connection is 0,75 times the phase impedance.

NOTE 1 For circuit-breakers to be used in systems with a first-pole-to-clear factor lower than 1,3, it may be necessary to lower the value of the impedance between the neutral point and the earth to satisfy the breaking current conditions in the second and third pole-to-clear. Care should be taken for the TRVs for all three poles.

NOTE 2 The test circuit shown in Figure 26b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex O of this standard and in IEC 62271-101.

c) Single-phase tests of a single pole of a three-pole circuit-breaker with a first-pole-to-clear factor 1,5:

The test circuit and the circuit-breaker structure shall be connected as in Figure 27a, so that the voltage conditions between live parts and the structure after arc extinction are the same as those which would exist in the first-pole-to-clear of a three-pole circuit-breaker if tested in the test circuit shown in Figure 25a.

The preferred test circuit is shown in Figure 27a. Where there are limitations on test station equipment, then the circuit shown in Figure 27b may be used.

NOTE 3 The test circuit shown in Figure 27b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex O of this standard and in IEC 62271-101.

d) Single-phase tests of a single pole of a three-pole circuit-breaker with a first-pole-to-clear factor 1,3:

The test circuit and the circuit-breaker structure shall be connected as in Figure 28a, so that the voltage conditions between live parts and the structure after arc extinction are approximately the same as those that would exist in the first-pole-to-clear of a three-pole circuit-breaker if tested in the test circuit shown in Figure 26a.

The preferred test circuit is shown in Figure 28a. Where there are limitations on test station equipment, then the circuit shown in Figure 28b may be used.

NOTE 4 The test circuit shown in Figure 28b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex O of this standard and in IEC 62271-101.

e) Single-phase tests of a single-pole circuit-breaker:

The test circuit and the circuit-breaker structure shall be connected so that the voltage conditions between live parts and earth within the circuit-breaker after arc extinction reproduce the service voltage conditions. The connections used shall be indicated in the test report.

6.103.4 Connection of test circuit to circuit-breaker

Where the physical arrangement of one side of the circuit-breaker differs from that of the other side, the live side of the test circuit shall be connected for testing to that side of the circuit-breaker which gives the more severe conditions with respect to voltage to earth, unless the circuit-breaker is especially designed for feeding from one side only.

Where it cannot be demonstrated satisfactorily which connection gives the more severe conditions, test-duties T10 and T30 (6.106.1 and 6.106.2) shall be made with opposite connections, and likewise for test-duties T100s and T100a. If test-duty T100a is omitted, test-duty T100s shall be made with each of the two connections.

6.104 Short-circuit test quantities

6.104.1 Applied voltage before short-circuit making tests

For the short-circuit making tests of 6.106, the applied voltage shall be as follows.

a) For three-phase tests on a three-pole circuit-breaker, the average value of the applied voltages phase-to-phase shall not be less than the rated voltage U_r and shall not exceed this value by more than 10 % without the consent of the manufacturer.

   The differences between the average value and the applied voltages of each pole shall not exceed 5 %.

b) For single-phase tests on a three-pole circuit-breaker, the applied voltage shall not be less than the phase-to-earth value $U_r/\sqrt{3}$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

NOTE With the manufacturer's consent it is permissible, for convenience of testing, to apply a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,3 or 1,5) of the circuit-breaker.

   Where the circuit-breaker can be arranged for a single-pole reclosing cycle and the maximum time difference between the contacts touching in a subsequent three-pole closing operation exceeds one-quarter of a cycle of rated frequency (compare with the note of 5.101), the applied voltage shall be the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,3 or 1,5) of the circuit-breaker.

c) For a single-pole circuit-breaker, the applied voltage shall not be less than the rated voltage and shall not exceed this value by more than 10 % without the consent of the manufacturer.

   When performing synthetic tests IEC 62271-101 applies, see also 6.106.4.1 a), 6.106.4.2 a) and 6.106.4.3.

6.104.2 Short-circuit making current

6.104.2.1 General

The ability of the circuit-breaker to make the rated short-circuit making current is proven in test-duty T100s (see 6.106.4).

The circuit-breaker shall be able to make the current with pre-strike of the arc occurring at any point on the voltage wave. Two extreme cases are specified as follows (see Figure 1):

– making at the peak of the voltage wave, leading to a symmetrical short-circuit current and the longest pre-striking arc;
– making at the zero of the voltage wave, without pre-striking, leading to a fully asymmetrical short-circuit current.

The test procedure as outlined below aims to demonstrate the ability of the circuit-breaker to fulfil the following two requirements:

a) the circuit-breaker can close against a symmetrical current as a result of the pre-arcing commencing at a peak of the applied voltage. This current shall be the symmetrical component of the rated short-circuit breaking current (see 4.101);
b) the circuit-breaker can close against a fully asymmetrical short-circuit current. This current shall be the rated short-circuit making current (see 4.103).

   A circuit-breaker shall be able to operate at voltages below its rated voltage (see item a) of 4.101) at which it actually makes with a fully asymmetrical current. The lower limit of voltage, if any, shall be stated by the manufacturer.

NOTE 1 The short-circuit current is considered to be symmetrical, if the current flow commences within ± 15 ° of the peak value of the applied voltage.

NOTE 2 For circuit-breakers having a pre-arcing time exceeding 10 ms, more than two making operations may be necessary to meet the most onerous condition.

NOTE 3 Due to unintentional non-simultaneity of poles, the instants of contact touching during closing may differ such as to provoke an even higher peak making current in one pole (see also 5.101). This is particularly the case if, in one pole, the current begins to flow about one-quarter of a cycle later than in the other two poles, provided that there is no pre-arcing. Failure of the circuit-breaker during such an event is considered a failure of a circuit-breaker to satisfy the test-duty.

6.104.2.2 Test procedure

6.104.2.2.1 Three-phase tests

For three-phase tests on a three-pole circuit-breaker it is assumed that the requirements outlined in a) and b) above are adequately demonstrated during the test-duty T100s.

The control of the timing shall be such that at least in one of the two close-open (CO) cycles of test-duty T100s the rated short-circuit making current is obtained.

Where a circuit-breaker exhibits pre-arcing to such an extent that the rated short-circuit making current is not attained during the first CO operating cycle of test-duty T100s and, even after adjustment of the timing, the rated short-circuit making current is not achieved during the second CO operating cycle, a third CO operating cycle shall be carried out at reduced voltage. Before this operating cycle, the circuit-breaker may be reconditioned.

6.104.2.2.2 Single-phase tests

For single-phase tests, test-duty T100s or T100s(a) shall be carried out in such a way that the requirement outlined in a) of 6.104.2.1 is met in one and that of b) of 6.104.2.1 in the other closing operation. The sequence of these operations is not specified. If during test-duty T100s or T100s(a) (see Note of 6.106) one of the requirements outlined in a) and b) has not been adequately demonstrated, an additional CO operating cycle is necessary. Before this operating cycle the circuit-breaker may be reconditioned.

The additional CO operating cycle shall, depending on the results obtained during the normal test-duty T100s or T100s(a), demonstrate either

– requirements in a) or b) of 6.104.2.1, or
– evidence that the short-circuit making currents attained are representative of the conditions to be met in service due to the pre-arcing characteristics of the circuit-breaker.

If, during the test-duty T100s or T100s(a), the rated short-circuit making current has not been attained due to the characteristics of the circuit-breaker, the additional CO test may be made at a lower applied voltage.

If during the test-duty T100s or T100s(a) no symmetrical current has been obtained, as required in a) above, the additional CO test may be made at an applied voltage within the margins stated in 6.104.1.

6.104.3 Short-circuit breaking current

The short-circuit current to be interrupted by a circuit-breaker shall be determined at the instant of contact separation in accordance with Figure 8, and shall be stated in terms of the following two values:

– the average of the r.m.s. values of the a.c. components in all phases;

– the percentage value of the maximum d.c. component in any phase.

The r.m.s. value of the a.c. component in any phase shall not vary from the average by more than 10 %.

Although the short-circuit breaking current is measured at the instant corresponding to contact separation, the breaking performance of the circuit-breaker is determined, among other factors, by the current which is finally interrupted in the last loop of arcing. The decrement of the a.c. component of the short-circuit current is therefore very important, particularly when testing those circuit-breakers which arc for several loops of current. To obviate an easement of duty, the decrement of the a.c. component of the short-circuit current should be such that at a time corresponding to the final extinction of the main arc in the last pole to clear, the a.c. component of the prospective current is not less than 90 % of the appropriate value for the test-duty. This shall be proven by a record of the prospective current before commencing the tests.

If the characteristics of the circuit-breaker are such that it reduces the short-circuit current value below the prospective breaking current, or if the oscillogram is such that the current wave envelope cannot be drawn successfully, the average prospective short-circuit breaking current in all phases shall be used as the short-circuit breaking current and shall be measured from the oscillogram of prospective current at a time corresponding to the instant of contact separation.

The instant of contact separation can be determined according to the experience of the testing station and the type of apparatus under test by various methods, for instance, by recording the contact travel during the test, by recording the arc voltage or by a test on the circuit-breaker at no-load.

6.104.4 DC component of short-circuit breaking current

For circuit-breakers which operate in opening times preventing the control of the d.c. component, for example self-tripping circuit-breakers when in a condition for test as set out in 6.102.3, the d.c. component may be greater than that specified for test-duties T10, T30, T60 and T100s of 6.106.

Circuit-breakers shall be considered to have satisfied test-duty T100a, even if the percentage d.c. component in one opening operation is less than the specified value, provided that the average of the percentage d.c. components of the opening operations of the test-duty exceeds the specified percentage d.c. component. In any one test of the test-duty, the d.c. component shall not be less than 90 % relative to the specified value.

If the oscillogram of any breaking operation is such that the current wave envelope cannot be drawn successfully, then provided that the instants of initiation of short-circuits are comparable, the prospective percentage d.c. component shall be taken as the percentage d.c.

component at contact separation during the test. The percentage d.c. component shall be measured from the oscillogram of the prospective current at a time corresponding to the instant of contact separation.

6.104.5 Transient recovery voltage (TRV) for short-circuit breaking tests

6.104.5.1 General

~~The prospective TRV of the test circuits shall be determined by such a method as will produce and measure the TRV wave without significantly influencing it. It shall be measured at the terminals to which the circuit-breaker will be connected with all necessary test-measuring devices, such as voltage dividers, etc. Suitable methods are described in Annex F (see also 6.104.6). In such cases where a measurement is not possible, for instance in some synthetic circuits, a calculation of the prospective TRV is allowed. Guidance is given in Annex F.~~

~~For three-phase circuits, the prospective TRV refers to the first-pole-to-clear, i.e. the voltage across one open pole with the other two poles closed, with the appropriate test circuit arranged as specified in 6.103.3.~~

~~The prospective TRV for the test is represented by its envelope, drawn as shown in Annex E, and by its initial portion.~~

~~The TRV specified for the test is represented by a reference line, a delay line and initial transient recovery voltage (ITRV) envelope in the same manner as the TRV related to the rated short-circuit breaking current in accordance with 4.102.2 and Figures 10, 11 and 12.~~

~~TRV parameters are defined as follows as a function of the rated voltage (U_r), the first-pole-to-clear factor (k_{pp}) and the amplitude factor (k_{af}). The actual values of k_{pp} and k_{af} are stated in Tables 1, 2, 3, 4, 5, 24, 25, 26 and 27. The first-pole-to-clear factor k_{pp} is 1,3 as listed in Table 26 for all circuit-breakers rated 100 kV and above where systems are usually effectively earthed. For non-effectively earthed systems from 100 kV to 170 kV, k_{pp} = 1,5 as listed in Table 27.~~

~~a) *For rated voltages less than 100 kV*~~

– ~~A representation by two parameters of the prospective TRV is used for all test-duties.~~

– ~~In Table 24, for circuit-breakers in cable systems.~~

~~TRV peak value $u_c = k_{pp} \times k_{af} \sqrt{(2/3)} \times U_r$ where k_{af} is equal to 1,4 for test-duty T100, 1,5 for test-duty T60, 1,6 for test duty T30 and 1,7 for test duty T10, 1,25 for out-of-phase breaking.~~

~~Time t_3 for test-duty T100 is taken from Table 24. Time t_3 for test-duties T60, T30 and T10 is obtained by multiplying the time t_3 for test-duty T100 by 0,44 (for T60), 0,22 (for T30) and 0,22 (for T10).~~

– ~~In Table 25, for circuit-breakers in line systems.~~

~~TRV peak value $u_c = k_{pp} \times k_{af} \sqrt{(2/3)} \times U_r$ where k_{af} is equal to 1,54 for test-duty T100 and the supply side circuit for short-line fault, 1,65 for test-duty T60, 1,74 for test duty T30 and 1,8 for test duty T10, 1,25 for out-of-phase breaking.~~

~~Time t_3 for test-duty T100 is taken from Table 25. Time t_3 for test-duties T60, T30 and T10 is obtained by multiplying the time t_3 for test-duty T100 by 0,67 (for T60), 0,40 (for T30) and 0,40 (for T10).~~

– ~~Time delay t_d for test-duty T100 is 0,15 × t_3 for cable systems, 0,05 × t_3 for line systems, 0,05 × t_3 for the supply side circuit for short-line fault.~~

– ~~Time delay t_d is 0,15 × t_3 for test-duties T60, T30 and T10 and for out-of-phase breaking.~~

– ~~Voltage $u' = u_c/3$.~~

– ~~Time t' is derived from u', t_3 and t_d according to Figure 11, $t' = t_d + t_3/3$.~~

~~b) *For rated voltage from 100 kV to 800 kV*~~

~~– A representation by four parameters of the prospective TRV is used for test-duties T100 and T60, and the supply circuit of SLF for test duties L_{90} and L_{75} and for out-of-phase test duties OP1 and OP2 and by two parameters for test-duties T30 and T10.~~

- ~~First reference voltage~~ $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$
- ~~Time t_1 is derived from u_1 and the specified value of the rate of rise u_1/t_1.~~
- ~~TRV peak value~~ $u_c = k_{pp} \times k_{af} \times U_r \sqrt{\frac{2}{3}}$

  ~~where k_{af} is equal to 1,4 for test-duty T100 and for the supply side circuit for SLF, 1,5 for test-duty T60, 1,54 for test-duty T30, 0,9 × 1,7 for test-duty T10, and 1,25 for out-of-phase breaking.~~
- ~~Time t_2 is equal to $4t_1$ for test-duty T100 and for the supply side circuit for short-line fault and between t_2 (for T100) and $2t_2$ (for T100) for out-of-phase breaking. Time t_2 is equal to $6t_1$ for T60.~~
- ~~For test-duties T30 and T10, time t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3.~~
- ~~Time delay t_d is between 2 µs and $0{,}28t_1$ for test-duty T100, between 2 µs and $0{,}3t_1$ for test-duty T60, between 2 µs and $0{,}1t_1$ for test duty OP1 and OP2. Time delay is $0{,}15t_3$ for test-duty T30 and T10. For the supply side circuit for short-line fault the time delay is equal to 2 µs. The relevant value of t_d to be used for testing is given in 6.104.5.2 to 6.104.5.5.~~
- ~~Voltage $u' = u_1/2$ for test-duties T100 and T60 and the supply side for SLF and out-of-phase breaking, and $u_c/3$ for test-duties T30 and T10.~~
- ~~Time t' is derived from u', u_1/t_1 and t_d for test-duties T100, T60 and the supply circuit for SLF and out-of-phase breaking, and according to Figure 10; and from u', u_c/t_3 and t_d for test-duties T30 and T10 according to Figure 11.~~

~~The prospective transient recovery voltage wave of the test circuit shall comply with the following two requirements:~~

~~– Requirement a)~~

~~Its envelope shall at no time be below the specified reference line.~~

~~NOTE 1 It is stressed that the extent by which the envelope may exceed the specified reference line requires the consent of the manufacturer (see 6.104); this is of particular importance in the case of two-parameter envelopes when four-parameter reference lines are specified, and in the case of four-parameter envelopes when two-parameter reference lines are specified.~~

~~NOTE 2 For convenience of testing it is allowed to carry out test-duties for which a four parameter TRV is specified with a two parameter TRV, provided that the rate-of-rise of recovery voltage corresponds to the standard value u_1/t_1 and the peak value to the standard value u_c. This procedure requires the consent of the manufacturer.~~

~~– Requirement b)~~

~~Its initial portion shall fulfil the specified ITRV requirements. The ITRV has to be handled like a short-line fault. Consequently, it is necessary to measure the ITRV circuit independently of the source side in an inherent way. The ITRV is defined by the peak value u_i and the time coordinate t_i (Figure 12b). The inherent waveshape shall mostly follow a straight line reference line drawn from the beginning of the ITRV to the point defined by u_i and t_i. The inherent ITRV waveshape shall follow this reference line from 20 % to 80 % of the required ITRV peak value. Deviations from the reference line are permitted for the ITRV amplitude below 20 % and above 80 % of the specified ITRV peak value. It shall not be significantly higher than the above-mentioned reference line. If the 80 % value cannot be reached without significant increase of the rate of rise of the ITRV, it is preferred to raise the peak value u_i above the specified value in order to reach the 80 % point. The rate of rise of the ITRV shall~~

~~not be increased, because this would be connected to a change of the impedance and thus to an essential change of the severity of the test.~~

~~Testing under ITRV conditions is necessary for T100a, T100s and L_{90}. If the circuit-breaker has a short-line fault rating, the ITRV requirements are considered to be covered if the short-line fault tests are carried out using a line with insignificant time delay (see 6.104.5.2).~~

~~Since the ITRV is proportional to the busbar surge impedance and to the current, the ITRV requirements can be neglected for circuit-breakers installed in metal-enclosed, gas-insulated switchgear (GIS) because of the low surge impedance, and for all circuit-breakers with a rated short-circuit breaking current of less than 25 kA. The same applies to circuit-breakers with a rated voltage below 100 kV because of the small dimensions of the busbars.~~

The prospective TRV of the test circuits shall be determined by such a method as will produce and measure the TRV wave without significantly influencing it. It shall be measured at the terminals to which the circuit-breaker will be connected with all necessary test-measuring devices, such as voltage dividers, etc. Suitable methods are described in Annex F (see also 6.104.6). In such cases where a measurement is not possible, for instance in some synthetic circuits, a calculation of the prospective TRV is allowed. Guidance is given in Annex F.

For three-phase circuits, the prospective TRV refers to the first-pole-to-clear, i.e. the voltage across one open pole with the other two poles closed, with the appropriate test circuit arranged as specified in 6.103.3.

The prospective TRV for the test is represented by its envelope, drawn as shown in Annex E, and by its initial portion.

The TRV specified for the test is represented by a reference line, a delay line and initial transient recovery voltage (ITRV) envelope in the same manner as the TRV related to the rated short-circuit breaking current in accordance with 4.102.2 and Figures 10, 11 and 12.

TRV parameters are defined as follows as a function of the rated voltage (U_r), the first-pole-to-clear factor (k_{pp}) and the amplitude factor (k_{af}). The actual values of k_{pp} and k_{af} are stated in Tables 1, 2, 3, 4, 5, 24, 25, 26 and 27. The first-pole-to-clear factor k_{pp} is 1,3 as listed in Table 26 for all circuit-breakers of rated voltages 100 kV to 800 kV where systems are usually effectively earthed. For circuit-breakers of rated voltages higher than 800 kV, the first-pole-to-clear factor k_{pp} is 1,2 as listed in Table 26. For circuit-breakers in non-effectively earthed systems from 100 kV to 170 kV, k_{pp} is 1,5 as listed in Table 27.

a) *For rated voltages less than 100 kV*

A representation by two parameters of the prospective TRV is used for all test-duties.

– In Table 24, for circuit-breakers in cable systems.

TRV peak value $u_c = k_{pp} \times k_{af} \times \sqrt{\left(2/3\right)} \times U_r$ where k_{af} is equal to 1,4 for test-duty T100, 1,5 for test-duty T60, 1,6 for test duty T30 and 1,7 for test duty T10, 1,25 for out-of-phase breaking.

Time t_3 for test-duty T100 is taken from Table 24. Time t_3 for test-duties T60, T30 and T10 is obtained by multiplying the time t_3 for test-duty T100 by 0,44 (for T60), 0,22 (for T30) and 0,22 (for T10).

– In Table 25, for circuit-breakers in line systems.

TRV peak value $u_c = k_{pp} \times k_{af} \times \sqrt{\left(2/3\right)} \times U_r$ where k_{af} is equal to 1,54 for test-duty T100 and the supply side circuit for short-line fault, 1,65 for test-duty T60, 1,74 for test duty T30 and 1,8 for test duty T10, 1,25 for out-of-phase breaking.

Time t_3 for test-duty T100 is taken from Table 25. Time t_3 for test-duties T60, T30 and T10 is obtained by multiplying the time t_3 for test-duty T100 by 0,67 (for T60), 0,40 (for T30) and 0,40 (for T10).

– Time delay t_d for test-duty T100 is 0,15 × t_3 for cable systems, 0,05 × t_3 for line systems, 0,05 × t_3 for the supply side circuit for short-line fault. For line systems, the time delay t_d for test-duty T100 can be extended up to 0,15 × t_3 if short-line fault tests are performed.

– Time delay t_d is 0,15 × t_3 for test-duties T60, T30 and T10 and for out-of-phase breaking.

– Voltage $u' = u_c/3$.

– Time t' is derived from u', t_3 and t_d according to Figure 11, $t' = t_d + t_3/3$.

b) *For rated voltages from 100 kV to 800 kV*

A representation by four parameters of the prospective TRV is used for test-duties T100 and T60, and the supply circuit of SLF for test duties L_{90} and L_{75} and for out-of-phase test duties OP1 and OP2 and by two parameters for test-duties T30 and T10.

– First reference voltage $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\left(\frac{2}{3}\right)}$

– Time t_1 for terminal fault test duties is derived from u_1 and the specified value of the rate of rise u_1/t_1. For test duties OP1 and OP2, t_1 is two times t_1 for test duty T100 and the rate of rise is derived from u_1 and t_1.

– TRV peak value $u_c = k_{pp} \times k_{af} \times U_r \times \sqrt{\frac{2}{3}}$

where k_{af} is equal to 1,4 for test-duty T100 and for the supply side circuit for SLF, 1,5 for test-duty T60, 1,54 for test-duty T30, 0,9 × 1,7 for test-duty T10, and 1,25 for out-of-phase breaking.

– Time t_2 is equal to $4t_1$ for test-duty T100 and for the supply side circuit for short-line fault and between t_2 (for T100) and $2t_2$ (for T100) for out-of-phase breaking. Time t_2 is equal to $6t_1$ for T60.

– For test-duties T30 and T10, time t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3.

– Time delay t_d is 2 µs for test-duty T100, between 2 µs and $0{,}3t_1$ for test-duty T60, between 2 µs and $0{,}1t_1$ for test duties OP1 and OP2. Time delay is 0,15 t_3 for test-duties T30 and T10. For the supply side circuit for short-line fault the time delay is equal to 2 µs. When short-line fault tests are performed, the time delay t_d for test-duty T100 can be extended up to 0,28 t_1. The relevant value of t_d to be used for testing is given in 6.104.5.2 to 6.104.5.5.

– Voltage $u' = u_1/2$ for test-duties T100 and T60 and the supply side for SLF and out-of-phase breaking, and $u_c/3$ for test-duties T30 and T10.

– Time t' is derived from u', u_1/t_1 and t_d for test-duties T100, T60 and the supply circuit for SLF and out-of-phase breaking, and according to Figure 10; and from u', u_c/t_3 and t_d for test-duties T30 and T10 according to Figure 11.

c) *For rated voltages higher than 800 kV*

A representation by four parameters of the prospective TRV is used for test-duties T100 and T60, and the supply circuit of SLF for test duties L_{90} and L_{75} and by two parameters for test-duties T30, T10 and for out-of-phase test duties OP1 and OP2.

– First reference voltage $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$

– Time t_1 for terminal fault test duties is derived from u_1 and the specified value of the rate of rise u_1/t_1.

– Time t_3 for out-of-phase test duties OP1 and OP2 is derived from u_c and the specified value of the rate of rise.

– TRV peak value $u_c = k_{pp} \times k_{af} \times U_r \sqrt{\frac{2}{3}}$

  where k_{af} is equal to 1,5 for test-duty T100 and for the supply side circuit for SLF, 1,5 for test-duty T60, 1,54 for test-duty T30, 1,76 for test-duty T10, and 1,25 for out-of-phase breaking.

– Time t_2 is equal to 3 t_1 for test-duty T100 and for the supply side circuit for short-line fault. Time t_2 is equal to 4,5 t_1 for T60.

– For test-duties T30 and T10, time t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3.

– Time delay t_d is 2 µs for test-duty T100, between 2 µs and 0,3 t_1 for test-duty T60. Time delay is 0,15 t_3 for test duties T30 and T10, 0,05 t_3 for test duties OP1 and OP2. For the supply side circuit for short-line fault the time delay is equal to 2 µs. When short-line fault tests are performed, the time delay t_d for test-duty T100 can be extended up to 0,28 t_1. The relevant value of t_d to be used for testing is given in 6.104.5.2 to 6.104.5.5.

– Voltage $u' = u_1/2$ for test-duties T100 and T60 and the supply side for SLF, and $u_c/3$ for test-duties T30, T10 and out-of-phase test duties.

– Time t' is derived from u', u_1/t_1 and t_d for test-duties T100, T60 and the supply circuit for SLF, and according to Figure 10; and from u', u_c/t_3 and t_d for test-duties T30, T10 and out-of-phase test duties according to Figure 11.

The prospective transient recovery voltage wave of the test circuit shall comply with the following two requirements:

– Requirement a)

  Its envelope shall at no time be below the specified reference line.

NOTE 1 It is stressed that the extent by which the envelope may exceed the specified reference line requires the consent of the manufacturer (see 6.104); this is of particular importance in the case of two-parameter envelopes when four-parameter reference lines are specified, and in the case of four-parameter envelopes when two-parameter reference lines are specified.

NOTE 2 For convenience of testing it is allowed to carry out test-duties for which a four parameter TRV is specified with a two parameter TRV, provided that the rate-of-rise of recovery voltage corresponds to the standard value u_1/t_1 and the peak value to the standard value u_c. This procedure requires the consent of the manufacturer.

– Requirement b)

  Its initial portion shall fulfil the specified ITRV requirements. The ITRV has to be handled like a short-line fault. Consequently, it is necessary to measure the ITRV circuit independently of the source side in an inherent way. The ITRV is defined by the peak value u_i and the time coordinate t_i (Figure 12b). The inherent waveshape shall mostly follow a straight line reference line drawn from the beginning of the ITRV to the point defined by u_i and t_i. The inherent ITRV waveshape shall follow this reference line from 20 % to 80 % of the required ITRV peak value. Deviations from the reference line are permitted for the ITRV amplitude below 20 % and above 80 % of the specified ITRV peak value. It shall not be significantly higher than the above-mentioned reference line. If the 80 % value cannot be reached without significant increase of the rate of rise of the ITRV, it is preferred to raise the peak value u_i above the specified value in order to reach the 80 % point. The rate of rise of the ITRV shall not be increased, because this would be connected to a change of the impedance and thus to an essential change of the severity of the test.

  Testing under ITRV conditions is necessary for T100a, T100s and L_{90}.However, if a circuit-breaker with rated voltage equal or less than 800 kV has a short-line fault rating, the ITRV requirements are considered to be covered if the short-line fault tests are carried out using a line with a time delay less than 100 ns (see also 6.104.5.2).

If a circuit-breaker with rated voltage higher than 800 kV has a short-line fault rating, the ITRV requirements are covered if the short-line fault tests are carried out using a line with a time delay less than 100 ns and a surge impedance of 450 Ω (see also 6.104.5.2 and 6.109.3).

Since the ITRV is proportional to the busbar surge impedance and to the current, the ITRV requirements can be neglected for circuit-breakers installed in metal-enclosed, gas-insulated switchgear (GIS) because of the low surge impedance, and for all circuit-breakers with a rated short-circuit breaking current of less than 25 kA. The same applies to circuit-breakers with a rated voltage below 100 kV because of the small dimensions of the busbars.

6.104.5.2 Test-duties T100s and T100a

For rated voltages less than 100 kV, the specified standard values are given in

– Table 24 for circuit-breakers in cable systems,

– Table 25 for circuit-breakers in line systems.

For rated voltages of 100 kV and above, the specified standard values are given in Tables 26 and 27.

The specific reference lines, delay lines and ITRV are given by the standard values in Tables 1, 2, 3, 4, 5, 6 and 7.

With reference to ITRV, if a test is made with a TRV following the straight reference line specified in requirement b) of 6.104.5.1 and shown in Figure 12b, it is assumed that the effect on the circuit-breaker is similar to that of any ITRV defined in requirement b) of 6.104.5.1 and Figure 12b.

Owing to limitations of the testing station, it may not be feasible to comply with the requirement of item b) of 6.104.5.1 with respect to the time delay t_d as specified in Tables 3, 4 or 5. Where short-line fault duties are also to be performed, any such deficiency of the TRV of the supply circuit shall be compensated by an increase of the voltage excursion to the first peak of the line-side voltage (see 6.109.3). The time delay of the supply circuit shall be as small as possible, but shall in any case not exceed the values given in brackets in Table 25 or Table 26 or Table 27.

~~Where short-line fault duties are also to be performed, it may be convenient to combine the ITRV and SLF requirements in the line-side circuit. When the ITRV is combined with the transient voltage of a short line having a time delay t_{dL} as specified in Table 8, the total stress is, for practical considerations, equal to the stress of a short line with insignificant delay. Therefore, the ITRV requirements for test-duties T100s and T100a are considered to be covered when the short-line fault duties are performed using the short line with insignificant time delay t_{dL} (see 6.109.3) unless both terminals are not identical from an electrical point of view (for instance, where an additional capacitance is used as mentioned in Note 4 of 6.109.3).~~

Where short-line fault duties are also to be performed, it may be convenient to combine the ITRV and SLF requirements in the line-side circuit. When the ITRV is combined with the transient voltage of a short line having a time delay t_{dL} as specified in Table 8, the total stress is, for practical considerations, equal or covered by the stress of a short line with a time delay less than 100 ns and a surge impedance of 450 Ω. Therefore, the ITRV requirements for test-duties T100s and T100a are considered to be covered when the short-line fault duties are performed using the short line with a time delay less than 100 ns and a surge impedance of 450 Ω (see 6.109.3) unless both terminals are not identical from an electrical point of view (for instance, where an additional capacitance is used as mentioned in Note 4 of 6.109.3).

Where short-line fault duties with a time delay less than 100 ns are used to cover ITRV requirements, the initial part of the line side transient voltage up to 0,2 u_L* cannot cross the 20 % to 80 % SLF reference except if the time delay as defined in Figure 16b less than 100 ns.

6.104.5.3 Test duty T60

For rated voltages less than 100 kV, the specified standard values are given in

– Table 24 for circuit-breakers in cable systems,

– Table 25 for circuit-breakers in line systems.

For rated voltages of 100 kV and above, the specified standard values are given in Table 26 and Table 27.

6.104.5.4 Test duty T30

a) For rated voltages less than 100 kV, the specified standard values are given in

– Table 24 for circuit-breakers in cable systems,

– Table 25 for circuit-breakers in line systems.

~~In direct or synthetic testing, it may be difficult to meet the small values of time t_3. The shortest time that can be met should be used but not less than the values specified. The values used shall be stated in the test report.~~

In case that small values of time t_3 cannot be met, the shortest time that can be met shall be used. The values used shall be stated in the test report.

b) For rated voltages of 100 kV and above, the specified standard values are given in Tables 26 and 27.

~~NOTE The contribution of transformers to the short-circuit current is relatively larger at smaller values of short-circuit current as in T30 and T10 conditions. However, most systems have effectively earthed neutrals at ratings of 100 kV and above. With the system and transformer neutrals effectively earthed, the first-pole-to-clear factor of 1,3 is applicable for all test-duties except for T10, where in general a first-pole-to-clear factor of 1,5 is used in order to take also transformer fed faults into account. In some systems for rated voltages of 100 kV up to and including 170 kV, transformers with non-effectively earthed neutrals are in service, even though the rest of the system may have effectively earthed neutrals. Such systems are considered special cases and are covered in Tables 4 and 27 where the TRVs specified for all test duties are based on a first-pole-to-clear factor of 1,5. For rated voltages above 170 kV, all systems and their transformers are considered to have effectively earthed neutrals.~~

NOTE The contribution of transformers to the short-circuit current is relatively larger at smaller values of short-circuit current as in T30 and T10 conditions. However, most systems have effectively earthed neutrals at ratings of 100 kV up to 800 kV. With the system and transformer neutrals effectively earthed, the first-pole-to-clear factor of 1,3 is applicable for all test-duties except for T10, where in general a first-pole-to-clear factor of 1,5 is used in order to take also transformer fed faults into account. For rated voltages higher than 800 kV, the first-pole-to-clear factor of 1,2 is applicable for all test-duties.

In some systems for rated voltages of 100 kV up to and including 170 kV, transformers with non-effectively earthed neutrals are in service, even though the rest of the system may have effectively earthed neutrals. Such systems are considered special cases and are covered in Tables 4 and 27 where the TRVs specified for all test duties are based on a first-pole-to-clear factor of 1,5. For rated voltages above 170 kV, all systems and their transformers are considered to have effectively earthed neutrals.

6.104.5.5 Test duty T10

a) For rated voltages less than 100 kV, the specified standard values are given in

– Table 24 for circuit-breakers in cable systems,

– Table 25 for circuit-breakers in line systems.

b) For rated voltages of 100 kV and above, the specified standard values are given in Tables 26 and 27. The time t_3 is a function of the natural frequency of transformers.

~~In direct or synthetic testing, it may be difficult to meet the small values of time t_3. The shortest time that can be met should be used but not less than the values specified. The values used shall be stated in the test report.~~

In case that small values of time t_3 cannot be met, the shortest time that can be met shall be used. The values used shall be stated in the test report.

6.104.5.6 Test-duties OP1 and OP2

For rated voltages up to and including 72,5 kV, the specified standard values are given in Tables 1 and 2.

For rated voltages of 100 kV and above, the specified standard values are given in Tables 3, 4 and, 5. Two values of time, t_d and t', are given. They indicate the lower and the upper limits that should be used for testing.

6.104.6 Measurement of transient recovery voltage during test

During a short-circuit test, the circuit-breaker characteristics such as arc voltage, post-arc conductivity and presence of switching resistors (if any) will affect the transient recovery voltage. Thus, the test transient recovery voltage will differ from the prospective TRV-wave of the test circuit upon which the performance requirements are based to a degree depending upon the characteristics of the circuit-breaker.

Unless the modifying effect of the circuit-breaker is not significant and the breaking current does not contain a significant d.c. component, records taken during tests should not be used for assessing the prospective transient recovery voltage characteristics of the circuit; rather, this should be done by other means, as described in Annex F.

The transient recovery voltage during the test shall be recorded.

Table 24 – Standard values of prospective transient recovery voltage for class S1 circuit-breakers – Rated voltage higher than 1 kV and less than 100 kV – Representation by two parameters

Rated voltage U_r kV	Test duty	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [a] u_c/t_3 kV/µs
3,6	T100	1,5	1,4	6,2	41	6	2,1	20	0,15
	T60	1,5	1,5	6,6	18	3	2,2	9	0,37
	T30	1,5	1,6	7,1	9	1,4	2,4	4,4	0,79
	T10	1,5	1,7	7,5	9	1,4	2,5	4,4	0,83
4,76 [b]	T100	1,5	1,4	8,2	44	7	2,7	21	0,19
	T60	1,5	1,5	8,7	19	3	2,9	9	0,46
	T30	1,5	1,6	9,3	10	1,5	3,1	5	0,93
	T10	1,5	1,7	9,9	10	1,5	3,3	5	0,99
7,2	T100	1,5	1,4	12,3	51	8	4,1	25	0,24
	T60	1,5	1,5	13,2	22	3	4,4	11	0,60
	T30	1,5	1,6	14,1	11	2	4,7	5	1,28
	T10	1,5	1,7	15,0	11	2	5,0	5	1,36
8,25 [b]	T100	1,5	1,4	14,1	52	8	4,7	25	0,27
	T60	1,5	1,5	15,2	23	3	5,1	11	0,66
	T30	1,5	1,6	16,2	11	2	5,4	6	1,47
	T10	1,5	1,7	17,2	11	2	5,7	6	1,56
12	T100	1,5	1,4	20,6	61	9	6,9	29	0,34
	T60	1,5	1,5	22,0	27	4	7,3	13	0,81
	T30	1,5	1,6	23,5	13	2	7,8	6	1,81
	T10	1,5	1,7	25,0	13	2	8,3	6	1,92
15 [b]	T100	1,5	1,4	25,7	66	10	8,6	32	0,39
	T60	1,5	1,5	27,6	29	4	9,2	14	0,95
	T30	1,5	1,6	29,4	15	2	9,8	7	1,96
	T10	1,5	1,7	31,2	15	2	10,4	7	2,08
17,5	T100	1,5	1,4	30,0	71	11	10,0	34	0,42
	T60	1,5	1,5	32,1	31	5	10,7	15	1,04
	T30	1,5	1,6	34,3	16	2	11,4	8	2,14
	T10	1,5	1,7	36,4	16	2	12,1	8	2,28

Table 24 *(continued)*

Rated voltage U_r kV	Test duty	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [a] u_c/t_3 kV/µs
24	T100	1,5	1,4	41	87	13	13,7	42	0,47
	T60	1,5	1,5	44,1	38	6	14,7	19	1,16
	T30	1,5	1,6	47,0	19	3	15,7	9	2,47
	T10	1,5	1,7	50	19	3	16,7	9	2,63
25,8 [b]	T100	1,5	1,4	44,2	91	14	14,7	44	0,49
	T60	1,5	1,5	47,4	40	6	15,8	18	1,19
	T30	1,5	1,6	50,6	20	3	16,9	10	2,53
	T10	1,5	1,7	53,7	20	3	17,9	10	2,69
36	T100	1,5	1,4	61,7	109	16	20,6	53	0,57
	T60	1,5	1,5	66,1	48	7	22	23	1,38
	T30	1,5	1,6	70,5	24	3,6	23,5	12	2,94
	T10	1,5	1,7	75,0	24	3,6	25	12	3,13
38 [b]	T100	1,5	1,4	65,2	109	16	21,7	53	0,60
	T60	1,5	1,5	69,8	48	7	23,3	23	1,45
	T30	1,5	1,6	74,5	24	3,6	24,8	12	3,1
	T10	1,5	1,7	79,1	24	3,6	26,4	12	3,3
48,3 [b]	T100	1,5	1,4	82,8	125	19	27,6	60	0,66
	T60	1,5	1,5	88,7	55	8	29,6	27	1,61
	T30	1,5	1,6	94,6	28	4	31,5	13	3,38
	T10	1,5	1,7	101	28	4	33,5	13	3,61
52	T100	1,5	1,4	89,2	131	20	29,7	63	0,68
	T60	1,5	1,5	95,5	58	9	31,8	28	1,65
	T30	1,5	1,6	102	29	4	34	14	3,52
	T10	1,5	1,7	108	29	4	36,1	14	3,72
72,5	T100	1,5	1,4	124	165	25	41,4	80	0,75
	T60	1,5	1,5	133	73	11	44,4	35	1,82
	T30	1,5	1,6	142	36	5	47,4	18	3,94
	T10	1,5	1,7	151	36	5	50,3	18	4,19

[a] RRRV = rate of rise of recovery voltage.

[b] Used in North America.

Table 25 – Standard values of prospective transient recovery voltage[c] for class S2 circuit-breakers – Rated voltage equal to or higher than 15 kV and less than 100 kV – Representation by two parameters

Rated voltage U_r kV	Test duty	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [a] u_c/t_3 kV/µs
15 [b]	T100	1,5	1,54	28,3	31	2 (5)	9,4	12 (15)	0,91
	T60	1,5	1,65	30,3	21	3	10,1	10	1,44
	T30	1,5	1,74	32,0	12,5	2	10,7	6	2,56
	T10	1,5	1,80	33,1	12,5	2	11,0	6	2,67
17,5	T100	1,5	1,54	33,0	34	2 (5)	11,0	13 (17)	0,97
	T60	1,5	1,65	35,3	23	3	11,8	11	1,53
	T30	1,5	1,74	37,3	14	2	12,4	7	2,66
	T10	1,5	1,8	38,6	14	2	12,9	7	2,76
24	T100	1,5	1,54	45,3	43	2 (6)	15,1	16 (21)	1,05
	T60	1,5	1,65	48,4	29	4	16,1	14	1,67
	T30	1,5	1,74	51,2	17	3	17,0	8	3,01
	T10	1,5	1,8	52,9	17	3	17,6	8	3,11
25,8 [b]	T100	1,5	1,54	48,7	45	2 (7)	16,2	17 (22)	1,08
	T60	1,5	1,65	52,1	30	5	17,4	15	1,74
	T30	1,5	1,74	55,0	18	3	18,3	9	3,06
	T10	1,5	1,8	56,9	18	3	19,0	9	3,16
36	T100	1,5	1,54	67,9	57	3 (9)	22,6	22 (28)	1,19
	T60	1,5	1,65	72,7	38	6	24,2	18	1,91
	T30	1,5	1,74	76,7	23	3	25,6	11	3,33
	T10	1,5	1,8	79,4	23	3	26,5	11	3,45
38 [b]	T100	1,5	1,54	71,7	59	3 (9)	23,9	23 (29)	1,22
	T60	1,5	1,65	76,8	40	6	25,6	19	1,92
	T30	1,5	1,74	81,0	24	4	27,0	11,9	3,38
	T10	1,5	1,8	83,8	24	4	28,0	11,9	3,49
48,3 [b]	T100	1,5	1,54	91,1	70	4 (11)	30,4	27 (34)	1,30
	T60	1,5	1,65	97,5	47	7	32,5	23	2,07
	T30	1,5	1,74	103	28	4	34,3	13,5	3,68
	T10	1,5	1,8	107	28	4	35,5	13,5	3,82
52	T100	1,5	1,54	98,1	74	4 (11)	32,7	28 (36)	1,33
	T60	1,5	1,65	105	50	7	35,0	24	2,10
	T30	1,5	1,74	111	30	4	36,9	14	3,70
	T10	1,5	1,8	115	30	4	38,3	14	3,83
72,5	T100	1,5	1,54	137	93	5 (14)	45,6	36 (45)	1,47
	T60	1,5	1,65	146	62	9	48,8	30	2,35
	T30	1,5	1,74	155	37	6	51,5	18	4,19
	T10	1,5	1,8	160	37	6	53,3	18	4,32

[a] RRRV = rate of rise of recovery voltage.

[b] Used in North America.

[c] ~~Where two values of the times t_d and t' are given, separated by brackets (T100), the one in brackets can be used if short-line fault tests are also made. If this is not the case, the lower values of t_d and t' apply.~~

Where two values of times t_d and t' are given for test duty T100 separated by brackets, the time t_d in brackets is the upper limit of the time delay t_d that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at t' given in brackets. If this is not the case, the lower values of t_d and t' apply.

Table 26 – Standard values of prospective transient recovery voltage – Rated voltages of 100 kV and above ~~to 800 kV for effectively earthed neutral systems – Representation by four parameters (T100, T60, OP1 and OP2) or two parameters (T30, T10)~~

Rated voltage	Test-duty	First-pole-to-clear factor	Ampli-tude factor	First reference voltage	Time	TRV peak value	Time	Time delay	Voltage	Time	Rate-of-rise
U_r		k_{pp}	k_{af}	u_1	t_1	u_C	t_2 or t_3	t_d	u'	t'	u_1/t_1 u_c/t_3
kV		p.u.	p.u.	kV	µs	kV	µs	µs	kV	µs	kV/µs
100	T100	1,3	1,40	80	40	149	160	2 (11)	40	22 (31)	2
	T60	1,3	1,50	80	27	159	162	2-8	40	15-21	3
	T30	1,3	1,54	-	-	163	33	5	54	16	5
	T10	1,5	0,9 x 1,7	-	-	187	27	4	62	13	7
	OP1-OP2	2	1,25	122	80	204	160-320	2-8	61	42-48	1,54
123	T100	1,3	1,40	98	49	183	196	2 (14)	49	26 (38)	2
	T60	1,3	1,50	98	33	196	198	2-10	49	18-26	3
	T30	1,3	1,54	-	-	201	40	6	67	19	5
	T10	1,5	0,9 x 1,7	-	-	230	33	5	77	16	7
	OP1-OP2	2	1,25	151	98	251	196-392	2-10	75	51-59	1,54
145	T100	1,3	1,40	115	58	215	232	2 (16)	58	31 (45)	2
	T60	1,3	1,50	115	38	231	228	2-12	58	21-31	3
	T30	1,3	1,54	-	-	237	47	7	79	23	5
	T10	1,5	0,9 x 1,7	-	-	272	39	6	91	19	7
	OP1-OP2	2	1,25	178	116	296	232-464	2-12	89	60-70	1,54
170	T100	1,3	1,40	135	68	253	272	2 (19)	68	36 (53)	2
	T60	1,3	1,50	135	45	271	270	2-14	68	25-36	3
	T30	1,3	1,54	-	-	278	56	8	93	27	5
	T10	1,5	0,9 x 1,7	-	-	319	46	7	106	22	7
	OP1-OP2	2	1,25	208	136	347	272-544	2-14	104	70-82	1,54
245	T100	1,3	1,40	195	98	364	392	2 (27)	98	51 (76)	2
	T60	1,3	1,50	195	65	390	390	2-20	98	35-52	3
	T30	1,3	1,54	-	-	400	80	12	133	39	5
	T10	1,5	0,9 x 1,7	-	-	459	66	10	153	32	7
	OP1-OP2	2	1,25	300	196	500	392-784	2-20	150	99-117	1,54
300	T100	1,3	1,40	239	119	446	476	2 (33)	119	62 (93)	2
	T60	1,3	1,50	239	80	478	480	2-24	119	42-64	3
	T30	1,3	1,54	-	-	490	98	15	163	47	5
	T10	1,5	0,9 x 1,7	-	-	562	80	12	187	39	7
	OP1-OP2	2	1,25	367	238	612	476-952	2-24	184	121-143	1,54

Table 26 *(continued)*

Rated voltage	Test-duty	First-pole-to-clear factor	Amplitude factor	First reference voltage	Time	TRV peak value	Time	Time delay	Voltage	Time	Rate-of-rise
U_r		k_{pp}	k_{af}	u_1	t_1	u_C	t_2 or t_3	t_d	u'	t'	u_1/t_1 u_c/t_3
kV		p.u.	p.u.	kV	µs	kV	µs	µs	kV	µs	kV/µs
362	T100	1,3	1,40	288	144	538	576	2 (40)	144	74 (112)	2
	T60	1,3	1,50	288	96	576	576	2-29	144	50-77	3
	T30	1,3	1,54	-	-	592	118	18	197	57	5
	T10	1,5	0,9 x 1,7	-	-	678	97	15	226	47	7
	OP1-OP2	2	1,25	443	288	739	576-1152	2-29	222	146-173	1,54
420	T100	1,3	1,40	334	167	624	668	2 (47)	167	86 (130)	2
	T60	1,3	1,50	334	111	669	666	2-33	167	58-89	3
	T30	1,3	1,54	-	-	687	137	21	229	66	5
	T10	1,5	0,9 x 1,7	-	-	787	112	17	262	54	7
	OP1-OP2	2	1,25	514	334	857	668-1336	2-33	257	169-200	1,54
550	T100	1,3	1,40	438	219	817	876	2 (61)	219	111 (171)	2
	T60	1,3	1,50	438	146	876	876	2-44	219	75-117	3
	T30	1,3	1,54	-	-	899	180	27	300	87	5
	T10	1,5	0,9 x 1,7	-	-	1031	147	22	344	71	7
	OP1-OP2	2	1,25	674	438	1123	876-1752	2-44	337	221-263	1,54
800	T100	1,3	1,40	637	318	1189	1272	2 (89)	318	161 (248)	2
	T60	1,3	1,50	637	212	1274	1272	2-64	318	108-170	3
	T30	1,3	1,54	-	-	1308	262	39	436	126	5
	T10	1,5	0,9 x 1,7	-	-	1499	214	32	500	103	7
	OP1-OP2	2	1,25	980	636	1633	1272-2544	2-64	490	320-382	1,54
1 100	T100	1,2	1,50	808	404	1617	1212	2 (113)	404	204 (315)	2
	T60	1,2	1,50	808	269	1617	1212	2-81	404	137-216	3
	T30	1,2	1,54	-	-	1660	332	50	553	161	5
	T10	1,2	1,76	-	-	1897	271	41	632	131	7
	OP1-OP2	2	1,25	-	-	2245	1458	2-73	748	488-559	1,54
1 200	T100	1,2	1,50	882	441	1764	1323	2 (123)	441	222 (343)	2
	T60	1,2	1,50	882	294	1764	1323	2-88	441	149-235	3
	T30	1,2	1,54	-	-	1811	362	54	604	175	5
	T10	1,2	1,76	-	-	2069	296	44	690	143	7
	OP1-OP2	2	1,25	-	-	2449	1590	2-80	816	532-610	1,54

Table 26 *(continued)*

~~NOTE 1 Where two values of times t_d and t' are given for terminal fault test duty T100, separated by brackets, the one in brackets can be used if short-line fault tests are also made. If this is not the case, the times before the brackets apply.~~

~~Where two values of times t_d and t' are given for terminal fault test duties T60 and out-of-phase test duties OP1 and OP2, those indicate the lower and upper limits which should be used for testing. The time delay t_d and the time t' during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.~~

NOTE 1 Where two values of times t_d and t' are given for test duty T100 separated by brackets, the time t_d in brackets is the upper limit of the time delay t_d that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at t' given in brackets. If this is not the case, the lower values of t_d and t' apply.

Where two values of times t_d and t' are given for terminal fault test duties T60 and out-of-phase test duties OP1 and OP2, those indicate the lower and upper limits which should be used for testing. The time delay t_d and the time t' during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.

NOTE 2 First-pole-to-clear factor k_{pp}= 1,5 is specified to cover transformer-limited fault conditions with X_0/X_1 higher than 3,2 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems). The TRV specified covers also cases of 3-phase line faults with effectively earthed neutral systems (k_{pp} = 1,3) where coupling between phases can lead to an amplitude factor of 1,76. Therefore the arcing time window for effectively earthed neutral systems has to be demonstrated for T10 (see 6.102.10.2.2.1).

Table 27 – Standard values of prospective transient recovery voltage – Rated voltages of 100 kV to 170 kV for non-effectively earthed neutral systems – Representation by four parameters (T100, T60, OP1 and OP2) or two parameters (T30 and T10)

Rated voltage	Test-duty	First-pole-to-clear factor	Amplitude factor	First reference voltage	Time	TRV peak value	Time	Time delay	Voltage	Time	Rate-of-rise
U_r		k_{pp}	k_{af}	u_1	t_1	u_C	t_2 or t_3	t_d	u'	t'	u_1/t_1 u_c/t_3
kV		p.u.	p.u.	kV	µs	kV	µs	µs	kV	µs	kV/µs
	T100	1,5	1,40	92	46	171	184	2 (13)	46	25 (36)	2
	T60	1,5	1,50	92	31	184	186	2-8	46	15-21	3
100	T30	1,5	1,54	-	-	189	38	5	63	16	5
	T10	1,5	0,9 x 1,7	-	-	187	27	4	62	13	7
	OP1-OP2	2,5	1,25	153	92	255	184-368	2-8	77	42-48	1,67
	T100	1,5	1,40	113	56	211	224	2 (16)	56	30 (44)	2
	T60	1,5	1,50	113	38	226	228	2-10	56	18-26	3
123	T30	1,5	1,54	-	-	232	46	6	77	19	5
	T10	1,5	0,9 x 1,7	-	-	230	33	5	77	16	7
	OP1-OP2	2,5	1,25	188	112	314	224-448	2-10	94	51-59	1,67
	T100	1,5	1,40	133	67	249	268	2 (19)	67	35 (52)	2
	T60	1,5	1,50	133	44	266	264	2-12	67	21-31	3
145	T30	1,5	1,54	-	-	273	55	7	91	23	5
	T10	1,5	0,9 x 1,7	-	-	272	39	6	91	19	7
	OP1-OP2	2,5	1,25	222	134	370	268-536	2-12	111	60-70	1,67
	T100	1,5	1,40	156	78	291	312	2 (22)	78	41 (61)	2
	T60	1,5	1,50	156	52	312	312	2-14	78	25-36	3
170	T30	1,5	1,54	-	-	321	64	8	107	27	5
	T10	1,5	0,9 x 1,7	-	-	319	46	7	106	22	7
	OP1-OP2	2,5	1,25	260	156	434	312-624	2-14	130	70-82	1,67

~~NOTE 1 Where two values of times t_d and t' are given for terminal fault test duty T100, separated by brackets, the one in brackets can be used if short-line fault tests are also made. If this is not the case, the times before the brackets apply.~~

NOTE 1 Where two values of times t_d and t' are given for test duty T100 separated by brackets, the time t_d in brackets is the upper limit of the time delay t_d that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at t' given in brackets. If this is not the case, the lower values of t_d and t' apply.

Where two values of times t_d and t' are given for terminal fault test duties T60 and out-of-phase test duties OP1 and OP2, those indicate the lower and upper limits which should be used for testing. The time delay t_d and the time t' during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.

NOTE 2 First-pole-to-clear factor k_{pp} = 1,5 is specified to cover transformer-limited fault conditions with X_0/X_1 higher than 3,2 (e.g. non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems). The TRV specified covers also cases of 3-phase line faults with effectively earthed neutral systems (k_{pp} = 1,3) where coupling between phases can lead to an amplitude factor of 1,76. Therefore the arcing time window for effectively earthed neutral systems has to be demonstrated for T10 (see 6.102.10.2.2.1).

6.104.7 Power frequency recovery voltage

The power frequency recovery voltage of the test circuit may be stated as a percentage of the power frequency recovery voltage specified below. It shall not be less than 95 % of the specified value and shall be maintained for at least 0,3 s.

For synthetic test circuits, details and tolerances are given in IEC 62271-101.

For the basic short-circuit test-duties of 6.106, the power frequency recovery voltage shall be as follows, subject to the 95 % minimum stated above:

a) For three-phase tests on a three-pole circuit-breaker, the average value of the power frequency recovery voltage shall be equal to the rated voltage U_r of the circuit-breaker divided by $\sqrt{3}$.

   The power frequency recovery voltage of any pole should not deviate by more than 20 % from the average value at the end of the time for which it is maintained.

   For an effectively earthed neutral system, it shall be proved that the insufficient build-up of dielectric strength in one pole will not lead to prolonged arcing and possible failure. The single-phase test (6.108) shall be applied as a demonstration.

b) ~~For single-phase tests on a three-pole circuit-breaker, the power frequency recovery voltage shall be equal to the product of the phase-to-earth value $U_r/\sqrt{3}$ and the first-pole-to-clear factor (1,3 or 1,5); the power frequency recovery voltage may be reduced to $U_r/\sqrt{3}$ after an interval of one cycle of rated frequency.~~

   For single-phase tests on a three-pole circuit-breaker, the power frequency recovery voltage shall be equal to the product of the phase-to-earth value $U_r/\sqrt{3}$ and the first-pole-to-clear factor (1,2 or 1,3 or 1,5); the power frequency recovery voltage may be reduced to $U_r/\sqrt{3}$ after an interval of one cycle of rated frequency.

c) For a single-pole circuit-breaker, the power frequency recovery voltage shall be equal to the rated voltage U_r of the circuit-breaker.

The power frequency recovery voltage shall be measured between terminals of a pole in each phase of the test circuit. Its r.m.s. value shall be determined on the oscillogram within the time interval of one half-cycle and one cycle of test frequency after final arc extinction, as indicated in Figure 44. The vertical distance (V_1, V_2 and V_3 respectively) between the peak of the second half-wave and the straight line drawn between the respective peaks of the preceding and succeeding half-waves shall be measured, and this, when divided by $2\sqrt{2}$ and multiplied by the appropriate calibration factor, gives the r.m.s. value of the power frequency recovery voltage recorded.

6.105 Short-circuit test procedure

6.105.1 Time interval between tests

The basic short-circuit tests and, if applicable, short-line fault tests, consist of the series of test-duties specified in 6.106 and 6.109.

The time intervals between individual operations of a test sequence shall be the time intervals of the rated operating sequence of the circuit-breaker, given in 4.104, but taking into account 6.105.3, subject to the following provision:

Due to test plant limitations, it may not be possible to achieve the 15 s, 1 min or 3 min time interval of the rated operating sequence. In such cases the time interval may be extended to 10 min without the test being disqualified; time intervals even longer than 10 min may be required. Prolonged time intervals shall not be due to faulty operation of the circuit-breaker. The actual time interval between operations shall be stated in the test report. If it is longer than 10 min the reason for such a delay shall be recorded in the test report.

For circuit-breakers with a rated operating sequence of O – t – CO – t' – CO rated for different time intervals of t', the test may be performed with the shortest time interval t'. This test is considered to cover all rated operating sequences with longer t' time intervals. This makes it possible to combine the testing for rated operating sequences according to 4.104 a) and b). The actual time interval shall be recorded.

6.105.2 Application of auxiliary power to the opening release – Breaking tests

Auxiliary power shall be applied to the opening release after the initiation of the short-circuit, but when due to test plant limitations this is impracticable the power may be applied before the initiation of the short-circuit (with the limitation that contacts shall not start to move before the initiation of the short-circuit).

6.105.3 Application of auxiliary power to the opening release – Make-break tests

~~In make-break tests auxiliary power shall not be applied to the opening release before the circuit-breaker has reached the closed position. In the closing-opening operating cycles of test-duty T100s (see 6.106.4) the power shall not be applied until at least one half-cycle has elapsed from the instant of contact make. It is permissible to delay the circuit-breaker opening so that the permissible d.c. component is not exceeded but the close-open time shall remain as close as possible to the close-open time as defined in 3.7.143.~~

In make-break tests the auxiliary power shall not be applied to the opening release before the circuit-breaker has reached the closed position. In the close-open operations of the short-circuit test-duties the power shall not be applied until at least one half-cycle has elapsed from the instant of contact touch. The close-open time shall remain as close as possible to the minimum close-open time (see Note of 3.7.143), but it is permissible to delay the circuit-breaker opening such that the d.c. component at contact separation is within the permissible limits.

6.105.4 Latching on short-circuit

A circuit-breaker is latched when the main current-carrying contacts have achieved a stationary, fully engaged position at closing and this position is maintained until intentionally released, either mechanically or electrically. Unless the circuit-breaker is fitted with a making current release, or equivalent device, it shall be verified that it latches satisfactorily without undue hesitation when there is negligible decrement of the a.c. component of the current during the closing period.

The ability of the circuit-breaker to latch on short-circuit making current may be verified in test-duty T100s (see 6.106.4) or in the verification test for making (see 6.102.4.1). During this test the following applies:

- for three-phase tests on a three-pole circuit-breaker, the closing angle should be chosen in order to stress the pole most remote from the drive with the peak making current;
- if a single-phase test is carried out, care should be taken to stress the pole most remote from the mechanism in the same way as during a three-phase test in respect to applied voltage across the pole and current through the pole.

If the characteristics of the test plant are such that it is impossible to carry out test-duty T100s within the specified limits of the applied voltage stated in 6.104.1, the test shall be repeated at reduced voltage using a test circuit which gives the rated short-circuit making current, with negligible decrement of the a.c. component.

Several methods may be used to establish whether a circuit-breaker has closed and latched, for example:

- by proper recording the auxiliary contacts or the contact travel;
- by visually checking the latching position after the performance of the making test;

– by recording the action of the device in order to detect latching (for example a micro-switch suitably fitted to the mechanism).

The method employed to prove satisfactory latching shall be recorded in the test report.

6.106 Basic short-circuit test-duties

The basic short-circuit test series shall consist of test-duties T10, T30, T60, T100s and T100a, as specified below.

The breaking current may deviate from the specified values by not more than 20 % of the specified values for test-duties T10 and T30 and by not more than 10 % for test-duty T60.

The peak short-circuit current during the breaking-current tests of test-duties T100s, T100s(b) and T100a shall not exceed 110 % of the rated short-circuit making current of the circuit-breaker.

NOTE In the cases explained in 6.106.4, it may be necessary to separate the making and breaking tests of test-duty T100s. In this case, the part consisting of the making operations is designated T100s(a) and the part consisting of the breaking operations is designated T100s(b).

For test-duties T10, T30 and T60, it is permissible to omit the making operation before any breaking operation for convenience in testing. The time intervals between the individual breaking operations, shall be the time intervals of the rated operating sequence of the circuit-breaker (see 6.105.1).

6.106.1 Test-duty T10

Test-duty T10 consists of the rated operating sequence at 10 % of the rated short-circuit breaking current with a d.c. component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 6.104.5.5 and 6.104.7 (see also Tables 24, 25, 26 and 27).

6.106.2 Test-duty T30

Test-duty T30 consists of the rated operating sequence at 30 % of the rated short-circuit breaking current with a d.c. component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 6.104.5.4 and 6.104.7 (see also Tables 24, 25, 26 and 27).

6.106.3 Test-duty T60

Test-duty T60 consists of the rated operating sequence at 60 % of the rated short-circuit breaking current with a d.c. component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 6.104.5.3 and 6.104.7 (see also Tables 24, 25, 26 and 27).

6.106.4 Test-duty T100s

Test-duty T100s consists of the rated operating sequence at 100 % of the rated short-circuit breaking current taking account of 6.104.3, and with a transient and power frequency recovery voltage as specified in 6.104.7 (see also Tables 24, 25, 26 and 27) and 100 % of the rated short-circuit making current taking account of 6.104.2 and an applied voltage as specified in 6.104.1.

For this test-duty, the percentage of the d.c. component at contact separation shall not exceed 20 % of the a.c. component.

When making single-phase tests on one pole of a three-pole circuit-breaker, or when the characteristics of the test plant are such that it is impossible to carry out test-duty T100s within the specified limits of applied voltage in 6.104.1, making current in 6.104.2, breaking current in 6.104.3 and transient and power frequency recovery voltages in 6.104.5.2 and 6.104.7 taking account also of 6.105.3 and 6.105.4 the making and breaking tests in test-duty T100s may be made separately. The short-circuit current in the separate making operations shall be maintained for an interval of at least 100 ms. The test procedures are as follows.

6.106.4.1 Time constant of the d.c. component of the test circuit equal to the specified value

Where the time constant of the d.c. component of the test circuit is equal to the specified value as defined by 4.101.2, the alternative for performing test-duty T100s described above is as follows:

a) making tests, test-duty T100s(a)

The sequence C – *t*' – C or C – *t*'' – C shall be carried out for the rated operating sequence O – *t* – CO – *t*' – CO or CO – *t*'' – CO respectively, with the first closing operation against a symmetrical current equal to the rated short-circuit breaking current and the second closing operation against the rated short-circuit making current according to 6.104.2. The first closing operation shall be carried out at the applied voltage specified in 6.104.1;

b) breaking tests, test-duty T100s(b)

These closing operations detailed in a) shall be followed by O – *t* – CO – *t*' – CO or CO – *t*'' – CO for the rated operating sequence O – *t* – CO – *t*' – CO or CO – *t*'' – CO respectively, at 100 % of the rated short-circuit breaking current and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7.

During this test sequence, the following applies:

– no maintenance is allowed between a) and b);

– the second closing operation of a) can be omitted, provided that during b) one of the closing operations is such that the rated short-circuit making current is achieved;

– for synthetic testing IEC 62271-101 applies.

6.106.4.2 Time constant of the d.c. component of the test circuit less than the specified value

Where the time constant of the d.c. component of the test circuit is less than the specified value as defined by 4.101.2, the alternative for performing test-duty T100s described above is as follows:

a) making tests, test-duty T100s(a)

A single closing operation against the rated short-circuit making current according to 6.104.2 shall be performed. This closing operation may be performed at reduced voltage with the limitations stated in 6.104.2;

b) breaking tests, test-duty T100s(b)

This closing operation shall be followed by O – *t* – CO – *t*' – CO or CO – *t*'' – CO for the rated operating sequence O – *t* – CO – *t*' – CO or CO – *t*'' – CO respectively, at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 6.104.1 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. In this second part, one of the closing operations shall be such that it closes against a symmetrical current equal to the rated short-circuit breaking current.

NOTE Due to the smaller time constant of the d.c. component of the test circuit with respect to the specified value used for the rated short-circuit breaking current, the symmetrical value of the current during a) will need to be greater than the rated value. During b), for the same reason, the current peak, already demonstrated during a), will be smaller than the rated short-circuit making current.

During this test sequence the following applies:

– no maintenance is allowed between a) and b);
– for synthetic testing IEC 62271-101 applies.

6.106.4.3 Time constant of the d.c. component of the test circuit greater than the specified value

Where the time constant of the d.c. component of the test circuit is greater than the specified value as defined by 4.101.2, the alternative for performing test-duty T100s described above is as follows:

a) The sequence O – *t* – CO – *t*' – CO or CO – *t*'' – CO shall be carried out for rated operating sequence O – *t* – CO – *t*' – CO or CO – *t*'' – CO respectively, at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 6.104.1 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. During this sequence, one of the closing operations shall be such that the circuit-breaker closes against a symmetrical current equal to the rated short-circuit breaking current, and the other one against a full asymmetrical current. Due to the larger time constant of the d.c. component of the test circuit with respect to the specified value as per 4.101.2, the current peak during the asymmetrical closing will be larger than the rated short-circuit making current. Therefore, the closing operation may be controlled by use of point on wave control to obtain the required rated short-circuit making current. The performance of the test procedure a) is, however, subject to the consent of the manufacturer;

NOTE 1 Because of the larger peak of the current during the asymmetrical closing, a separate closing operation against the rated short-circuit making current according to 6.104.2 is not required.

b) Alternatively the above sequence a) can be performed with the first closing operation against a symmetrical current equal to the rated short-circuit breaking current and the second closing operation at no load, i.e. O – *t* – CO – *t*' – O or CO – *t*'' – O for the rated operating sequence O – *t* – CO – *t*' – CO or CO – *t*'' – CO respectively, at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 6.104.1 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7.

   In this case evidence of the ability of the circuit-breaker to perform the rated operating sequence will be demonstrated by repeating the test sequence a), with relevant requirements, and with a symmetrical current smaller than the rated short-circuit breaking current in such a manner that the rated short-circuit making current is obtained in one of the closing operations. During this repeated duty, the closing operations may be performed at reduced voltage with the limitations stated in 6.104.2.

NOTE 2 Since the ability of the circuit-breaker to close against the rated short-circuit making current is proven during the repeated duty, a separate closing operation against the rated short-circuit making current according to 6.104.2 is not required.

During this test sequence the following applies:

– where sequence b) is adopted, maintenance before repetition of the rated operating sequence is permitted;
– for synthetic testing IEC 62271-101 applies.

6.106.4.4 Significant decay of the a.c. component of the test circuit

Where the decay of the a.c. component of the test circuit is significant, it may be impossible to test the rated operating sequence without overstressing the circuit-breaker extensively. In such cases it is permitted to split the making and the breaking tests in test-duty T100s as follows, providing that the time constant of the a.c. component of the test circuit, corresponding to the decay of the a.c. component, is at least three times longer than the specified d.c. time constant of the system the circuit-breaker under test is intended to be used for:

a) Making tests, test-duty T100s(a)

C – *t*' – C in case of a rated operating sequence O – *t* – CO – *t*' – CO,

C – *t*'' – C in case of a rated operating sequence CO – *t*'' – CO

with the making current as specified in 6.104.2 and the applied voltage as specified in 6.104.1. For the time interval between the individual tests 6.105.1 applies.

b) Breaking tests, test-duty T100s(b)

The testing procedure depends upon the rated operating sequence.

– In case of a rated operating sequence O – *t* – CO – *t*' – CO, the closing operations of test-duty T100s(a) shall be followed by the testing sequence O – *t* – CO – *t*' – CO at 100 % of the rated short-circuit breaking current as specified in 6.104.3 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. For the time interval between the individual tests 6.105.1 applies.

  The operating sequence O – *t* – CO (initial part of the rated operating sequence O – *t* – CO – *t*' – CO) may be demonstrated by two tests. In this case the following applies:

  In the first test the first opening operation shall be tested at 100 % of the rated short-circuit breaking current as specified in 6.104.3 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. The subsequent closing and opening operations shall be tested with making current and applied voltage or breaking current and transient and power frequency recovery voltage respectively as close as possible to the values specified for test-duty T100s.

  In the second test an additional CO operating cycle shall be performed with the opening operation at 100 % of the rated short-circuit current as specified in 6.104.3 and with the transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. This CO operating cycle shall be preceded by a no-load opening operation to complete the operating sequence O – *t* – CO. For the C operation the provisions of 6.104.1 and 6.104.2 may be omitted, however, the making current and the applied voltage shall meet the specified values as close as possible.

  The operating cycle CO (last part of the rated operating sequence O – *t* – CO – *t*' – CO) is demonstrated by another CO operation where the opening operation shall be performed at 100 % of the rated short-circuit current as specified in 6.104.3 and with the transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. For the C operation the provisions of 6.104.1 and 6.104.2 may be omitted, however, the making current and the applied voltage shall meet the specified values as close as possible.

– In case of a rated operating sequence CO – *t*'' – CO the closing operations of test-duty T100s(a) shall be followed by the testing sequence CO – *t*'' – CO at 100 % of the rated short-circuit breaking current as specified in 6.104.3 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. For the time interval between the individual tests 6.105.1 applies. For the two C operations the provisions of 6.104.1 and 6.104.2 may be omitted, however, the making current and the applied voltage shall meet the specified values as close as possible.

– Where a closing operation in test-duty T100s(b) fulfils the requirements given in a) above, the respective closing operation in test-duty T100s(a) may be omitted. In order to not overstress the circuit-breaker controlled closing may be necessary in test-duty T100s(b). Where needed an auxiliary circuit-breaker may be used. If due to inconsistency of the opening or the closing time the specified test values cannot be met, it is allowed to supply the releases at their maximum operating voltage; in this case the provisions of 6.102.3.1 as to the supply voltage of closing and opening devices are omitted.

No maintenance is allowed between the test-duties T100s(a) and T100s(b). When this testing procedure results in actual stresses exceeding the limits specified in Table B.1 the consent of the manufacturer is necessary.

6.106.5 Test-duty T100a

Test-duty T100a is only applicable when the minimum opening time T_{op} of the circuit-breaker, as stated by the manufacturer, plus the relay time is such that the d.c. component at the instant of contact separation is greater than 20 %. The d.c. component at contact separation is determined by the following equation:

$$\%\,\mathrm{dc} = 100 \times \mathrm{e}^{\frac{-(T_{op}+T_r)}{\tau}}$$

where

% dc	percentage of d.c. component at contact separation;
T_{op}	minimum opening time declared by the manufacturer;
T_r	relay time (0,5 cycle; 10 ms for 50 Hz and 8,3 ms for 60 Hz);
τ	d.c. time constant of the rated short circuit current (45 ms, 60 ms, 75 ms or 120 ms; see 4.101.2).

Test-duty T100a consists of three opening operations at intervals t' in accordance with 6.105.1 at 100 % of the rated short-circuit breaking current with the required asymmetry criteria given in 6.106.6 and the prospective transient and power frequency recovery voltages as specified in 6.104.5.2 and 6.104.7 (see also 6.104.6 and Annex P; for table references see 6.104.5.2).

Moreover, depending on the actual test parameters, an individual test may cover several ratings if the applicable asymmetry criteria for each rating with their associated tolerances are met (for details see I.2.1).

NOTE The change of an opening or a closing release does not constitute an alternative operating mechanism. If the opening time of the circuit-breaker is reduced due exclusively, to the use of a faster acting release, it should be checked whether the percentage of the d.c. component, stated in Tables 15 through 22 for this release, is still covered by the actual tests. If a higher percentage of the d.c. component is needed, it is sufficient to repeat test-duty T100a only, the rest of the type tests remains valid, provided the release is tested to the relevant subclauses and standards.

6.106.6 Asymmetry criteria

The following asymmetry criteria shall be fulfilled when performing T100a.

- last current loop amplitude;
- last current loop duration;
- d.c. component at current zero (parameter controlling the di/dt and the following TRV parameters).

Several test parameters shall be simultaneously reproduced during T100a in order to obtain a valid interruption. These criteria are different depending on, whether the tests are performed with a direct test circuit or with a synthetic test method.

The prospective percentage of d.c. component at current zero shall be either:

- measured from a prospective current calibration test or;
- calculated from the percentage of d.c. component at contact separation during the test and from the d.c. time constant of the test circuit. The d.c. time constant of the test circuit shall be measured from the oscillogram of a prospective current calibration test in the region corresponding to the instant of contact separation.

The instant of initiation of the short-circuit during the actual tests and during the prospective current calibration test shall be comparable (within ±10°).

For the prospective current calibration test, it is necessary to extend the duration of the current by at least an extra current loop in order to be able to measure accurately the prospective d.c. component at the predicted current zero.

NOTE The percentage of d.c. component at current zero during actual tests can also be calculated by the following equation:

$$p_0 = p_{cs} \times e^{\left(-\frac{t_a}{\tau}\right)}$$

where

p_0 is the d.c. component at current zero during the actual test;

p_{cs} is the d.c. component at contact separation measured during the actual test;

t_a is the arcing time;

τ is the d.c. time constant of the test circuit measured during the prospective current calibration test.

The applicable asymmetry criteria for each particular test method are described in 6.106.6.1 and 6.106.6.2.

6.106.6.1 Three-phase tests

6.106.6.1.1 Test current amplitude and last current loop duration

The criteria given in 6.102.10.2.1.2 b) for single-phase tests apply also to the phase having the maximum d.c. component (major loop or extended major loop). The resultant amplitude and duration of the current loops in the other two phases are automatically met within reasonable tolerances.

NOTE The prospective duration of the extended major loop should be determined from the prospective current calibration test. The duration of the major current loop during the prospective current calibration test that will be extended during the actual breaking test should be within the limits given in 6.102.10.2.1.2 b). If the duration of that loop meets the criteria given in 6.102.10.2.1.2 b) then the duration of the extended major loop during the actual breaking test is automatically met within reasonable tolerances.

The circuit-breaker may modify the last current loop shape beyond the criteria given in 6.102.10.2.1.2 b). In such cases, the prospective current loop shape shall be determined from a previous prospective current calibration test. The test is considered to be valid if the moment of current initiation is within ±10° of that obtained during the prospective current calibration test.

6.106.6.1.2 Percentage of d.c. component at current zero

The percentage of the d.c. component at current zero for the phase having the highest d.c. component shall be equal to or less than (see Note 1) those given in Tables 15 through 22. The resultant d.c. component in the two other phases are automatically met.

For the current calibration test, it is recommended to extend the duration of the current by at least an extra current loop in order to be able to measure accurately the prospective d.c. component at the predicted current zero.

If the percentage of the d.c. component at current zero in one opening operation is higher (see Note 1) than the specified value, the circuit-breaker should be considered to have satisfied test-duty T100a provided that the average of the percentage of d.c. component at current zero of the opening operations of the test-duty does not exceed the specified percentage of the d.c. component at current zero. In any one test of the test-duty, the d.c. component at current zero shall not be higher than 110 % of the specified value.

NOTE 1 The d.c. component at current zero is controlling the resultant di/dt and TRV. A lower d.c. component at current zero gives higher di/dt and higher TRV amplitude and du/dt. A tolerance of –5 % is given in Annex B.

NOTE 2 The d.c. component at current zero can be difficult to be measured with sufficient accuracy since the circuit-breaker may modify the last loop current shape. The d.c. component at current zero can be determined with the results obtained from a previous prospective current calibration test. The test is considered to be valid if the moment of current initiation is within ±10° of that obtained during the prospective current calibration test.

6.106.6.2 Single-phase tests

6.106.6.2.1 Test current amplitude and last current loop duration

The criteria given in 6.102.10.2.1.2 b) shall be met.

The circuit-breaker may modify the last current loop shape beyond the criteria given in 6.102.10.2.1.2 b). In such cases, the prospective current loop shape shall be determined from a previous prospective current calibration test. The test is considered to be valid if the moment of current initiation is within ±10° of that obtained during the prospective current calibration test.

6.106.6.2.2 Percentage of the d.c. component at current zero

The percentage of the d.c. component at current zero shall be equal to or less than (see Note 1) those given in Tables 15 through 22.

If the percentage of d.c. component at current zero in one opening operation is higher (see Note 1) than the specified value, the circuit-breaker shall be considered to have satisfied test-duty T100a provided that the average of the percentage of the d.c. component at current zero of the opening operations of the test-duty does not exceed the specified percentage of the d.c. component at current zero. In any one test of the test-duty, the asymmetrical level at current zero shall not be higher than 110 % of the specified value.

NOTE 1 The d.c. component at current zero is controlling the resultant di/dt and TRV. A lower d.c. component at current zero gives higher di/dt and higher TRV amplitude and du/dt. A tolerance of –5 % is given in Annex B.

NOTE 2 The d.c. component at current zero can be difficult to be measured with sufficient accuracy since the circuit-breaker may modify the last loop current shape. The d.c. component at current zero can be determined with the results obtained from a previous prospective current calibration test. The test is considered to be valid if the moment of current initiation is within ±10° of that obtained during the prospective current calibration test.

6.106.6.3 Adjustment measures

Several test parameters may be modified in order to fulfil the asymmetry criteria. For example:

a) The amplitude and the duration of the last current loop may be adjusted by several means like:
   – by increasing or decreasing the r.m.s. value of the short-circuit test current (within ±10 % of the required value);
   – by changing the frequency of the test current within the tolerances given in 6.103.2;
   – by using pre-tripping or delayed tripping; pre-tripping being only allowed if the contact system starts to move after current initiation;

NOTE 1 Pre-tripping is defined to be the energisation of the opening release before what is expected in service conditions (before the minimum relay time: 0,5 cycle). Pre-tripping may mean that the energisation of the opening release is done before current initiation. This is permissible only if the contact system starts to move after current initiation.

NOTE 2 Delayed tripping is defined to be the energisation of the opening release after what is expected in service conditions (after the minimum relay time: 0,5 cycle).

   - by changing the instant of current initiation (initial d.c. component).

b) The TRV parameters may be compensated by changing the amplitude factor of the TRV shaping circuit. Annex P is giving the calculation method for the determination of the applicable prospective TRV parameters under asymmetrical fault conditions.

6.107 Critical current tests

6.107.1 Applicability

These tests are short-circuit tests additional to the basic short-circuit test-duties covered by 6.106 and are applicable only to circuit-breakers which have a critical current. It shall be assumed that this is the case if the minimum arcing times in any of the test-duties T10, T30 or T60 is one half-cycle or more longer than the minimum arcing times in the adjacent test-duties. For three-phase tests the arcing times of all three phases shall be taken into account.

6.107.2 Test current

Where applicable, the behaviour of the circuit-breaker with respect to the critical current shall be tested in two test-duties.

The test currents for these two test-duties shall be equal to the average of the breaking current corresponding to the test-duty in which the prolonged arcing times occurred (see 6.107.1) and:

a) the breaking current corresponding to the next higher breaking current for one test-duty; and

b) the breaking current corresponding to the next lower breaking current for the other test-duty.

In the case of prolonged arcing times in test-duty T10, the critical current tests shall be performed at a current of 20 % of the rated short-circuit breaking current for one test-duty and at a current of 5 % of the rated short-circuit breaking current for the other one.

6.107.3 Critical current test-duty

The critical current test-duty consists of the rated operating sequence at the current according to 6.107.2 with a d.c. component at contact separation less than 20 %. The transient and power frequency recovery voltage shall be that associated with the basic short-circuit test-duty having the breaking current the next higher to the critical current.

The critical current test-duty may be performed on a reconditioned circuit-breaker.

6.108 Single-phase and double-earth fault tests

6.108.1 Applicability

Circuit-breakers shall be capable of clearing single-phase short-circuit currents which may occur in two different cases:

– in effectively earthed neutral systems in case of single-phase faults or,

– in non-effectively earthed neutral systems in case of double earth faults, i.e. earth faults on two different phases, one of which occurs on one side of the circuit-breaker and the other one on the other side.

Depending on the neutral earthing condition of the system in which the circuit-breaker is intended to be used, on the circuit-breaker operating mechanism design (single-pole or three-pole operated) and on whether the circuit-breaker was tested single-phase or three-phase in test-duty T100s, additional single-phase breaking tests may be necessary (see Figure 45).

These tests are intended to demonstrate

– that the circuit-breaker is able to clear a single-phase fault current at relevant parameters;
– for circuit-breakers having a common operating mechanism for all three poles and being fitted with a common opening release, that the operation of the circuit-breaker is not adversely affected by unbalanced forces produced in the case of a single-phase fault current.

The test for single-phase fault shall be performed on an outer pole resulting in the maximum stress on the inter-pole coupling mechanism, while the test for double earth fault can be performed on any pole.

NOTE If two single-phase tests are carried out on a circuit-breaker with a three-pole common operating mechanism, the test may be carried out on two different poles to prevent overstressing of one pole.

6.108.2 Test current and recovery voltage

The breaking current and the recovery voltage for the additional single-phase breaking tests are as shown in Figure 45.

The d.c. component of the breaking current at contact separation shall not exceed 20 % of the a.c. component. The transient recovery voltage shall meet the requirements of Items a) and b) of 6.104.5.1 with standard values derived from Tables 1, 2, 3 and 4. The values to be used for single-phase and double earth fault tests are given in Table 28 marked by the index (sp).

Table 28 – TRV parameters for single-phase and double earth fault tests

System neutral	**Rated voltage**					
	U_r < 100 kV 2-parameter-TRV		**$U_r \geq$ 100 kV 4-parameter-TRV**			
	$u_{c,sp}$	$t_{3,sp}$	$u_{1,sp}$	$t_{1,sp}$	$u_{c,sp}$	$t_{2,sp}$
Effectively earthed	$k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$t_3 \times u_{c,sp} / u_c$	$0{,}75 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$t_1 \times u_{1,sp} / u_1$	$k_{af} \times u_{1,sp} / 0{,}75$	~~$4 \times t_{1,sp}$~~ [a]
Non-effectively earthed	$k_{af} \times \sqrt{2} \times U_r$		$0{,}75 \times \sqrt{2} \times U_r$			

[a] $4 \times t_{1,\ sp}$ for rated voltages from 100 kV up to and including 800 kV $3 \times t_{1,\ sp}$ for rated voltages above 800 kV.

The other parameters are related to $u_{1,sp}$, $u_{c,sp}$, $t_{1,sp}$ and $t_{3,sp}$ as defined in 6.104.5.1 for test-duty T100. Where necessary, advantage may be taken of the provisions of 6.104.5.2 concerning test plant limitations.

6.108.3 Test-duty

The test-duty for each of the two specified fault cases shall consist of one single breaking operation.

The arcing time during the breaking operation shall not be shorter than the following value t_a:

$$t_a \geq t_{a100s} + 0{,}7 \times T/2$$

where

t_{a100s} – is the minimum of the arcing times of first-poles-to-clear during the three breaking operations of test-duty T100s, if terminal fault test-duty T100s is tested in three-phase;

– is the minimum arcing time of terminal fault test-duty T100s, if terminal fault test-duty T100s is tested in single-phase.

T is the duration of one period of power frequency

If the minimum arcing time under the conditions of single-phase or double-earth fault tests is shorter than the minimum arcing time of terminal fault test-duty T100s by more than 0,1 × T, the test may be carried out at a shorter arcing time based on the following equation:

$$t_a \geq t_{\text{arc min single phase}} + 0{,}9 \times T/2$$

where

$t_{\text{arc min single phase}}$ is the minimum arcing time under the conditions of single-phase or double-earth fault tests;

T is the duration of one period of power frequency.

NOTE It is not necessary to determine the minimum arcing time for single-phase or double-earth fault breaking tests. However, the manufacturer may show that under these conditions a shorter minimum arcing time than for T100s is achievable. Then testing may be done, as shown above, with this shorter minimum arcing time.

To reduce the amount of testing, it is allowed to replace the two applicable tests by one test, provided that both test conditions are met simultaneously. This allowance is permitted only with the consent of the manufacturer.

6.109 Short-line fault tests

6.109.1 Applicability

Short-line fault tests are short-circuit tests additional to the basic short-circuit test-duties covered by 6.106. These tests shall be made to determine the ability of a circuit-breaker to break short-circuit currents under short-line fault conditions characterised by a transient recovery voltage as a combination of the source and the line side components.

~~Short-line fault tests are applicable only to class S2 circuit-breakers designed for direct connection to overhead lines, irrespective of the type of network on the source side, having a rated voltage of 15 kV and above and a rated short-circuit breaking current exceeding 12,5 kA.~~

Short-line faults tests are required for class S2 circuit-breakers designed for direct connection to overhead lines, irrespective of the type of network on the source side, having a rated voltage equal or higher than 15 kV and less than 100 kV and a rated short-circuit breaking current exceeding 12,5 kA. Short-line faults tests are also required for all circuit-breakers designed for direct connection to overhead lines having a rated voltage of 100 kV and above and a rated short-circuit breaking current exceeding 12,5 kA.

6.109.2 Test current

The test current shall take into account the source and line side impedances. The source side impedance shall be that corresponding to approximately 100 % rated short-circuit breaking current I_{sc} and the phase-to-earth value of the rated voltage U_r.

Standard values of the line side impedance are specified corresponding to a reduction of the a.c. component of the rated short-circuit breaking current to:

– 90 % (L_{90}) and 75 % (L_{75}) for circuit-breakers with a rated voltage equal to or higher than 48,3 kV,

– 75 % (L_{75}) for circuit-breakers with a rated voltage 15 kV and above and less than 48,3 kV.

In a test, the line length represented on the line side of a circuit-breaker may differ from the length of the line corresponding to currents equal to 90 % and 75 % of the rated short-circuit breaking current.

For rated voltages equal or higher than 48,3 kV, tolerances on these standardised lengths are –20 % and 0 % for tests at 90 % of the rated short-circuit breaking current and ±20 % for tests at 75 % of the rated short-circuit breaking current.

For rated voltages equal and higher than 15 kV and less than 48,3 kV, tolerances on these standardised lengths are 0 % and –20 % for tests at 75 % of the rated short-circuit breaking current.

These tolerances for the line lengths give the following deviations of the short-circuit currents:

- L_{90} at 0 % deviation: I_L = 90 % of I_{sc};
- L_{90} at –20 % deviation: I_L = 92 % of I_{sc};
- L_{75} at +20 % deviation: I_L = 71 % of I_{sc};
- L_{75} at 0 % deviation: I_L = 75 % of I_{sc};
- L_{75} at –20 % deviation: I_L = 79 % of I_{sc}.

For the case stated in 6.109.4, item c) another test (L_{60}) at 60 % of the rated short-circuit breaking current is required. The tolerance on the corresponding standardised line length is ±20 %. This results in the following deviations of the short-circuit current:

- L_{60} at +20 % deviation: I_L = 55 % of I_{sc};
- L_{60} at –20 % deviation: I_L = 65 % of I_{sc}.

For further information see Annex J and Clause L.3.

6.109.3 Test circuit

The test circuit shall be single-phase and consists of a supply circuit and a line circuit (see Figures 46, 47 and 48). The basic requirements are given in 4.105.

Regarding the time delays on the source side and on the line side and the ITRV (see 4.102.1), two main requirements are specified and shall be distinguished:

a) source side: with time delay (t_d) and without ITRV;
   line side: with time delay (t_{dL});

b1) source side: with ITRV;
   line side: with time delay (t_{dL});

b2) source side: with time delay (t_d);
   line side: with ~~insignificant~~ a time delay less than 100 ns (t_{dL}).

~~The representation of the ITRV on the source side can be neglected if a line side oscillation without a time delay is used (see 6.104.5.2). A line side time delay not greater than 100 ns is considered as an insignificant time delay.~~

The representation of the ITRV on the source side can be neglected if a line side oscillation with a time delay less than 100 ns is used.

Figure 16b shows the determination of the line side time delay in case of a non-linear rate of rise. The tangent on the line-side TRV drawn in parallel to the line through $0{,}2\times u_L$ and $0{,}8\times u_L$ crosses the zero line at a time t_{dL}.

~~NOTE 1 If no ITRV on the source side and insignificant time delay on the line side is used, within the specified limits yet close to 100 ns, depending on the ratings of the circuit-breaker the voltage across the circuit-breaker at the time t_L may be lower to some extent than in the case of the source side with ITRV and the line side with time delay.~~

NOTE 1 (Void)

Taking this into account, three types of test circuits characterised by their time delays are applicable for testing:

– circuit SLF a): source side with time delay (t_d) and line side with time delay (t_{dL}) (see A.4.1); circuit shown in Figure 46;
– circuit SLF b1): source side with ITRV and line side with time delay (t_{dL}) (see A.4.2); circuit shown in Figure 47;
– circuit SLF b2): source side with time delay (t_d) and line side with ~~insignificant~~ a time delay less than 100 ns (t_{dL}) (see A.4.3); circuit shown in Figure 48.

Circuit a) shall only be used in the case where no ITRV requirements apply. Circuit b2) can be used as a substitute for the circuit b1) unless both terminals are not identical from an electrical point of view (for instance where an additional capacitance is used as mentioned in Note 4 of 6.109.3).

For the choice of test circuit, see flow chart diagram, Figure 49.

Other characteristics of the source side and the line side of the test circuit shall be in line with the explanations and calculations given in Annex A.

Where applicable, a circuit-breaker with rated voltage higher than 800 kV can be tested with a line having a time delay less than 100 ns and a surge impedance of 450 Ω (see 6.104.5.1). If the circuit-breaker fails during this test procedure after a time corresponding to the first peak of ITRV, the test can be repeated with the required test circuit having the specified ITRV and a line having a surge impedance of 330 Ω and the specified time delay (t_{dL}). For both cases it is not required to perform T100s and T100a with circuits reproducing the rated ITRV.

If the TRV requirements of the source side cannot be met due to testing station limitations, a deficiency of the time delay of the source side TRV can be compensated by an increase of the excursion of the line side voltage. The increased value $u_{L,mod}^*$ is calculated as follows (see also Figure 16 and Figure 50):

$$t_d < t'_d \leq t_L \qquad u_{L,mod}^* = u_L^* + L_f \times \mathrm{RRRV} \times (t'_d - t_d)$$

$$t_d < t_L \leq t'_d \qquad u_{L,mod}^* = u_L^* + L_f \times \mathrm{RRRV} \times (t_L - t_d)$$

where

RRRV is the required rate of rise of recovery voltage of the source side (kV/µs);

L_f is the SLF current factor I_L/I_{sc} (0,9 or 0,75 or 0,6);

t_d is the required time delay of the source side (µs);

t'_d is the actual time delay of the source side (µs);

t_L is the time to the peak voltage u_L^* of the line side transient voltage (µs);

u_L^* is the required peak voltage across the line (kV);

$u_{L,mod}^*$ is the adjusted peak voltage across the line (kV).

If the tests are carried out on a circuit-breaker with one terminal earthed, as may be the case during synthetic testing, measurements or calculations of voltage distribution factors of line and source side oscillations shall be carried out. The higher stressed unit from the line side oscillation is the lower stressed unit from the source side oscillation. It is recognised that the more significant stress is due to the line. The voltage distribution factors shall be as follows:

– unit tests: factors calculated or measured on the line side unit;
– multi-unit tests: factors calculated or measured on the multi-unit next to the line-side. Attention should be paid that the factors to be applied do not overstress the circuit-breaker because of the voltage distribution within the multi-unit. A new measurement or calculation may be required for the portion to be tested.

The measurement of the prospective TRV shall be carried out with the line connected to the actual circuit in order to take into account all the effects due to voltage dividers, stray capacitances and inductances of the test circuit.

An extra capacitance may be applied at the line side or at the source side of the circuit-breaker or across the circuit-breaker in order to adjust the time delays of the individual sections of the test circuit.

NOTE 2 The term 'actual' is used as distinct from the nominal value (90 %, 75 % or 60 %); the use of prospective short-circuit breaking current in accordance with 6.104.3 is not precluded.

NOTE 3 If an extra capacitance is applied in order to adjust the time delay of the line to the standard value given in Table 8, the rate of rise of the line side TRV will reach its standard value ($du_L/dt = - s \times I_L$) after the decay of the delaying effect of this extra capacitance.

NOTE 4 Where the breaking capability of the circuit-breaker is not sufficient to interrupt a short-line fault, an additional capacitance at the line side of the circuit-breaker or parallel to the breaking unit(s) may be used, both during the test and in service. In this way, the stress on the circuit-breaker is facilitated. The value and the location of this additional capacitance used during the tests should be stated in the test report.

For a large additional capacitance, the surge impedance of the line and the line side time delay may seem to be reduced, caused by the effect of this additional capacitance. However, the correct value of the surge impedance of the line itself (in advance adjusted in accordance with the standard values given in Table 8) remains unchanged. Since the period of the decay of the delaying effect of the additional capacitance may be longer than the time to the first peak of the line side TRV, the lower rate of rise at the rising slope of the TRV may be misinterpreted as a decreased surge impedance of the line. Therefore, the values of the time delay and the surge impedance evaluated for the line in connection with the additional capacitance are not relevant to the test.

The test report should show the specified transient recovery voltage appropriate to the rating of the circuit-breaker, and, for comparative purposes, the prospective transient recovery voltage of the test circuit used.

6.109.4 Test-duties

The short-line fault tests shall be single-phase tests. The series of test-duties is specified below. Each test-duty consists of the rated operating sequence. For convenience of testing, the closing operations may be performed as no-load operations.

The test circuit shall be in accordance with 6.109.3.

For these test-duties, the percentage d.c. component at the instant of contact separation shall be less than 20 % of the a.c. component.

The test-duties related to test currents according to 6.109.2 are as follows:

Test-duty L_{90}

a) At the current for L_{90} given in 6.109.2 and the appropriate prospective transient recovery voltage.

   This test duty is only mandatory for circuit-breakers with a rated voltage equal to or higher than 48,3 kV.

b) Test-duty L_{75}

At the current for L_{75} given in 6.109.2 and the appropriate prospective transient recovery voltage.

c) Test-duty L_{60}

At the current for L_{60} given in 6.109.2 and the appropriate prospective transient recovery voltage.

This test-duty is mandatory only for circuit-breakers with a rated voltage equal to or higher than 48,3 kV and only if the minimum arcing time obtained during test-duty L_{75} is a quarter of a cycle or more longer than the minimum arcing time determined during test-duty L_{90}.

6.109.5 Short-line fault tests with a test supply of limited power

When the maximum short-circuit power available at a testing plant is not sufficient to make the short-line fault tests on a complete pole of a circuit-breaker, it may be possible to make unit tests (see 6.102.4.2).

Short-line fault tests may also be made at reduced power frequency voltage, the provisions of 6.109.3 being relaxed. These provisions shall be met as well as possible and, for the transient recovery voltage at least up to three times the specified time of the first line side peak. This method is used if the basic short-circuit tests in 6.106 have been satisfactory, it being assumed that the dielectric strength of the circuit-breaker near the peak value of transient recovery voltage is independent of stresses applied immediately after current zero. The test method may also be used in combination with unit tests.

If short-line fault tests are performed at reduced power frequency voltage and in any one short-line fault test-duty the maximum arcing time according to 6.102.10.2.2.1 is more than 2 ms longer than the maximum arcing time achieved in test-duty T100s, a single opening operation with the maximum arcing time achieved in the short-line fault tests shall be performed, applying the test conditions of terminal fault T100s. The TRV parameters for this additional operation may be reduced to values corresponding to a first-pole-to-clear factor 1,0, as usual for short-line fault testing. The circuit-breaker is considered to have passed the short-line fault test only, if the current is interrupted successfully in this additional opening operation.

6.110 Out-of-phase making and breaking tests

6.110.1 Test circuit

The power factor of the test circuit shall not exceed 0,15.

Usually the tests are carried out in a single-phase test circuit. This subclause therefore concerns single-phase test procedures only.

NOTE Instead of single-phase tests, three-phase tests are permissible. Where three-phase tests are performed, the test procedure should be agreed upon between the manufacturer and user.

The test circuit should be so arranged that approximately one half of the applied voltage and of the recovery voltage is on each side of the circuit-breaker (see Figure 51).

If it is not practicable to use this circuit in the testing station, it is permissible, with the agreement of the manufacturer, to use two identical voltages separated in phase by 120° instead of 180°, provided that the total voltage across the circuit-breaker is as stated in 6.110.2 (see Figure 52).

Tests with one terminal of the circuit-breaker earthed are permissible, with the agreement of the manufacturer (see Figure 53).

6.110.2 Test voltage

For the test voltages used during closing and opening operations the following applies:

a) for circuit-breakers intended to be used in effectively earthed neutral systems the applied voltage and the power frequency recovery voltage shall have a value of 2,0/√3 times the rated voltage;

b) for circuit-breakers intended to be used in non-effectively earthed neutral systems the applied voltage during the closing operation shall have a value of 2,0/√3 times the rated voltage and the power frequency recovery voltage shall have a value of 2,5/√3 times the rated voltage.

The transient recovery voltage shall be in accordance with 4.106.

6.110.3 Test-duties

The test-duties to be made are indicated in Table 29. For arcing times see 6.102.10.2.1 and 6.102.10.2.2.

For the opening operation of each test-duty, the d.c. component of the breaking current at contact separation shall be less than 20 % of the a.c. component.

For the closing operation of the close-open cycle of test-duty OP2:

a) the applied voltage shall be $2U_r/\sqrt{3}$; for convenience of testing the applied voltage for circuit-breakers intended to be used in non-effectively earthed neutral systems may be increased with the agreement of the manufacturer to $2{,}5U_r/\sqrt{3}$.

NOTE 1 A power frequency voltage of 2,0 p.u. is specified for closing as it is the highest value the first-pole-to-close (which is stressed by the longest pre-arcing time) is normally exposed to.

~~NOTE 2 Power frequency voltages of 2,0 p.u. and 2.5 p.u. are specified for breaking, respectively, in effectively earthed neutral systems and non-effectively earthed neutral systems, as they cater to the great majority of applications of circuit-breakers intended for switching during out-of-phase conditions (see 8.103.3). The out-of-phase angle corresponding to 2,0 p.u. in effectively earthed neutral systems is approximately 105°, and the out-of-phase angle corresponding to 2,5 p.u. in non-effectively earthed neutral systems is approximately 115°.~~

NOTE 2 Power frequency recovery voltages corresponding to out-of-phase voltage factors of 2,0 p.u. and 2,5 p.u. are specified for breaking, respectively, in effectively earthed neutral systems and non-effectively earthed neutral systems, as they cater to the great majority of applications of circuit-breakers intended for switching during out-of-phase conditions (see 8.103.3). The out-of-phase angle corresponding to 2,0 p.u. in effectively earthed neutral systems is approximately 105° for rated voltages up to 800 kV and approximately 115° for rated voltages higher than 800 kV The out-of-phase angle corresponding to 2,5 p.u. in non-effectively earthed neutral systems is approximately 115°. However higher values of angle are covered when considering other factors such as the non simultaneity of voltage peaks, lower k_{pp} (see IEC 62271-306 [4]).

b) the making shall occur within ± 15° of the peak of the applied voltage.

c) the making shall produce a symmetrical current with the longest pre-arcing time. The making current shall be equal to the rated out-of-phase making current.

   1) if the pre-arcing time when making at the peak of the applied voltage is shorter than or equal to half a cycle of the rated frequency, then the making current may be reduced to any smaller value, but not less than 1 kA;

   2) if the pre-arcing time when making at the peak of the applied voltage does not exceed ¼ cycle of power frequency with a tolerance of 20 %, due to possible limitations of the testing facilities it is allowed to replace the CO operating cycle of OP2 by the following sequence:

      – C at full voltage;

      – CO with C at no load.

Table 29 – Test-duties to demonstrate the out-of-phase rating

Test-duty	Operating sequence	Breaking current in per cent of the rated out-of-phase breaking current
OP1	O – O – O	30
OP2	CO – O – O or alternatively C* – C**O – O – O C* = C at full voltage C** = C at no-load	100
NOTE 1 For circuit-breakers fitted with closing resistors, the thermal capability of the closing resistors may be tested separately. NOTE 2 Test-duty OP1 may be omitted for those circuit-breakers whose arcing characteristics are such that critical current tests according to 6.107.1 at a current level lower than that one associated with terminal fault T10 are not required.		

6.111 Capacitive current switching tests

6.111.1 Applicability

Capacitive current switching tests are applicable to all circuit-breakers to which one or more of the following ratings have been assigned:

– rated line-charging breaking current;

– rated cable-charging breaking current;

– rated single-capacitor bank breaking current;

– rated back-to-back capacitor bank breaking current;

– rated back-to-back capacitor bank inrush making current.

Preferred values of rated capacitive switching currents are given in Table 9.

NOTE 1 The determination of overvoltages when switching capacitive currents is not covered by this standard.

NOTE 2 An explanatory note on capacitive current switching is given in I.4.

6.111.2 General

Re-ignitions during the capacitive current switching tests are permitted. Two classes of circuit-breakers are defined according to their restrike performances:

– class C1: low probability of restrike during capacitive current breaking as demonstrated by specific type tests (6.111.9.2);

– class C2: very low probability of restrike during capacitive current breaking as demonstrated by specific type tests (6.111.9.1).

NOTE 1 The probability is related to the performance during the series of type tests.

NOTE 2 Phenomena occurring after a restrike or a re-ignition event are not representative of service conditions as the test circuit does not adequately reproduce the post-event voltage conditions.

In laboratory tests the lines and cables may be partly or fully replaced by artificial circuits with lumped elements of capacitors, reactors or resistors.

The test circuit frequency shall be the rated frequency with a tolerance of ± 2 %.

NOTE 3 Tests at 60 Hz may be considered to prove the breaking characteristics at 50 Hz.

NOTE 4 Tests at 50 Hz may be considered to prove the characteristics at 60 Hz, provided that the voltage across the circuit-breaker is not less during the first 8,3 ms than it would be during a test at 60 Hz with the specified voltage. If restrikes occur after 8,3 ms, due to the instantaneous voltage being higher than it would be during a test at 60 Hz with the specified voltage, the test-duty should be repeated at 60 Hz.

NOTE 5 The specification of the circuits may be replaced by a specification of the recovery voltage.

6.111.3 Characteristics of supply circuits

The test circuit shall fulfil the following requirements:

a) the characteristics of the test circuit shall be such that the power frequency voltage variation, when switching, shall be less than 2 % for test-duty 1 (LC1, CC1 and BC1) and less than 5 % for test-duty 2 (LC2, CC2 and BC2). Where the voltage variation is higher than the values specified, it is alternatively permissible to perform tests with the specified recovery voltage (6.111.10) or synthetic tests;
b) the impedance of the supply circuit shall not be so low that its short-circuit current exceeds the rated short-circuit current of the circuit-breaker.

For line-charging, cable-charging or single capacitor bank current switching tests the prospective transient recovery voltage of the supply circuit shall be no more severe than the transient recovery voltage specified for short-circuit T100 in 6.104.5.2.

For back-to-back capacitor bank breaking current tests, the capacitance of the supply circuit and the impedance between the capacitors on the supply and load sides shall be such as to give the rated back-to-back capacitor bank inrush making current when testing with 100 % of the rated back-to-back capacitor bank breaking current.

NOTE 1 If a circuit-breaker is intended to be used in a system with appreciable lengths of cable on the supply side, a supply circuit incorporating appropriate additional capacitance should be used.

NOTE 2 For back-to-back capacitor bank switching current tests where separate making tests are performed, a lower capacitance of the supply circuit may be chosen for the breaking tests. The capacitance should, however, not be so low that the prospective transient recovery voltage of the supply side exceeds that specified for short-circuit in 6.104.5.2.

6.111.4 Earthing of the supply circuit

For single-phase laboratory tests, either terminal of the single-phase supply circuit can be earthed. However, when it is necessary to ensure that the correct voltage distribution exists between the units of the circuit-breaker, another point of the supply circuit may be connected to earth.

For three-phase tests the earthing shall be as follows:

a) for capacitor bank current switching tests, the neutral of the supply circuit shall be earthed. For capacitor banks with effectively earthed neutral, the zero sequence impedance shall be no more than three times its positive sequence impedance. For capacitor banks with isolated neutral this ratio is not relevant;
b) for line-charging and cable-charging current switching tests, the earthing of the supply circuit shall, in principle, correspond to the earthing conditions in circuits for which the circuit-breaker is to be used:
   – for three-phase tests of a circuit-breaker intended for use in effectively earthed neutral systems, the neutral point of the supply circuit shall be earthed and its zero sequence impedance shall be no more than three times its positive sequence impedance;
   – for three-phase tests of a circuit-breaker intended for use in non-effectively earthed systems the neutral point of the supply side shall be isolated.

NOTE For convenience of testing, an alternative test circuit can be used as long as the testing authority can prove that equivalent values of the recovery voltage will be obtained, for example a test circuit with an earthed neutral system and an isolated capacitor bank can be replaced, in many cases, by a test circuit with an isolated neutral system and an earthed capacitor bank.

Moreover, attention should be given to the influence of TRV control capacitors on the values of the recovery voltage especially for low capacitive currents. Table 32 gives values of the required recovery voltage.

6.111.5 Characteristics of the capacitive circuit to be switched

There are three possibilities:

a) three-phase tests, where in case of line- or cable-charging current switching tests it is permissible to use parallel lines or cables respectively or to partly, or fully, replace the real three-phase line or cable with concentrated capacitor banks. The resulting positive sequence capacitance shall be approximately twice the zero sequence capacitance tests representing three-core belted cables for rated voltages 52 kV and above, and three times the zero sequence capacitance for rated voltages less than 52 kV;

b) single-phase tests in a three-phase test circuit with two phases of the capacitive circuit connected directly to the three-phase supply circuit and one phase connected to the supply circuit through the circuit-breaker pole to be tested;

c) single-phase laboratory tests, where in case of line- or cable-charging current switching tests it is allowed to replace partly or fully the real lines or cables respectively by concentrated capacitor banks and to use any parallel connection of the conductors in the individual phases with the return current through earth or through a conductor.

The characteristics of the capacitive circuit shall, with all necessary measuring devices such as voltage dividers included, be such that the decay of the voltage at load side does not exceed 10 % at the end of an interval of 300 ms after final arc extinction.

Where the test circuit is unable to supply the recovery voltage for 300 ms, the withstand ability of the circuit-breaker shall be demonstrated in another way. This demonstration can be done by performing an additional test without current, applying the required recovery voltage one cycle of the power frequency after contact separation. The required recovery voltage can be obtained by applying, for example, a d.c. voltage at one terminal and an a.c. voltage to the other terminal for the required time duration. The number of voltage applications shall be five in each polarity. Where the capacitive current switching tests are performed three-phase, this additional dielectric test shall be carried out on each of the three phases. The pressure for interruption and insulation during this test shall, where applicable, be that specified for the corresponding capacitive current switching test.

6.111.5.1 Line-charging and cable-charging current switching tests

When capacitors are used to simulate overhead lines or cables, a non-inductive resistor of a maximum value of 5 % of the capacitive impedance may be inserted in series with the capacitors. Higher values may unduly influence the recovery voltage. If, with this resistor connected, the peak inrush current is still unacceptably high, then an alternative impedance (for example LR) may be used instead of the resistor, provided that the current and voltage conditions at the instant of breaking and the recovery voltage do not differ significantly from the specified values.

Caution is needed when using such alternative impedances, since this impedance can generate an overvoltage after re-ignition, which may lead to further re-ignitions or restrikes.

NOTE In case of cable-charging current switching tests a short overhead line may be used in series with a cable for the tests, provided the line charging current does not exceed 1 % of the cable charging current.

6.111.5.2 Capacitor bank current switching tests

The neutral of the capacitor shall be isolated except that, for rated voltages equal to or above 52 kV, the earthing conditions of the test capacitor shall be the same as for the capacitor when in service if the circuit-breaker is intended for use in effectively earthed neutral systems.

NOTE The back-to-back capacitor bank making performance is covered when:

– the tested peak inrush making current is equal to or greater than the rated value and
– the tested frequency of the inrush current is equal to or greater than 77 % of the rated value. The applicability of this rule is limited to frequencies below 6 000 Hz.

6.111.6 Waveform of the current

The waveform of the current to be broken should, as nearly as possible, be sinusoidal. This condition is considered to be complied with if the ratio of the r.m.s. value of the current to the r.m.s. value of the fundamental component does not exceed 1,2.

The current to be interrupted shall not go through zero more than once per half-cycle of power frequency.

6.111.7 Test voltage

For direct three-phase tests and for single-phase tests with the capacitive circuit to be switched according to the arrangement in item b) of 6.111.5, the test voltage measured between the phases at the circuit-breaker location immediately prior to opening shall be not less than the rated voltage U_r of the circuit-breaker.

For direct single-phase laboratory tests, the test voltage measured at the circuit-breaker location immediately before the opening shall be not less than the product of $U_r/\sqrt{3}$ and the following capacitive voltage factor k_c:

a) **1,0** for tests corresponding to normal service in solidly earthed neutral systems without significant mutual influence of adjacent phases of the capacitive circuit, typically capacitor banks with earthed neutral and screened cables.

b) **1,2** for tests on belted cables and for line-charging current switching tests according to item c) of 6.111.5 corresponding to normal service conditions in effectively earthed neutral systems for rated voltages 52 kV and above.

c) **1,4** for tests corresponding to

   – breaking during normal service conditions in systems non-effectively earthed neutral systems;

   – breaking of capacitor banks with isolated neutral.

   Moreover, the factor **1,4** will be applied for tests on belted cables and for line-charging current switching according to item c) of 6.111.5 corresponding to normal service conditions in effectively earthed neutral systems for rated voltages less than 52 kV.

Where verification of capacitive current switching is required in presence of single or two-phase earth faults, the following factors apply (see also 6.111.9.3 for the test currents).

d) **1,4** for tests corresponding to breaking in the presence of single or two-phase earth faults in effectively earthed neutral systems;

e) **1,7** for tests corresponding to breaking in non-effectively earthed neutral systems in the presence of single or two-phase earth faults.

For unit tests, the test voltage shall be chosen to correspond to the most stressed unit of the pole of the circuit-breaker.

The power frequency test voltage and the d.c. voltage resulting from the trapped charge on the capacitive circuit shall be maintained for a period of at least 0,3 s after breaking.

NOTE 1 The voltage factors in b) to c) above are applicable to single circuit line construction. Switching test requirements for multiple circuit overhead line constructions may be greater than these factors.

NOTE 2 When the non-simultaneity of contact separation in the different poles of the circuit-breaker exceeds one sixth of the cycle of the rated frequency, it is recommended to raise further the voltage factor or to make only three-phase tests.

6.111.8 Test current

The test currents for the various test-duties shall be defined following the rules given in this standard. Preferred values of rated capacitive currents are specified in Table 9. They are chosen for standardisation purposes and cover the majority of typical applications. If different values are needed, any appropriate value, also different from the preferred ones, may be specified as rated value.

6.111.9 Test-duties

The test-duties of each test series shall be performed on one specimen without any maintenance. The following abbreviations apply:

– line-charging current, test-duty 1 LC1
– line-charging current, test-duty 2 LC2
– cable-charging current, test-duty 1 CC1
– cable-charging current, test-duty 2 CC2
– capacitor bank current, test-duty 1 BC1
– capacitor bank current, test-duty 2 BC2

These test-duties may be combined in order to demonstrate the performance of a circuit-breaker for covering several applications or ratings (for example LC and/or CC and/or BC). If such combination method is used, the following rules apply:

– The test voltage, as defined in 6.111.7, shall be equal to the highest value for which the circuit-breaker performance is required to be demonstrated.
– The test-duties and test currents shall be as follows:
  1) a test-duty 2, covering all test-duties 2 of the combination, with a current not less than 100 % of the highest capacitive current rating to be demonstrated;
  2) a test-duty 1 with a current between 10 % and 40 % of the highest capacitive current rating to be demonstrated;
  3) a test-duty 1 for each lower capacitive current rating if the range of 10 % to 40 % of that rating is not covered by a previous test-duty 1;
  4) all other requirements for the individual test-duties shall also be met (for example type and number of operations, pressure conditions and test circuits). Where CO operations are specified for one application and O operations for a different one, CO operations are considered to cover O operations if the testing conditions are the same.

NOTE In the following an example is given in which these rules are applied on class C2 single-phase tests carried out on a circuit-breaker rated 145 kV; the voltage factor is assumed to be the same for all ratings.

If a line-charging current rating and a cable-charging current rating are assigned, the following tests have to be carried out:

– a test-duty 1 at minimum functional pressure for operation and interruption, consisting of 48 O operations; the current has to cover 10 % to 40 % of both, the rated line-charging breaking current (50 A for a rated voltage of 145 kV) and the rated cable-charging breaking current (160 A for a rated voltage of 145 kV). Thus, the test current has to be between 16 A and 20 A.
– a test-duty 2 at rated pressure for operation and interruption, consisting of 24 O operations and 24 CO operating cycles; the current has to be not less than both, the rated line-charging breaking current (50 A for a rated voltage of 145 kV) and the rated cable-charging breaking current (160 A for a rated voltage of 145 kV). Thus, the current has to be 160 A or higher.

If in addition a capacitor bank current rating is assigned too, and the tests for the three different ratings are to be combined the following tests should be carried out:

– at first a test-duty 2 at rated pressure for operation and interruption, consisting of 120 CO operating cycles; the current should be not less than the rated line-charging breaking current (50 A for a rated voltage of 145 kV), the rated cable-charging breaking current (160 A for a rated voltage of 145 kV) and the rated single capacitor bank breaking current (400 A for all rated voltages). Thus, the current should be 400 A or higher;
– a test-duty 1 at minimum functional pressure for operation and interruption, consisting of 48 O operations; the current should be 10 % to 40 % of the highest current to be demonstrated, i.e. 400 A. Thus, the current should be between 40 A and 160 A. This test-duty can cover also the requirements for cable-charging current switching; then the current should be between 40 A and 64 A;
– a further test-duty 1 at minimum functional pressure for operation and interruption, consisting of 48 O operations; the current should be either 5 A to 20 A – in the case the previous test-duty 1 was carried out with a current of 40 A to 64 A, as explained above and the conditions for cable-charging current switching are already fulfilled – or 16 A to 20 A – in the case this second test-duty 1 covers both the line-charging and the cable-charging current breaking requirements.

6.111.9.1 Test conditions for class C2 circuit-breakers

6.111.9.1.1 Class C2 test-duties

Capacitive current switching tests for class C2 circuit-breakers shall be made after performing test-duty T60 as a preconditioning test (T60 is related to the a.c component of the rated short-circuit breaking current). The test arrangement should be such that no interference with the circuit-breaker between the tests is necessary. However, if this is not possible and local safety rules require depressurising to enter the test cell, it is allowed to decrease the pressure in the circuit-breaker provided that the gas is reused when refilling the circuit-breaker.

As an alternative, the preconditioning test may consist of the following:

– same current as test-duty T60;
– ~~low voltage and no specified TRV~~ the test voltage shall be the phase-to-earth voltage;
– ~~three opening operations~~ making shall occur within ±25° of the peak value (on the same phase for three-phase tests) and evenly distributed in both polarities;
– arcing time: as for T60 or expected T60 arcing time values given by the manufacturer;
– rated or lock-out conditions.

NOTE 1 For practical reasons, for circuit-breakers rated less than 52 kV, the manufacturer may choose to add other test-duties to the T60 preconditioning tests.

NOTE 2 If several capacitive current switching tests, for instance line-charging, cable-charging and capacitor bank current switching tests, are performed with the same circuit-breaker without reconditioning, the T60 preconditioning tests must be performed only once at the beginning of the capacitive current switching test.

The capacitive current switching tests shall consist of the test-duties as specified in Table 30.

Table 30 – Class C2 test-duties

Test-duty	Operating voltage of the releases	Pressure for operation and interruption	Test current as percentage of the rated capacitive breaking current %	Type of operation or operating sequence
1: LC1, CC1 and BC1	Maximum voltage	Minimum functional pressure	10 to 40	O
2: LC2, CC2 and BC2	Maximum voltage	Rated pressure	Not less than 100	O and CO or CO
NOTE 1 The tests are performed at maximum operating voltage of the releases in order to facilitate consistent control of the opening operation. NOTE 2 For convenience of testing, CO operating cycles may be performed in test-duty 1 (LC1, CC1 and BC1).				

For sealed-for-life fluid circuit-breakers, the minimum functional pressure is replaced by the rated pressure for interruption less the pressure drop due to leakage during life duration. For vacuum circuit-breakers the pressure conditions for interruption are not applicable.

For make-break tests, the contacts of the circuit-breaker shall not be separated until the transient currents have subsided. To achieve this, the time between the closing and the opening operations may need to be adjusted but shall remain as close as possible to the close-open time as defined in 3.7.143.

No appreciable charge shall remain on the capacitive circuits before the making operations.

When testing back-to-back capacitor bank switching current, the inrush making current shall be equal to the rated back-to-back capacitor bank inrush making current with a tolerance of ±10 %. The tolerance on the inherent value of back-to-back making inrush current shall be $^{+10}_{-0}$ %. For all making operations, the making shall occur within ±25° of the peak value of the applied voltage (on one phase for three-phase tests) and evenly distributed in both polarities.

Where in case of back-to-back capacitor bank switching tests due to limitations of the test plant it is not possible to comply with the requirements during the CO operating cycles, then it is permitted to perform the requirements of test-duty 2 (BC2) as a series of separate making tests followed by a series of CO tests.

It is also permitted to perform these split tests not in two subsequent blocks, one consisting of all C operations and one of all CO operations, but to mix C and CO operations provided the number of making operations is larger than or equal to the number of breaking operations at any time during this test.

The separate making tests of this test series shall comprise the following:

– the same number of operations;

  when testing back-to-back capacitor bank switching current the inrush making current shall be at least equal to the rated back-to-back capacitor bank inrush making current;

– the test voltage shall be the same as for test-duty 2 (BC2);

– making shall occur within 15° of the peak value (on the same phase for three-phase tests) and evenly distributed in both polarities.

After the separate making operations, the CO operations shall be performed with no-load conditions on the closing. The CO operations shall be carried out on the same pole without intermediate re-conditioning.

NOTE 3 When switching capacitive currents, the opening operation in a CO operating cycle is not influenced by the pre-arc of the preceding closing operation but may be impacted by the actual behaviour of the fluid for interruption caused by the closing operation (for example, local differences in density, turbulence, fluid motion). Therefore, the closing and the opening operations may be separated as mentioned above with regard to the electrical stress but not with regard to the motion conditions of the fluid for interruption. A no-load closing operation prior to the opening operation is necessary for these reasons.

The prospective damping factor for the inrush current during back-to-back switching, i.e. the ratio between the second peak and the first peak of the same polarity, shall be equal to or greater than 0,75 for circuit-breakers having a rated voltage less than 52 kV and equal to or greater than 0,85 for circuit-breakers having a rated voltage equal to or greater than 52 kV.

For opening operations, the minimum arcing time is determined by changing the setting of the contact separation on opening by periods of approximately 6°. Using this method, several tests may be necessary to demonstrate the minimum arcing time and the maximum arcing time.

NOTE 4 In order to obtain more consistent opening and closing times of the circuit-breaker, by agreement of the manufacturer voltages even higher than the relevant upper tolerance limit of the supply voltages of the operating devices may be applied during these tests.

If a maximum arcing time is obtained instead of an expected minimum arcing time this is a valid test and shall be included in the count for the total requirement. In such an event, the following will be necessary:

– advance the setting of the control of the tripping impulse by 6° and repeat the test. The new setting shall be kept for other tests at minimum arcing time;
– make one less opening operation to retain the overall total count of tests.

The number of operations at minimum arcing time as stated in 6.111.9.1.2, 6.111.9.1.3, 6.111.9.1.4 and 6.111.9.1.5 shall be achieved, even if the specified total number of operations is exceeded.

A re-ignition followed by interruption at a later current zero shall be treated as a breaking operation with long arcing time.

~~The preferred order for the line-charging or cable-charging current switching tests is as follows:~~

– ~~terminal fault T60 (mandatory at the beginning);~~
– ~~capacitive current switching, test-duty 1 (LC1 or CC1);~~
– ~~capacitive current switching, test-duty 2 (LC2 or CC2).~~

No preferred order is specified for line-charging and cable-charging current switching tests, except that the required preconditioning test at T60 level shall be carried out at the beginning of the test.

The mandatory order for capacitor bank (single or back-to-back) current switching tests is as follows:

– terminal fault T60;
– capacitive current switching, test-duty 2 (BC2);
– capacitive current switching, test-duty 1 (BC1).

Within each test-duty, the order of the operations as written in 6.111.9.1.2 to 6.111.9.1.5 is suggested but not mandatory.

For circuit-breakers with a non-symmetrical current path, the terminal connections shall be reversed between test-duty 1 (LC1, CC1 and BC1) and test-duty 2 (LC2, CC2 and BC2).

6.111.9.1.2 Three-phase line-charging and cable-charging current switching tests

Each test-duty shall comprise a total of 24 operations or operating cycles as follows:

Test-duty 1 (LC1 and CC1):

– 4 O, distributed on one polarity (step: 15°);
– 6 O at minimum arcing time on one polarity;
– 4 O, distributed on the other polarity (step: 15°);
– 6 O at minimum arcing time on the other polarity;
– additional tests to achieve 24 O, distributed (step: 15°).

Test-duty 2 (LC2 and CC2):

– 4 CO, distributed on one polarity (step: 15°);
– 6 CO at minimum arcing time on one polarity;
– 4 CO, distributed on the other polarity (step: 15°);
– 6 CO at minimum arcing time on the other polarity;
– additional tests to achieve 24 CO, distributed (step: 15°).

~~During these tests, all minimum arcing times shall occur on the same phase.~~

With the exception of the additional tests, all distributed and minimum arcing times shall occur on the same phase.

NOTE If the opening time of the circuit-breaker prevents accurate control of contact separation, the requirement for minimum arcing times to be on the same phase can be ignored.

The C operations may be no-load operations.

6.111.9.1.3 Single-phase line-charging and cable-charging current switching tests

Each test-duty shall comprise a total requirement of 48 operations or operating cycles as follows:

Test-duty 1 (LC1 and CC1):

– 12 O, distributed on one polarity (step: 15°);
– 6 O at minimum arcing time on one polarity;
– 12 O, distributed on the other polarity (step: 15°);
– 6 O at minimum arcing time on the other polarity;
– additional tests to achieve 48 O, distributed (step:15°).

Test-duty 2 (LC2 and CC2):

– 6 O and 6 CO, distributed on one polarity (step 30°);
– 3 O and 3 CO at minimum arcing time on one polarity;
– 6 O and 6 CO, distributed on the other polarity (step: 30°);
– 3 O and 3 CO at minimum arcing time on the other polarity;
– additional tests to achieve 24 O and 24 CO, distributed (step:30°).

The C operations may be no-load operations.

6.111.9.1.4 Three-phase capacitor bank (single or back-to-back) current switching tests

Test-duty 1 (BC1) shall comprise a total of 24 O tests. Test-duty 2 (BC2) shall comprise a total of 80 CO tests as follows:

Test-duty 1 (BC1):

– 4 O, distributed on one polarity (step:15°);
– 6 O at minimum arcing time on one polarity;
– 4 O, distributed on the other polarity (step: 15°);
– 6 O at minimum arcing time on the other polarity;
– additional tests to achieve 24 O, distributed (step: 15°).

Test-duty 2 (BC2):

- 4 CO, distributed on one polarity (step 15°);
- 32 CO at minimum arcing time on one polarity;
- 4 CO, distributed on the other polarity (step: 15°);
- 32 CO at minimum arcing time on the other polarity;
- additional tests to achieve 80 CO, distributed (step:15°).

During these tests, all minimum arcing times shall be obtained on the same phase.

For the C operations in single capacitor bank tests the making current provided by the test circuit is considered to be sufficient. In case of back-to-back capacitor bank switching tests, for convenience of testing, the C operations of test-duty 2 may be no-load operations; then a series of separate making tests according to 6.111.9.1.1 shall be performed.

NOTE If the opening time of the circuit-breaker prevents accurate control of contact separation, the requirement for minimum arcing times to be on the same phase can be ignored.

6.111.9.1.5 Single-phase capacitor bank (single or back-to-back) current switching tests

Test-duty 1 (BC1) shall comprise a total of 48 O tests. Test-duty 2 (BC2) shall comprise a total of 120 CO tests.

Test-duty 1 (BC1):

- 12 O, distributed on one polarity (step: 15°);
- 6 O at minimum arcing time on one polarity;
- 12 O, distributed on the other polarity(step: 15°);
- 6 O at minimum arcing time on the other polarity;
- additional tests to achieve 48 O, distributed (step: 15°).

Test-duty 2 (BC2):

- 12 CO, distributed on one polarity (step: 15°);
- 42 CO at minimum arcing time on one polarity;
- 12 CO, distributed on the other polarity (step: 15°);
- 42 CO at minimum arcing time on the other polarity;
- Additional tests to achieve 120 CO, distributed (step: 15°).

For the C operations in single capacitor bank tests the making current provided by the test circuit is considered to be sufficient. In case of back-to-back capacitor bank switching tests, for convenience of testing, the C operations of test-duty 2 may be no-load operations; then a series of separate making tests according to 6.111.9.1.1 shall be performed.

6.111.9.2 Test conditions for class C1 circuit-breakers

6.111.9.2.1 Class C1 test-duties

The capacitive current switching tests for class C1 circuit-breakers shall consist of test-duties as specified in Table 31 without preconditioning (6.111.9.1.1).

For the make-break tests, the contacts of the circuit-breaker shall not be separated until the transient currents have subsided. To achieve this, the time between the closing and opening operations may need to be adjusted but shall remain as close as possible to the close-open time as defined in 3.7.143.

No appreciable charge shall remain on the capacitive circuits before the making operations.

For all making operations, the making shall occur within ~~±15°~~ ±25° of the peak value of the applied voltage (on one phase for three-phase tests) and evenly distributed in both polarities. When testing back-to-back capacitor bank switching current the inherent inrush making current shall be at least equal to the back-to-back capacitor bank inrush making current.

Where in case of back-to-back capacitor bank switching tests due to limitations of the test plant it is not possible to comply with the requirements during the CO operating cycles, then it is permitted to perform the requirements of test-duty 2 (BC2) as a series of separate making tests followed by a series of CO tests.

It is also permitted to perform these split tests not in two subsequent blocks, one consisting of all C operations and one of all CO operations, but to mix C and CO operations provided the number of making operations is larger than or equal to the number of breaking operations at any time during this test.

The separate making tests of this test series shall comprise the following:

– the same number of operations;

  when testing back-to-back capacitor bank switching current the inrush making current shall be at least equal to the rated back-to-back capacitor bank inrush making current;

– the test voltage shall be the ~~same as for test-duty 2 (BC2)~~ phase-to-earth voltage;

– making shall occur within ~~15°~~ ±25° of the peak value (on the same phase for three-phase tests) and evenly distributed in both polarities.

After the separate making operations, the CO operations shall be performed with no-load conditions on the closing. The CO operations shall be carried out on the same pole without intermediate re-conditioning.

Table 31 – Class C1 test-duties

Test-duty	Operating voltage of the releases	Pressure for operation and interruption	Test current as percentage of rated capacitive switching current %	Type of operation or operating sequence
1: LC1, CC1 and BC1	Maximum voltage	Rated pressure	10 to 40	O
2: LC2, CC2 and BC2	Maximum voltage	Rated pressure [a]	Not less than 100	CO

NOTE 1 The tests are performed at maximum operating voltage of the releases in order to facilitate consistent control of the opening operation.

NOTE 2 For convenience of testing, CO operating cycles may be performed in test-duty 1 (LC1, CC1 and BC1).

[a] If applicable, pressure for operation and interruption shall be at the minimum functional pressure conditions for at least three CO operating cycles, one at the minimum arcing time and two at the maximum arcing time. This is not applicable for sealed for life circuit-breakers.

NOTE 1 When switching capacitive currents, the opening operation in a CO operating cycle is not influenced by the pre-arc of the preceding closing operation but may be impacted by the actual behaviour of the fluid for interruption caused by the closing operation (for example local differences in density, turbulence, fluid motion). Therefore, the closing and opening operations may be separated as mentioned above with regard to the electrical stress but not with regard to the motion conditions of the fluid for interruption. A no-load closing operation prior to the opening operation is necessary for these reasons.

The prospective damping factor for the inrush current during back-to-back switching, i.e. the ratio between the second peak and the first peak of the same polarity, shall be equal to or greater than 0,75 for circuit-breakers having a rated voltage less than 52 kV and equal to or greater than 0,85 for circuit-breakers having a rated voltage equal to or greater than 52 kV.

For opening operations, the minimum arcing time is determined by changing the setting of the contact separation on opening by periods of approximately 6°. Using this method, several tests may be necessary to demonstrate the minimum arcing time and the maximum arcing time.

NOTE 2 In order to obtain more consistent opening and closing times of the circuit-breaker, by agreement of the manufacturer voltages even higher than the relevant upper tolerance limit of the supply voltages of the operating devices may be applied during these tests.

If a maximum arcing time is obtained instead of an expected minimum arcing time, this is a valid test and shall be included in the count for the total requirement. In such an event the following will be necessary:

– advance the setting of the control of the tripping impulse by 6° and repeat the test. The new setting shall be kept for other tests at minimum arcing time;
– make one less opening operation to retain the overall total count of tests.

The number of operations and operating cycles at minimum arcing time as stated in 6.111.9.2.2 for three-phase tests or in 6.111.9.2.3 for single-phase tests shall be achieved, even if the specified total number of operations is exceeded.

A re-ignition followed by interruption at a later current zero shall be treated as a breaking operation with a long arcing time.

Within each test-duty, the order of the operations as written in 6.111.9.2.2 for three-phase tests or in 6.111.9.2.3 for single-phase tests is suggested but not mandatory.

For circuit-breakers with a non-symmetrical current path, the terminal connections shall be reversed between test-duty 1 (LC1, CC1 and BC1) and test-duty 2 (LC2, CC2 and BC2).

No preferred order is specified for capacitive current switching tests.

6.111.9.2.2 Single-phase and three-phase capacitive current switching tests

Test-duty 1 (LC1, CC1 and BC1) shall comprise a total of 24 O tests. Test-duty 2 (LC2, CC2 and BC2) shall comprise a total of 24 CO tests.

Test-duty 1 (LC1, CC1 and BC1):

– 6 O, distributed on one polarity (step: 30°);
– 3 O at minimum arcing time on one polarity;
– 3 O at minimum arcing time on other polarity;
– 6 O at maximum arcing time on the other polarity;
– additional tests to achieve 24 O, distributed (step: 30°).

Test-duty 2 (LC2, CC2 and BC2):

– 6 CO, distributed on one polarity (step: 30°);
– 3 CO at minimum arcing time on one polarity;
– 3 CO at minimum arcing time on the other polarity;
– 6 CO at maximum arcing time on the other polarity;
– additional tests to achieve 24 CO, distributed (step: 30°).

For line-charging and cable-charging switching tests the C operations may be no-load operations. For the C operations in single capacitor bank tests the making current provided by the test circuit is considered to be sufficient. In case of back-to-back capacitor bank switching tests, for convenience of testing, the C operations of test-duty 2 may be no-load operations; then a series of separate making tests according to 6.111.9.1.1 shall be performed.

The preferred order for the tests is the following:

– capacitive current switching, test-duty 1 (LC1 or CC1 or BC1);
– capacitive current switching, test-duty 2 (LC2 or CC2 or BC2).

6.111.9.3 Test conditions corresponding to breaking in the presence of earth faults

a) Lines and cables

   Where tests corresponding to switching of line and cable charging currents in the presence of earth faults are required, the following shall apply:

   Single-phase laboratory tests shall be made with a test voltage as given in 6.111.7 and a capacitive current equal to

   – 1,25 times the rated capacitive breaking current in effectively earthed neutral systems;
   – 1,7 times the rated capacitive breaking current in non-effectively earthed neutral systems.

Test procedures are as given in 6.111.9.1 and 6.111.9.2, except that the total number of tests required is divided by two for each relevant test-duty.

NOTE If the tests corresponding to breaking in the presence of earth faults are carried out using the number of operations stated in 6.111.9.1 or 6.111.9.2, respectively, these tests cover the requirements given in 6.111.9.1 or 6.111.9.2 and the tests to 6.111.9.1 or 6.111.9.2 do not need to be performed.

b) Single capacitor banks

   Tests are not necessary for capacitor banks in effectively earthed neutral systems.

   Switching effectively earthed neutral capacitor banks on non-effectively earthed neutral systems can result in higher stresses. As this is not a normal system condition, such test requirements are not considered in this standard.

c) Back-to-back capacitor banks

   As this is not a normal system condition, such test requirements are not considered in this standard.

6.111.10 Tests with specified TRV

As an alternative to using the test circuits defined in 6.111.3 through 6.111.5, switching tests may be performed in circuits which fulfil the following requirements for the prospective recovery voltage:

– with the envelope of the prospective test recovery voltage defined as (see Figure 54)

  $u'_c \geq u_c$

  $t'_2 \leq t_2$.

– In addition the initial part of the prospective recovery voltage shall remain below the line from the origin to the point defined by u_1 and t_1.
– Care should be taken in order to assure that the actual recovery voltage shall not exceed the theoretical test voltage of the corresponding single-phase direct test (1-cos curve) by more than 6 % of the peak value of the test voltage (i.e. approximately 3 % of the peak recovery voltage u_c shown in Figure 54).

NOTE The use of a series resistor (6.111.5.1 and 6.111.5.2) in the load circuit causes a phase shift which may lead to the above given limit be exceeded. In those cases the value of the resistor may be decreased or an appropriate LR circuit may be used instead (6.111.5.1 and 6.111.5.2).

Specified values of u_1, t_1, u_c and t_2 are given in Table 32.

Table 32 – Specified values of u_1, t_1, u_c and t_2

Test-duties	Recovery voltage values of Figure 54 in relation to the peak value of the test voltage		Time values of Figure 54	
	u_c p.u.	u_1 p.u.	t_1	t_2
1	$\geq$ 1,98	$\leq 0{,}02k_{af}$ *	$\geq t_1$ or t_3 in 4.102.3 for terminal fault	8,7 ms for 50 Hz
2	$\geq$ 1,95	$\leq 0{,}05k_{af}$ *		7,3 ms for 60 Hz
NOTE For single-phase synthetic tests the prospective recovery voltage is calculated based on the test voltage of the corresponding single-phase direct test.				
~~* k_{af} = amplitude factor = 1,4 (see Tables 1, 3 and 5) for class S1 circuit-breakers and for circuit-breakers with rated voltage of 100 kV and above.~~ ~~* k_{af} = amplitude factor = 1,54 (see Table 2) for class S2 circuit-breakers.~~ * k_{af} = 1,4 (see Tables 1, 3 and 5) for class S1 circuit-breakers and for circuit-breakers with rated voltage of 100 kV up to 800 kV; k_{af} = 1,5 (see Table 5) for circuit-breakers with rated voltage higher than 800 kV; k_{af} = 1,54 (see Table 2) for class S2 circuit-breakers.				

6.111.11 Criteria to pass the test

6.111.11.1 General

The circuit-breakers of the individual classes shall have successfully passed the tests if the following conditions are fulfilled:

a) the behaviour of the circuit-breaker during making and breaking of the capacitive currents in all prescribed test-duties fulfils the conditions given in 6.102.8;

b) the condition of the circuit-breaker after the test series corresponds to the conditions given in 6.102.9.4. If no restrike occurred during test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2), visual inspection is sufficient.

Where combined testing in accordance with 6.111.9 is carried out, the criteria to pass the test apply to each combination of test-duties 1 and 2 relevant to cover the application or rating the tests have been carried out for.

6.111.11.2 Class C2 circuit-breaker

The circuit-breaker shall have successfully passed the tests if no restrike occurred during test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2).

If one restrike occurred during the complete test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2), then both test-duties shall be repeated on the same apparatus without any maintenance. If no additional restrike happens during this extended series of tests, the circuit-breaker shall have successfully passed the tests. External flashover and phase-to-ground flashover shall not take place.

In the case of combined testing according to 6.111.9, the circuit-breaker shall have passed the test for those applications or ratings for which both a test-duty 2 and a matching test-duty 1 were carried out without restrike. Where due to restrikes test-duties have to be repeated, the affected set of matching test-duties (test-duty 1 and test-duty 2) shall be repeated. If in more than one test-duty 1 one restrike occurred, each of them shall be repeated together with one single test-duty 2. If one restrike occurred in test-duty 2, this one and any one of the test-duties 1 shall be repeated.

6.111.11.3 Class C1 circuit-breaker

The circuit-breaker shall have successfully passed the tests if up to one restrike occurred during test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2).

If two restrikes occurred during the complete test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2), then both test-duties shall be repeated on the same apparatus without any maintenance. If no more than one additional restrike happens during this extended series of tests, the circuit-breaker shall have successfully passed the tests. External flashover and phase-to-ground flashover shall not take place.

In the case of combined testing according to 6.111.9, the circuit-breaker shall have passed the test for those applications or ratings for which both, a test-duty 2 and a matching test-duty 1 were carried out with less than two restrikes in total. Where due to restrikes test-duties have to be repeated, the affected set of matching test-duties (test-duty 1 and test-duty 2) shall be repeated. If in more than one test-duty 1 restrikes occurred, each of them shall be repeated together with one single test-duty 2. If restrikes occurred only in test-duty 2, this one and any one of the test-duties 1 shall be repeated.

6.111.11.4 Criteria for reclassification of a circuit-breaker tested to the class C2 requirements as a class C1 circuit-breaker

A circuit-breaker which has met the requirements for class C2 for a particular switching duty (LC, CC, BC) can be class C1 for the same duty without further testing.

A circuit-breaker tested in accordance with the class C2 test program but which has failed to achieve class C2 performance can be qualified as a class C1 circuit-breaker if the requirements of 6.111.11.1 are fulfilled and if the following condition is met:

a) Line- or cable-charging current switching tests

   The total number of restrikes during line-charging current switching tests (LC1 and LC2) or cable-charging current switching tests (CC1 and CC2) does not exceed two in the first series of test operations i.e. 96 in case of single-phase tests and 48 in case of three-phase tests, see 6.111.9.1.2 or 6.111.9.1.3 respectively. In the event of a single restrike during the first series of test operations a repetition series may be carried out in accordance with 6.111.11.2. The behaviour of the circuit-breaker during the repetition series is not relevant for the purposes of reclassification.

b) Capacitor bank current switching tests

   The total number of restrikes during capacitor bank switching tests (BC1 and BC2) does not exceed five in the first series of operations, i.e. 168 in case of single-phase tests and 104 in case of three-phase tests, see 6.111.9.1.4 or 6.111.9.1.5 respectively. In the event of a single restrike during the first series of test operations a repetition series may be carried out in accordance with 6.111.11.2. The behaviour of the circuit-breaker during the repetition series is not relevant for the purposes of reclassification.

   The reclassification procedure is shown in Figures 55 and 56.

6.112 Special requirements for making and breaking tests on class E2 circuit-breakers

6.112.1 Class E2 circuit-breakers intended for use without auto-reclosing duty

The electrical endurance capability of circuit-breakers, which are intended to be used without auto-reclosing duty, for example in cable-connected networks, is demonstrated by performing the basic short-circuit test-duties of 6.106 without intermediate maintenance. Additional tests are not required.

6.112.2 Class E2 circuit-breakers intended for auto-reclosing duty

Circuit-breakers intended for auto-reclosing duty, as usual for overhead-line networks, shall perform an electrical endurance test in accordance with, and in the order specified in, Table 33 in addition to the basic short-circuit test-duties of 6.106, which shall be carried out without intermediate maintenance.

The test shall be carried out on a circuit-breaker, which is in a clean and new condition and identical to that which has been submitted to the basic short-circuit tests, given in 6.106. No intermediate maintenance shall be carried out. The test parameters shall be in accordance with 6.106 except as follows:

a) in the case of gas-filled circuit-breakers, the test shall be made at the rated pressure for insulation and/or operation and at the rated supply voltage of closing and opening devices and of auxiliary and control circuits;

b) the values of *t* shall be chosen for convenience of testing;

c) the minimum time interval between operating sequences should be stated by the manufacturer.

Arcing times shall be at random for the 10 % and 30 % tests. Adjustment of the arcing times shall be made in accordance with 6.102.10 for the 60 % and 100 % tests.

The condition of the circuit-breaker after the test shall comply with 6.102.9.2 and 6.102.9.3.

Table 33 – Operating sequence for electrical endurance test on class E2 circuit-breakers intended for auto-reclosing duty according to 6.112.2

Testing current (percentage of rated short-circuit breaking current) %	Operating sequences	Number of operating sequences (list 1) [a]	Number of operating sequences (list 2) [a]	Number of operating sequences (list 3) [a]
10	O	84	12	-
	O – 0,3 s – CO	14	6	-
	O – 0,3 s – CO – *t* – CO	6 [b]	4 [b]	1 [b]
30	O	84	12	-
	O – 0,3 s – CO	14	6	-
	O – 0,3 s – CO – *t* – CO	6 [b]	4 [b]	1 [b]
60	O	2	8	15
	O – 0,3 s – CO – *t* – CO	2 [b]	8 [b]	15 [b]
100 % (symmetrical)	O – 0,3 s – CO – *t* – CO	2 [b]	4 [b]	2 [b]

[a] List 1 is preferred. List 2 may be used as an alternative to list 1 for circuit-breakers used for effectively earthed neutral systems. Calculations have been carried out on the basis of publication [7]. These calculations are applicable for certain circuit-breaker types (single-pressure SF_6 and vacuum circuit-breakers). Calculation results may be different for other types of circuit-breakers. Using these calculations and setting the wear generated by list 1 at 100 %, list 2 results in 125 % and list 3 in 134 %. Therefore, list 3 may be used as an alternative to list 1 and to list 2 to reduce the number of different test circuits.

[b] When no reconditioning is made on the sample after the basic short-circuit test sequences in 6.106, the test already carried out may be taken into account in determining the number of additional operating sequences required to satisfy the requirements of Table 33. In practice, this means reducing these figures marked [b] by 1.

7 Routine tests

Clause 7 of IEC 62271-1 is applicable with the following addition:

7.1 Dielectric test on the main circuit

Subclause 7.1 of IEC 62271-1 is applicable with the following addition:

In the case of circuit-breakers constructed by assembling identical breaking and making units in series, the test voltage to be applied across each single unit, when open, shall be the higher fraction of the total withstand voltage resulting from actual power-frequency voltage distribution with the circuit-breaker fully open and one terminal earthed.

With reference to Figure 2 of IEC 62271-1, which shows a diagram of a three-pole circuit-breaker, the test voltage shall be applied, according to Table 34.

Table 34 – Application of voltage for dielectric test on the main circuit

Test condition No.	Circuit-breaker	Voltage applied to	Earth connected to
1	Closed	AaCc	BbF
2	Closed	Bb	AaCcF
3	Open	ABC	abcF

NOTE If the insulation between poles is air at atmospheric pressure, test conditions nos. 1 and 2 may be combined, the test voltage being applied between all parts of the main circuit connected together and the base.

7.2 Tests on auxiliary and control circuits

Subclause 7.2 of IEC 62271-1 is applicable.

7.3 Measurement of the resistance of the main circuit

Subclause 7.3 of IEC 62271-1 is applicable.

7.4 Tightness test

Subclause 7.4 of IEC 62271-1 is applicable.

7.5 Design and visual checks

Subclause 7.5 of IEC 62271-1 is applicable with the following addition:

The circuit-breaker shall be checked to verify its compliance with the order specification.

The following items shall be checked as applicable:

– the language and data on the nameplates;
– identification of any auxiliary equipment;
– the colour and quality of paint and corrosion protection of metallic surfaces;
– the values of the resistors and capacitors connected to the main circuit.

7.101 Mechanical operating tests

Mechanical operating tests shall include the following:

a) at maximum supply voltage of operating devices and of auxiliary and control circuits and maximum pressure for operation (if applicable):
   - five closing operations;
   - five opening operations.
b) at specified minimum supply voltage of operating devices and of auxiliary and control circuits and minimum functional pressure for operation (if applicable):
   - five closing operations;
   - five opening operations.
c) at rated supply voltage of operating devices and of auxiliary and control circuits and rated pressure for operation (if applicable):
   - five close-open operating cycles with the tripping mechanism energised by the closing of the main contacts;
   - moreover, for circuit-breakers intended for rapid auto-reclosing (see 4.104), five open-close operating cycles O – *t* – C where *t* shall be not more than the time interval specified for the rated operating sequence.

Mechanical operating tests should be made on the complete circuit-breaker. However, when circuit-breakers are assembled and shipped as separate units, routine tests may be performed on components according to 6.101.1.2. In such cases, the manufacturer shall produce a programme of commissioning tests for use at site to confirm the compatibility of such separate units and components when assembled as a circuit-breaker. A guidance for commissioning tests is given in 10.2.101.

For all required operating sequences the following shall be performed and records made of the closing and opening operations:

- measurement of operating times;
- where applicable, measurement of fluid consumption during operations, for example pressure difference.

Proof shall be given that the mechanical behaviour conforms to that of the test specimen used for type testing. For example, a no-load operating cycle, as described in 6.101.1.1, can be performed to record the no-load travel curves at the end of the routine tests. Where this is done, the curve shall be within the prescribed envelope of the reference mechanical travel characteristic, as defined in 6.101.1.1, from the instant of contact separation to the end of the contact travel.

Where the mechanical routine tests are performed on sub-assemblies, the reference mechanical travel characteristics shall be confirmed to be correct, as above, at the end of the commissioning tests on site.

If the measurement is performed on site, the manufacturer shall state the preferred measuring procedure. If other procedures are used, the results may be different and the comparison of the instantaneous contact stroke may be impossible to achieve.

The mechanical travel characteristics can be recorded directly, using a travel transducer or similar device on the circuit-breaker contact system or at other convenient locations on the drive to the contact system where there is a direct connection, and a representative image of the contact stroke can be achieved. The mechanical travel characteristics shall be preferably a continuous curve as shown in Figure 23 a). Where the measurements are taken on site, other methods may be applied which record points of travel during the operating period.

In these circumstances, the number of points recorded shall be sufficient to derive the time to, and contact speed at, contact touch and contact separation, together with the total travel time.

After completion of the required operating sequences, the following tests and inspections shall be performed (if applicable):

– connections shall be checked;
– the control and/or auxiliary switches shall correctly indicate the open and closed positions of the circuit-breaker;
– all auxiliary equipment shall operate correctly at the limits of supply voltage of operating devices and of auxiliary and control circuits and/or pressures for operation.

Furthermore the following tests and inspections shall be made (if applicable):

– measurement of the resistance of heaters (if fitted) and of the control coils;
– inspections of the wiring of the control, heater and auxiliary equipment circuits and checking of the number of auxiliary contacts, in accordance with the order specification;
– inspection of control cubicle (electrical, mechanical, pneumatic and hydraulic systems);
– recharging duration(s);
– functional performance of pressure relief valve;
– operation of electrical, mechanical, pneumatic or hydraulic interlocks and signalling devices;
– operation of anti-pumping device;
– general performance of equipment within the required tolerance of the supply voltage;
– inspection of earthing terminals of the circuit-breaker.

For self-tripping circuit-breakers, the releases or the relays shall be set at the minimum calibration mark on the scale of current settings.

It shall be shown that the over-current releases or relays correctly initiate the opening of the circuit-breaker with the current through the main circuit not exceeding 110 % of the minimum tripping current corresponding to the value set on the scale of current settings. A secondary injection test may be used as an alternative.

For these tests, the current through over-current releases, or through current transformers, may be supplied from a suitable low-voltage source.

For circuit-breakers fitted with under-voltage opening releases, it shall be shown that the circuit-breaker opens and can be closed when voltages within the specified limits are applied to the releases (see 5.8.4 of IEC 62271-1).

If adjustments are required during the mechanical operating tests, the complete test sequence shall be repeated following the adjustments.

8 Guidance to the selection of circuit-breakers for service

8.101 General

A circuit-breaker suitable for a given duty in service is best selected by considering the individual rated values required by load conditions and fault conditions.

The complete list of rated characteristics is given in Clause 4. The following individual ratings are dealt with in this clause.

Type of rating and characteristic	*Subclause*
Rated voltage	8.102.1
Rated insulation level	8.102.2
Rated frequency	8.102.3
Rated normal current	8.102.4
Rated short-circuit breaking current	8.103.1
Transient recovery voltage for terminal faults	8.103.2
Rated out-of-phase making and breaking current	8.103.3
Rated short-circuit making current	8.103.4
Rated operating sequence	8.103.5
Rated duration of short-circuit	8.103.6
Classification as for electrical endurance (class E1 or E2 (with/without auto-reclosing duty)), where applicable	8.104

For rated characteristics not dealt with in Clause 8, reference should, if applicable, be made to Clause 4 as follows:

Type of rating and characteristic	*Subclause*
Rated short-time withstand current	4.5
Rated peak withstand current	4.6
Rated supply voltage of closing and opening devices and of auxiliary and control circuits	4.8
Rated supply frequency of opening and closing devices and of auxiliary circuits	4.9
Rated pressures of compressed gas supply for insulation, operation and/or interruption	4.10
Characteristics for short-line faults	4.105
Restrike performance during capacitive current switching (class C1 or C2)	4.107
Characteristics as for capacitive switching conditions (for example earthing conditions, type of capacitive load, etc.)	4.107
Rated line-charging breaking current	4.107.1
Rated cable-charging breaking current	4.107.2
Rated single capacitor bank breaking current	4.107.3
Rated back-to-back capacitor bank breaking current	4.107.4
Rated single capacitor bank inrush making current	4.107.5
Rated back-to-back capacitor bank inrush making current	4.107.6
Number of mechanical operations (class M1 or M2)	4.110

Other parameters to be considered when selecting a circuit-breaker are, for example:

Local atmospheric and climatic conditions	8.102.5
Use at high altitudes	8.102.6
Opening time	8.103.1
Inductive load breaking current	4.108

The duty imposed by the fault conditions with which a circuit-breaker is required to deal should be determined by calculating the fault currents at the place where the circuit-breaker is to be located in the system, in accordance with some recognised method of calculation.

When selecting a circuit-breaker, due allowance should be made for the likely future development of the system as a whole, so that the circuit-breaker may be suitable not merely for immediate needs but also for the requirements of the future.

Circuit-breakers which have satisfactorily completed type tests for a combination of rated values (i.e. voltage, normal current, making and/or breaking current) are suitable for any lower rated values (with the exception of rated frequency) without further testing. Switching of inductive loads (magnetising currents of transformers, high-voltage motors and shunt reactors) are specified in IEC 62271-110.

NOTE Some fault conditions such as evolving faults and some service conditions such as switching of arc furnaces are not dealt with in this standard and should therefore be considered as special conditions for which agreement should be reached between manufacturer and user.

The same is applicable to circuit-breakers used for any operation leading to a power-frequency recovery voltage higher than that corresponding to the rated voltage of the circuit-breaker, which may be the case at certain points of the system and, in particular, at the end of long lines. In this particular case, the value of current to be interrupted at the highest voltage which may occur across the terminals of the circuit-breaker when opening should be subject to a similar agreement.

8.102 Selection of rated values for service conditions

8.102.1 Selection of rated voltage

The rated voltage of the circuit-breaker should be chosen so as to be at least equal to the highest voltage of the system at the point where the circuit-breaker is to be installed.

The rated voltage of a circuit-breaker should be selected from the standard values given in 4.1 of IEC 62271-1.

In selecting the rated voltage the corresponding insulation levels specified in 4.2 should also be taken into account (see also 8.102.2).

8.102.2 Insulation coordination

The rated insulation level of a circuit-breaker should be selected according to 4.2.

The values in the tables stated there apply to both indoor and outdoor circuit-breakers. It should be specified in the enquiry whether the circuit-breaker is to be of indoor or outdoor type.

The insulation coordination in an electrical system serves to minimise damage to the electrical equipment due to overvoltages and tends to confine flashovers (when these cannot be economically avoided) to points where they will cause no damage.

Precautions should be taken to limit the overvoltages on the terminals of the circuit-breaker to stated values below the insulation level (see IEC 60071-2).

Where a circuit-breaker is required for a position necessitating a higher insulation level, this should be specified in the enquiry (see 9.101).

For circuit-breakers intended for use in synchronising operation when a substantial switching surge may simultaneously occur, refer to 4.2 and 6.2.7.2.

When selecting circuit-breakers for service, it is also necessary to take into account their characteristics in respect of transient phenomena and overvoltages. Experience shows that the unfavourable effects of transient phenomena and the risk of overvoltages for certain critical cases of application can be minimised by

- appropriate selection of the type of circuit-breaker;
- changes in the system or the use of additional equipment for damping and limiting transient phenomena (RC circuits, overvoltage arresters, non-linear resistances, etc.).

These precautions shall be discussed with the manufacturer for individual cases. Special tests can be agreed for evaluating the selected solution.

8.102.3 Rated frequency

The manufacturer should be consulted if a circuit-breaker is to be used at any frequency other than its rated frequency (see 4.3 of IEC 62271-1).

When circuit-breakers rated 50 Hz are tested at 60 Hz and vice versa, care should be exercised in the interpretation of the test results, taking into account all significant facts such as the type of circuit-breaker and the type of test performed.

8.102.4 Selection of rated normal current

The rated normal current of a circuit-breaker should be selected from the standard values given in 4.4.

It should be noted that circuit-breakers have no specified continuous over-current capability. When selecting a circuit-breaker therefore, the rated normal current should be such as to make it suitable for any load current that may occur in service. Where intermittent over-currents are expected to be frequent and severe, the manufacturer should be consulted.

8.102.5 Local atmospheric and climatic conditions

The normal atmospheric and climatic conditions for circuit-breakers are given in Clause 2.

A distinction is made between classes "minus 5 indoor", "minus 15 indoor", "minus 25 indoor", "minus 10 outdoor", "minus 25 outdoor" and "minus 40 outdoor" circuit-breakers, these being suitable for differing minimum ambient air temperatures. The manufacturer should be consulted if a circuit-breaker is to be located where the ambient air temperature may fall below –25 °C for an indoor circuit-breaker, and below –40 °C for an outdoor circuit-breaker, or where the temperature may exceed 40 °C (or if the 24 h average value exceeds 35 °C).

For outdoor circuit-breakers, the atmospheric conditions in certain areas are unfavourable on account of smoke, chemical fumes, salt-laden spray and the like. Where such adverse conditions are known to exist, special consideration should be given to the design of those parts of the circuit-breaker, especially the insulators, normally exposed to the atmosphere.

The performance of an insulator in such atmospheres also depends on the frequency of washing or cleaning operations and on the frequency of natural washing by rain. Since the performance of an insulator under such conditions is dependent on so many factors, it is not possible to give precise definitions of normal and heavily polluted atmospheres. Experience in the area where the insulator is to be used is the best guide.

The manufacturer should be consulted when the circuit-breaker is to be located where the wind pressure exceeds 700 Pa.

Three different classes of circuit-breakers are specified with regard to ice-coating. These classes correspond to an ice-coating not exceeding 1 mm, 10 mm and 20 mm. If a circuit-breaker is to be located where an ice-coating exceeding 20 mm is expected, agreement should be reached between manufacturer and user as to the ability of the circuit-breaker to perform correctly under such conditions.

Where applicable, the seismic qualification levels referred to in 2.2.4 of IEC 62271-1 should be taken into account.

For indoor installations, the humidity conditions are given in 2.1.1e) of IEC 62271-1. When selecting the circuit-breaker for service, it is recommended to indicate the cases, where the high values of humidity are expected and condensation can occur. The responsibility and the amount of precaution to be taken against the occurrence of condensation mentioned in Note 3 of 2.1.1e) of IEC 62271-1 should be agreed between the manufacturer and user.

For indoor circuit-breakers, the manufacturer should be consulted for any special service conditions, for example when chemical fumes, aggressive atmosphere, salt laden spray, etc., are present.

8.102.6 Use at high altitudes

The normal service conditions specified in Clause 2 of IEC 62271-1 provide for circuit-breakers intended for use at altitudes not exceeding 1 000 m.

For installation at altitudes above 1 000 m, 2.2.1 of IEC 62271-1 is applicable.

8.103 Selection of rated values for fault conditions

8.103.1 Selection of rated short-circuit breaking current

As stated in 4.101, the rated short-circuit breaking current is expressed by two values:

a) the r.m.s. value of its a.c. component;

b) the d.c. time constant of the rated short-circuit breaking current which results in a percentage of d.c. component at contact separation.

The percentage d.c. component varies with time from the incidence of the short-circuit and with the corresponding d.c. time constant of the rated short-circuit breaking current. When the circuit-breaker meets the standard requirements or special case d.c. time constants stated in 4.101.2, the percentage d.c. component that the circuit-breaker can deal with, at the earliest possible current zero, is defined by the values given in Tables 15 through 22, for the corresponding minimum clearing time range. The minimum clearing time is defined in 3.7.159.

~~The curves in Figure 9 are based on a constant a.c. component and on the short-circuit power factors stated in Table 35, corresponding to a standard time constant τ = 45 ms and the special case time constant 60 ms, 75 ms and 120 ms, respectively.~~

The curves in Figure 9 are based on a constant a.c. component and on the short-circuit power factors stated in Table 35, corresponding to a d.c. time constant τ = 45 ms (i.e. the standard d.c. time constant for rated voltages up to and including 800 kV), 60 ms, 75 ms and 120 ms (i.e. the standard d.c. time constant for rated voltages higher than 800 kV).

Tests with a higher d.c. component at current zero cover tests at lower d.c. component provided that the current loop parameters (peak and duration) are within the tolerances given in 6.102.10.2.1.2 b) and the TRV conditions associated with the lower d.c. component are met.

Table 35 – Relationship between short-circuit power factor, time constant and power frequency

Time constant τ (ms)	Short-circuit power factor $\cos\varphi$ 50 Hz	60 Hz
45	0,071	0,059
60	0,053	0,044
75	0,042	0,035
120	0,026	0,022

~~When the location of the installation is sufficiently remote electrically from rotating machines, the decrement of the a.c. component is negligible and it is only necessary to verify that in case of 50 Hz the short-circuit power factor is not less than 0,071 in case of the standard time constant τ = 45 ms and the minimum relay time of the protective equipment is not less than one half cycle of rated frequency. In these conditions it is sufficient that the selected circuit-breaker has a rated short-circuit breaking current not less than the r.m.s. value of the short-circuit current at the point where the circuit-breaker is to be installed.~~

When the location of the installation is sufficiently remote electrically from rotating machines, the decrement of the a.c. component at the time of the fault is negligible and it is only necessary to verify that in case of 50 Hz the short-circuit power factor is not less than 0,071 in case of the standard d.c. time constant τ = 45 ms, or 0,026 in case of a standard d.c. time constant τ = 120 ms, and the minimum relay time of the protective equipment is not less than one half cycle of rated frequency. In these conditions it is sufficient that the selected circuit-breaker has a rated short-circuit breaking current not less than the r.m.s. value of the short-circuit current at the point where the circuit-breaker is to be installed.

The basic short-circuit test-duties, see 6.106, together with the critical current tests, see 6.107, and where applicable, short-line fault tests, see 6.109, have been chosen to prove the circuit-breaker for all values of current up to the rated short-circuit breaking current. Therefore, for situations where the prospective short-circuit current is lower, it is not necessary to perform a short-circuit test series based on a lower rated short-circuit breaking current.

In some cases the percentage of the d.c. component at the earliest possible current zero may be higher than the values given in Tables 15 through 22. For example, when circuit-breakers are in the vicinity of centres of generation, the a.c. component may decrease more quickly than in the normal case. The short-circuit current may then not have a current zero for a number of cycles. In such circumstances the duty of the circuit-breaker can be eased, for example, by delaying its opening, or by connecting an additional damping device with another circuit-breaker and opening the circuit-breakers in sequence. If the standard or special case d.c. time constants values cannot be adhered to, the required percentage should be specified in the enquiry and testing should be subject to agreement between manufacturer and user; in this relation attention is drawn to item b) of 8.103.2.

NOTE The current zero can be advanced by the effects of the arc voltages of the circuit-breaker and/or the interruptions of the short-circuit currents in the other phases with earlier current zeros. For such circumstances, standard circuit-breakers are applicable subject to careful investigation.

The rated short-circuit breaking current should be selected from the standard values given in 4.101.1.

8.103.2 Selection of transient recovery voltage (TRV) for terminal faults, first-pole-to-clear factor and characteristics for short-line faults

The prospective transient recovery voltage (TRV), of the system should not exceed the reference line representing the rated transient recovery voltage specified for the circuit-breaker; it should cross the specified delay line close to zero voltage but should not re-cross it later (see 4.102.2). Standard values are shown in 6.104.5.

NOTE 1 The transient recovery voltages which appear when breaking the highest short-circuit currents are not necessarily more severe than those which appear in other cases. For example, the rate-of-rise of transient recovery voltage may be higher when breaking smaller short-circuit currents.

In the range of rated voltages higher than 1 kV and less than 100 kV, in order to cover all types of networks (distribution, industrial and sub-transmission) and for standardisation purposes, two types of systems are defined:

– cable systems (see 3.1.132);
– line systems (see 3.1.133).

The following considerations should facilitate the choice by the user of the class of circuit-breaker for rated voltages higher than 1 kV and less than 100 kV:

– standard values of TRVs specified in e dition 1.1 (edition 1 + amendment 1) of IEC 62271-100 can still be required by specifying class S1 (these standard values of TRVs are given in Table 24);
– to cover all cases of cable systems and line systems, except those mentioned in a), b) and c) below, class S2 of circuit-breakers has to be specified (standard values of TRVs are given in Table 25).

NOTE 2 In the special cases where the total length of cable (or equivalent length when capacitors are also present) on the supply side of the circuit-breaker is between 20 m and 100 m, the system is considered as a line system except if a calculation can show that the actual TRV is covered by the envelope defined from Table 24. If the TRV is covered the system is then considered as a cable system.

~~The standard values given for rated voltages below 100 kV are applicable to a first-pole-to-clear factor (k_{pp}) of 1,5. For rated voltages 100 kV to 800 kV, the k_{pp} is 1,3 since most systems at 100 kV and above are effectively earthed. For rated voltages 100 kV to 170 kV, the choice of a first-pole-to-clear factor of 1,5 is provided for those special cases with non-effectively earthed neutrals (see also the note in 6.104.5.4).~~

~~The first-pole-to-clear factor of 1,3 is based on a system with effectively earthed neutral where three-phase faults not involving earth are considered highly improbable. For applications in non-effectively earthed neutral systems, a first-pole-to-clear factor of 1,5 should be used. For applications in systems with effectively-earthed neutral in cases where the probability of three-phase faults not involving earth cannot be disregarded, and for applications in systems other than with effectively-earthed neutral systems, a first-pole-to-clear factor of 1,5 may be necessary.~~

The standard values given for rated voltages below 100 kV are applicable to a first-pole-to-clear factor k_{pp} of 1,5. For rated voltages 100 kV to 800 kV, k_{pp} is 1,3 since most systems at 100 kV and above are effectively earthed. For rated voltages 100 kV to 170 kV, the choice of k_{pp} between 1,3 and 1,5 is provided for those special cases with non-effectively earthed neutrals (see also the note in 6.104.5.4). For rated voltages higher than 800 kV k_{pp} is 1,2.

The values of k_{pp} of 1,3 and 1,2 are based on a system with effectively earthed neutral where three-phase faults not involving earth are considered highly improbable. For applications in non-effectively earthed neutral systems, k_{pp} = 1,5 should be used. For applications in systems with effectively-earthed neutral in cases where the probability of three-phase faults not involving earth cannot be disregarded, and for applications in systems other than with effectively-earthed neutral systems, k_{pp} = 1,5 may be necessary.

Generally it will not be necessary to consider alternative transient recovery voltages as the standard values specified cover the majority of practical cases.

More severe conditions may occur in some cases, for example:

a) One case is when a short-circuit occurs close to a transformer but on the opposite side to the circuit-breaker and where there is no appreciable additional capacitance between the transformer and the circuit-breaker. In this case both the peak voltage and rate-of-rise of transient recovery voltage may exceed the values specified in this standard.

   NOTE 3 Care should also be taken when selecting a circuit-breaker for the primary side of a transformer which may have to interrupt a short circuit on the secondary side.

   ~~For circuit-breakers with rated voltages less than 100 kV,~~ Such cases are covered in Annex M.

   ~~NOTE 4 For circuit-breakers with rated voltages 100 kV and higher, values for TRVs for transformer limited faults are proposed in ANSI C37.06.1 [8] for fast transient recovery voltage rise times.~~

b) Circuit-breakers being used next to current-limiting reactors may fail to interrupt due to the high natural frequency of these reactors (see 8.103.7).

c) In the case of a short-circuit on circuit-breakers close to generators, the rate-of-rise of transient recovery voltage may exceed the values specified in this standard.

In such cases it may be necessary for special TRV characteristics to be agreed between manufacturer and user.

Short-line fault tests are applicable only to circuit-breakers designed for direct connection to overhead lines, irrespective of the type of network on the source side, having a rated voltage of 15 kV and above and a rated short-circuit breaking current exceeding 12,5 kA. When circuit-breakers are required for installations necessitating the assignment of rated characteristics for short-line faults, the line on which they are to be used should have a surge impedance and peak-factor not greater than, and a time delay not less than, the standard values of rated line characteristic given in Table 8. However, if this should not be the case, it is still possible that a standard circuit-breaker is suitable, especially if the short-circuit current of the system is less than the rated short-circuit breaking current of the circuit-breaker. This can be established by calculating the prospective TRV for short-line faults from the rated characteristics by the method given in Annex A and comparing this with the prospective TRV derived from the actual characteristics of the system.

If special characteristics for short-line faults are required, they should be agreed between manufacturer and user.

A higher rate of rise than specified in Tables 1, 2, 3, 4 and 5 may occur when one circuit-breaker terminal is transformer-connected. Circuit-breakers tested in accordance with this standard are considered to comply with this higher rate-of-rise requirement, provided that they have satisfied test-duty T30 of the basic short-circuit test series (see 6.106.2).

8.103.3 Selection of out-of-phase characteristics

The requirements of this standard cater for the great majority of applications of circuit-breakers intended for switching during out-of-phase conditions. Several circumstances would have to be combined to produce a severity in excess of those covered by the tests of the standard and, as switching during out-of-phase conditions is rare, it would be uneconomical to design circuit-breakers for the most extreme conditions.

The actual system conditions should be considered when frequent out-of-phase switching is expected or where excessive stresses are probable.

A special circuit-breaker, or one rated at a higher voltage, may sometimes be required. As an alternative solution, the severity of out-of-phase switching duty is reduced in several systems by using relays with coordinated impedance-sensitive elements to control the tripping instant, so that interruption will occur either substantially after or substantially before the instant the phase angle reaches 180°.

In the case of applications of circuit-breakers with rated voltages higher than 800 kV, an out-of-phase angle of approximately 115° is covered; however, higher values of angle are covered when considering other factors such as the non simultaneity of voltage peaks, lower k_{pp} (see IEC 62271-306 [4]).

8.103.4 Selection of rated short-circuit making current

~~As stated in 4.103, the rated short-circuit making current shall correspond to the rated voltage and is related to the rated frequency and the d.c. time constant of the system. For a rated frequency of 50 Hz and based on the standard time constant τ = 45 ms, it shall be 2,5 times (i.e. approximately 1,8√2 times) the a.c. component of the rated short-circuit breaking current of the circuit-breaker. For a rated frequency of 60 Hz and based on the standard time constant τ = 45 ms, it shall be 2,6 times the a.c. component of the rated short-circuit breaking current of the circuit-breaker.~~

~~If one of the special case d.c. time constants (60 ms, 75 ms or 120 ms) stated in 4.101.2 applies, taking the explanations given in I.2 into account, the rated short-circuit making current shall be 2,7 times the a.c. component of the rated short-circuit breaking current of the circuit-breaker, for both 50 Hz and 60 Hz whatever the rated frequency.~~

As stated in 4.103, the rated short-circuit making current is derived from the rated voltage and is related to the rated frequency and the d.c. time constant of the rated short-circuit current. For a rated frequency of 50 Hz and based on a time constant τ = 45 ms, it is 2,5 times (i.e. approximately 1,8√2 times) the a.c. component of the rated short-circuit breaking current of the circuit-breaker. For a rated frequency of 60 Hz and based on a time constant τ = 45 ms, it is 2,6 times the a.c. component of the rated short-circuit breaking current of the circuit-breaker.

If one of the other d.c. time constants (60 ms, 75 ms or 120 ms) stated in 4.101.2 applies, taking the explanations given in I.2 into account, the rated short-circuit making current is 2,7 times the a.c. component of the rated short-circuit breaking current of the circuit-breaker, for both 50 Hz and 60 Hz rated frequencies.

The selected circuit-breaker should have a rated short-circuit making current not less than the highest peak value of the short-circuit currents expected at the application point.

In some cases, for example when induction motors are electrically close, the maximum peak value of the fault current may be more than the a.c. component of the short-circuit current multiplied by the factors given above. In such cases, a special design should be avoided and a standard circuit-breaker having a suitable rated short-circuit making current should be selected.

8.103.5 Operating sequence in service

The rated operating sequence of a circuit-breaker should be one of the operating sequences given in 4.104. Unless otherwise specified, the values of the time intervals given in 4.104 apply and the rated operating sequences provided for are as follows:

a) O – 3 min – CO – 3 min – CO;

b) CO – 15 s – CO;

c) O – 0,3 s – CO – 3 min – CO (for circuit-breakers intended for rapid auto-reclosing).

NOTE Instead of 3 min, other time intervals, namely 15 s for rated voltages less than or equal to 52 kV and 1 min are also used for circuit-breakers intended for rapid auto-reclosing. The interval to be chosen depends in principle upon system requirements such as continuity of service.

If the short-circuit current, which the circuit-breaker is capable of breaking on auto-reclosing, is less than the rated short-circuit breaking current, this should be specified by the manufacturer.

When the operating sequence in service is more severe than is provided for in this standard, this should be specified by the user in his enquiry and/or order in such a way that the manufacturer may modify the rating of the circuit-breaker appropriately. Examples of circuit-breakers for special duty are those used for controlling arc furnaces, electrode boilers and, in certain cases, rectifiers. Single-pole operation of a multi-pole circuit-breaker, for example with a view to single-phase making and breaking, is also a special duty.

8.103.6 Selection of rated duration of short-circuit

The standard value of rated duration of short-circuit (4.7 of IEC 62271-1) is 1 s.

If, however, a lower or higher duration is necessary, the recommended values of 0,5 s, 2 s and 3 s should be selected as the rated value.

For short-circuit durations greater than the rated duration, the relation between current and time, unless otherwise stated by the manufacturer, is in accordance with the equation:

$$I^2 \times t = \text{constant}$$

For self-tripping circuit-breakers, a rated duration of short-circuit shall be assigned only if the maximum time-lag is greater than the prospective one. In such a case, it shall be defined as above.

8.103.7 Faults in the presence of current limiting reactors

Due to the very small inherent capacitance of a number of current limiting reactors, the natural frequency of transients involving these reactors can be very high. A circuit-breaker installed immediately in series with such type of reactor will face a high frequency TRV when clearing a terminal fault (reactor at supply side of circuit-breaker) or clearing a fault behind the reactor (reactor at load side of circuit-breaker). The resulting TRV frequency generally exceeds by far the standardised TRV values.

In these cases, it is necessary to take mitigation measures, such as the application of capacitors in parallel to the reactors or connected to earth. The available mitigation measures are very effective and cost efficient. It is strongly recommended to use them, unless it can be demonstrated by tests that a circuit-breaker can successfully clear faults with the required high frequency TRV.

The mitigation method should be such that the rate-of-rise of TRV for the fault current, as limited by the series reactor, is reduced to a value lower than the standard values given in Tables 24 or 25, depending on the circuit-breaker ratings. It has to be considered that the fault current can be close to 100 % of the rating of the circuit-breaker.

Based on the preceding considerations, no rated values of TRV and no special test duty are specified for this fault case.

8.104 Selection for electrical endurance in networks of rated voltage above 1 kVand up to and including 52 kV

A circuit-breaker class E2 is defined in 3.4.113. Its electrical endurance capability for such service is demonstrated by performing the short-circuit test-duties of 6.106 without intermediate maintenance. This electrical endurance is considered to be sufficient for circuit-breakers used on cable-connected networks where auto-reclosing is not required.

For the more severe conditions of use on an overhead-line connected network, including auto-reclosing duty, a low-maintenance circuit-breaker capable of meeting the electrical endurance requirements specified in 6.112 is recommended.

8.105 Selection for capacitive current switching

Caution is required where capacitor banks are to be installed at substations where cables are already installed, and vice versa, as this can inflict back-to-back switching duties on the controlling circuit-breakers for these circuits. The back-to-back duty may be similar to that detailed in 4.107.4.

9 Information to be given with enquiries, tenders and orders

9.101 Information to be given with enquiries and orders

When enquiring for or ordering a circuit-breaker, the following particulars should be supplied by the enquirer:

a) particulars of systems, i.e. nominal and highest voltages, frequency, number of phases and details of neutral earthing;

b) service conditions including minimum and maximum ambient air temperatures, altitude if over 1 000 m and any special conditions likely to exist or arise, for example unusual exposure to water vapour, moisture, fumes, explosive gases, excessive dust or salt air (see 8.102.5 and 8.102.6);

c) characteristics of circuit-breaker.

The following information should be given:

	Type of information	Reference
1)	number of poles	
2)	class: indoor or outdoor	8.102.5
3)	rated voltage	8.102.1
4)	rated insulation level where a choice exists between different insulation levels corresponding to a given rated voltage, or, if other than standard, the desired insulation level	8.102.2
5)	rated frequency	8.102.3
6)	rated normal current	8.102.4
7)	rated short-circuit breaking current	8.103.1
8)	first-pole-to-clear factor	8.103.2
9)	rated operating sequence	8.103.5
10)	break-time	4.109
11)	the frequency of mechanical operations (class M1 or M2)	4.110
12)	the type tests specified under special request (for example artificial pollution and radio interference, etc.)	6.2.8 and 6.3

The following information should be given, if the required performance is other than standard	
13) desired transient recovery voltage for terminal faults	8.103.2
14) desired characteristics for short-line faults	8.103.2
15) desired short-circuit making current	8.103.4
16) desired duration of short-circuit	8.103.6
The following information should be given in the case of applicability	
17) restrike performance during capacitive current switching (Class C1 or C2)	4.107
18) characteristics for capacitive switching conditions (for example, earthing conditions, type of capacitive load etc.)	4.107
19) rated line-charging breaking current	4.107.1
20) rated cable-charging breaking current	4.107.2
21) rated single capacitor bank breaking current	4.107.3
22) rated back-to-back capacitor bank breaking current	4.107.4
23) rated single capacitor bank inrush making current	4.107.5
24) rated back-to-back capacitor bank inrush making current	4.107.6
25) rated out-of-phase making and breaking current	4.106
26) characteristic for electrical endurance (class E1 or E2 (with/without auto-reclosing duty))	4.111
27) inductive load breaking current	4.108
28) any test exceeding the standardised type, routine and commissioning tests	

d) characteristics of the operating mechanism of circuit-breaker and associated equipment, in particular:
   1) method of operation, whether manual or power;
   2) number and type of spare auxiliary switches;
   3) rated supply voltage and rated supply frequency;
   4) number of releases for tripping, if more than one;
   5) number of releases for closing, if more than one.

e) requirements concerning the use of compressed gas and requirements for design and tests of pressure vessels.

NOTE The enquirer should give information of any special conditions not included above, that might influence the tender or order (see also the note in 8.101).

9.102 Information to be given with tenders

When the enquirer requests technical particulars of a circuit-breaker, the following information (those which are applicable) should be given by the manufacturer, with the descriptive matter and drawings:

a) rated values and characteristics:

	Type of information	Reference
1)	number of poles	
2)	class: indoor or outdoor, temperature, ice-coating	8.102.5
3)	rated voltage	8.102.1
4)	rated insulation level	8.102.2
5)	rated frequency	8.102.3
6)	rated normal current	8.102.4

7)	rated short-circuit breaking current	8.103.1
8)	first-pole-to-clear factor	8.103.2
9)	rated operating sequence	8.103.5
10)	rated opening time, rated break-time and rated closing time	4.109
11)	class M1 or class M2 for mechanical endurance	4.110
12)	the type tests specified under special request (for example artificial pollution and radio interference etc.)	6.2.8 and 6.3
The following information should be given, if the required performance is other than standard		
13)	transient recovery voltage for terminal faults	8.103.2
14)	characteristics for short-line faults	8.103.2
15)	rated short-circuit making current	8.103.4
16)	rated duration of short-circuit	8.103.6
The following information should be given in the case of applicability		
17)	restrike performance during capacitive current switching (Class C1 or C2)	4.107
18)	characteristics for capacitive current switching conditions	4.107
19)	rated line-charging breaking current	4.107.1
20)	rated cable-charging breaking current	4.107.2
21)	rated single capacitor bank breaking current	4.107.3
22)	rated back-to-back capacitor bank breaking current	4.107.4
23)	rated single capacitor bank inrush making current	4.107.5
24)	rated back-to-back capacitor bank inrush making current	4.107.6
25)	rated out-of-phase making and breaking current	4.106
26)	class E1 or class E2 (with/without auto re-close) for electrical endurance	4.111
27)	class S1, S2 circuit-breakers (circuit-breakers with rated voltage less than 100 kV)	6.104.5
28)	inductive load breaking current	4.108
29)	any test exceeding the standardised type, routine and commissioning tests	

b) type tests:

certificate or report on request;

c) constructional features:

The following details are required where they are applicable to the design:

1) mass of complete circuit-breaker without fluids for insulation, interruption and operation;
2) mass/volume of fluid for insulation, its quality and operating range, including the minimum functional value;
3) mass/volume of fluid for interruption (where different fluid to items 2) and/or 4)), its quality and operating range, including the minimum functional value;
4) mass/volume of fluid for operation (where different fluid to items 2) and/or 3)), its quality and operating range, including the minimum functional value;
5) tightness qualification;
6) mass/volume of fluids per pole to fill to a level sufficient to prevent deterioration of internal components during storage and transportation;
7) number of units in series per pole;
8) minimum clearances in air:
   - between poles;
   - to earth;
   - the safety boundaries during a breaking operation, for circuit-breakers with an external exhaust for ionised gasses or flame;

9) any special arrangements (for example heating or cooling) to maintain the rated characteristics of the circuit-breaker at the required temperatures of the ambient air;

d) operating mechanism of circuit-breaker and associated equipment:

1) type of operating mechanism;
2) whether the circuit-breaker is suitable for trip-free or fixed trip operation and whether it is provided with a lock-out device preventing closing;
3) rated supply voltage and/or pressure of closing mechanism, pressure limits where different to or expanding data required in c) 4) of 9.102;
4) current required at rated supply voltage to close the circuit-breaker;
5) energy expended to close the circuit-breaker, for example measured as a fall in pressure;
6) rated supply voltage of shunt opening release;
7) current required at rated supply voltage for shunt opening release;
8) number and type of spare auxiliary switches;
9) current required at rated supply voltage by other auxiliaries;
10) setting of high and low pressure interlocking devices;
11) number of releases for tripping, if more than one;
12) number of releases for closing, if more than one;

e) overall dimensions and other information:

The manufacturer should give the necessary information as regards the overall dimensions of the circuit-breaker and details necessary for the design of the foundation.

General information regarding maintenance of the circuit-breaker and its connections should be given.

10 Rules for transport, storage, installation, operation and maintenance

Clause 10 of IEC 62271-1 is applicable, with the following additions:

10.1 Conditions during transport, storage and installation

Subclause 10.1 of IEC 62271-1 is applicable.

10.2 Installation

Subclauses 10.2.1 to 10.2.4 of IEC 62271-1 are applicable, with the following addition:

10.2.101 Commissioning tests

After a circuit-breaker has been installed and all connections have been completed, commissioning tests are recommended to be performed. The purpose of these tests is to confirm that transportation and storage have not damaged the circuit-breaker. In addition, when a large part of the assembly and/or of the adjustment is performed on site, as identified in 7.101, the tests are required to confirm compatibility of the sub-components and the satisfactory nature of both the site work and the functional characteristics dependent upon it.

In addition to the requirements of 10.2.102, a minimum of 50 no-load operations shall be performed on site on the circuit-breaker where major sub-assemblies are combined at site without previous routine tests on the complete circuit-breaker. These operations shall be performed after assembly, all connections and checks having been made and the programme of commissioning tests having been completed. These operations may include deferred routine test operations forming part of the commissioning programme only where they are made after all site adjustments and tightness checks are complete. The purpose of these tests is to reduce occurrences of maloperation and failure early in the operational life of the circuit-breaker.

The manufacturer shall produce a programme of site commissioning checks and tests. Repetition of the full programme of routine tests, already performed in the factory, shall be avoided as the purpose of commissioning tests is for confirmation of

– absence of damage;
– compatibility of separate units;
– correct assembly;
– correct performance of the assembled circuit-breaker.

In general, this is achieved when the commissioning tests include, but are not limited to, the programme given in 10.2.102. The results of the tests shall be recorded in a test report.

10.2.102 Commissioning checks and test programme

10.2.102.1 Checks after installation

Subclause 10.2.101 requires the manufacturer to produce a programme of commissioning checks and tests. This should be based on, but is not limited to, the programme of checks and tests given here.

10.2.102.1.1 General checks

– assembly conforms to manufacturer's drawings and instructions;
– tightness of circuit-breaker, its fastenings, fluid systems and control devices;
– external insulation and, where applicable, internal insulation are undamaged and clean;
– paint and other corrosion protection are sound;
– operating devices, especially operating releases, are free from contamination;
– adequacy and integrity of the earth connection up to and including the interface with the substation earthing system;

and, where applicable:

– record the number on the operations counter(s) at delivery;
– record the number on the operations counter(s) at completion of all site testing;
– record the number on the operations counter(s) at first energisation.

10.2.102.1.2 Checks of electrical circuits

– Conformity to the wiring diagram.
– Correct operation of signalling (position, alarms, lockouts, etc.).
– Correct operation of heating and lighting.

10.2.102.1.3 Checks of the insulation and/or extinguishing fluid(s)

Oil	Type, dielectric strength (IEC 60296), level
SF_6	Filling pressure/density, and quality checks, to confirm the acceptance levels of IEC 60376, IEC 60480 and IEC 61634. These quality checks are not required on sealed equipment and new gas used from sealed bottles. A dewpoint check and a check of the total impurities shall be carried out to confirm the manufacturer's acceptance levels
Gas mixtures	Quality to be confirmed prior to energisation

Compressed air	Quality (if applicable) and pressure

10.2.102.1.4 Checks on operating fluid(s), where filled or added to on site

Hydraulic oil	Level and, unless otherwise agreed, confirmation that the moisture content is sufficiently low to prevent internal corrosion or other damage to the hydraulic system
Nitrogen	Filling pressure and purity (for example oxygen free or 1 % tracer gas)

10.2.102.1.5 Site operations

Confirmation shall be given that the programme of commissioning checks and tests required by 7.101 has been completed and, where applicable, extended by the additional 50 operations required by 10.2.101.

10.2.102.2 Mechanical tests and measurements

10.2.102.2.1 Measurements of the characteristic insulating and/or interrupting fluid pressures (where applicable)

10.2.102.2.1.1 General

The following measurements shall be taken in order to compare them with the values both recorded during the routine tests and guaranteed by the manufacturer. These values serve as the reference for future maintenance and other checks and will enable any drift in operating characteristics to be detected.

These measurements involve a check of the operation of the alarm and lockout devices (pressure switches, relays, transducers, etc.) where applicable.

10.2.102.2.1.2 Measurements to be taken

a) Where applicable, on rising pressure:
   – the reset value of the opening/tripping lockout;
   – the reset value of the closing lockout;
   – the reset value of the auto-reclosing lockout;
   – disappearance of the low-pressure alarm.
b) Where applicable, on dropping pressure:
   – appearance of low-pressure alarm;
   – operating value of lockout of the auto-reclosing feature;
   – operating value of lockout of the closing;
   – operating value of lockout of the opening.

10.2.102.2.2 Measurements of characteristic operating fluid pressures (if applicable)

10.2.102.2.2.1 General

The following measurements (list to be adapted as necessary) should be taken, in order to compare them with the values both recorded during routine tests and guaranteed by the manufacturer. These values may serve as a reference during later checks (maintenance) and will enable any drift in operating characteristics to be detected.

The measurements involve a check of the operation of the lockout or alarm devices (pressure switches, relays, etc.).

10.2.102.2.2.2 Measurements to be taken

a) On a rise in pressure with the pumping device (pump, compressor, controlled valve, etc.) in service:
   - the reset value of the opening lockout;
   - the reset value of the closing lockout;
   - the reset value of the auto-reclosing lockout (if applicable);
   - disappearance of the low-pressure alarm;
   - cut-off of the pumping device;
   - opening of the safety valve (if applicable).

NOTE The measurements may be combined with the measurements of the recharging time of the operating mechanism (see 10.2.102.2.5.2).

b) On a drop in pressure with the pumping device switched off:
   - closing of the safety valve (if applicable);
   - starting of the pumping device;
   - appearance of the low-pressure alarm;
   - lockout of the auto-reclosing (if applicable);
   - lockout of the closing;
   - lockout of the opening.

In the case of a hydraulic control, the pre-inflation pressure of the accumulators should be indicated together with the ambient air temperature before the tests are performed.

10.2.102.2.3 Measurement of consumption during operations (if applicable)

With the pumping device switched off and the individual reservoir at the cut-in pressure of the pumping device, the consumption during each of the following operations or operating sequences should be evaluated:

- O three-pole;
- C three-pole;
- O – 0,3 s – CO three-pole (if applicable).

The steady-state pressure after each operation or operating sequence should be noted.

10.2.102.2.4 Verification of the rated operating sequence

The ability of the circuit-breaker to perform its specified rated operating sequence should be verified. The tests should be performed with the recharging device in service, with site supply voltage and, if applicable, starting with the cut-in pressure of the pumping device, as in 10.2.102.2.3.

Evidence should be given to demonstrate the coordination between the interlocking device intervention levels and the minimum pressures for operation measured during the rated operating sequence.

The site supply voltage is the on-load voltage available at the circuit-breaker from the normal site supply and should be compatible with the rated supply voltage of auxiliary and control circuits.

10.2.102.2.5 Measurement of time quantities

10.2.102.2.5.1 Characteristic time quantities of the circuit-breaker

a) Closing and opening times, time spread

The following measurements should be made at maximum pressure (cut-off of pumping device) and at the supply voltage of the auxiliary and control circuits, measured at the terminals of the equipment and under typical load conditions of the supply voltage source:

– closing time of each pole, time spread of the poles and when possible time spread of the breaking units or groups of units of each pole;

– opening time of each pole, time spread of the poles and when possible time spread of the breaking units or groups of units of each pole.

These measurements should be carried out for separate opening and closing operations and for the individual opening and closing operations of a CO operating cycle, in case of a circuit-breaker with a rated operating sequence CO – t''– CO, or of an O – t – CO operating sequence, in case of a circuit-breaker with a rated operating sequence O – t – CO – t' – CO.

In the case of multiple trip coils, all should be tested and the times recorded for each.

The supply voltage before and during the operations should be recorded. Furthermore the instant at which the three-pole control relay, if any, is energised should also be recorded to enable calculation of the total time in three-pole operation (relay time plus closing or opening time).

When the circuit-breaker is provided with resistor closing or opening units, the resistor insertion times should be recorded.

b) Operation of control and auxiliary contacts

The timing of the operation of one of each kind (make and break) of control and auxiliary contacts should be determined in relation to the operation of the main contacts, on closing and on opening of the circuit-breaker.

10.2.102.2.5.2 Recharging time of the operating mechanism

a) Fluid-operated mechanism

The operation time of the pumping device (pump, compressor, control valve, etc.) should be measured:

– between minimum and maximum pressure (cut-in and cut-off of the pumping device);

– during the following operations or operating sequence, starting each time with minimum pressure (cut-in of the pumping device):

  – C three-pole;

  – O three-pole;

  – O – 0,3 s – CO three-pole (if applicable).

b) Spring-operated mechanism

The recharging time of the motor after a closing operation should be measured at the site supply voltage.

10.2.102.2.6 Record of mechanical travel characteristics

As required by 7.101, a record can be made of the mechanical travel characteristics where the circuit-breaker has been assembled as a complete circuit-breaker for the first time on site or where all or part of the routine tests are performed on site. The record shall confirm satisfactory performance by comparison with the reference mechanical travel characteristics obtained during the reference no-load tests detailed in 6.101.1.1.

10.2.102.2.7 Checks of certain specific operations

10.2.102.2.7.1 Auto-reclosing at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered to the lockout value for auto-reclosing and an auto-reclosing operating sequence be carried out (under site conditions it may be necessary to use a separate timing device to initiate reclosure). The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted and it should be ensured that there is sufficient safety margin to the minimum functional pressure for operation for opening, as a guard against pressure switch deviation and pressure transients.

In case of doubt, an alternative test to the one described above may be performed, starting with a lower pressure than the minimum functional pressure for operation for auto-reclosing (short-circuited contact). It should then be verified that an opening operation is still possible.

10.2.102.2.7.2 Closing at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered as far as the lockout value for closing and a closing operation be carried out. The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted and a sufficient safety margin ensured to the minimum functional pressure for operation for opening.

In case of doubt, an alternative test to the one described above may be performed, starting with a lower pressure than the minimum functional pressure for operation for closing (short-circuited contact). It should then be verified that an opening operation is still possible.

10.2.102.2.7.3 Opening at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered as far as the lockout value for opening and an opening operation be carried out. The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted.

10.2.102.2.7.4 Simulation of fault-making operation and check of anti-pumping device

Measurement should be taken of the time during which the circuit-breaker remains closed on a CO operating cycle with the trip circuit energised by the closing of the auxiliary contact.

The test also allows checking of the anti-pumping device operation and the absence of malfunction for any mechanical, hydraulic or pneumatic reasons, caused by the rapid application of the opening command.

The closing command should be maintained for 1 s to 2 s in order that the anti-pumping device can be checked for effective operation.

NOTE A simplified anti-pumping test may also be executed, using the local control. In this case, a closing command is applied and maintained, while a consecutive opening command is applied.

10.2.102.2.7.5 Behaviour of the circuit-breaker on a closing command while an opening command is already present

It should be verified that the circuit-breaker meets the technical specifications in the presence of a closing command when previously an opening command is applied and maintained.

10.2.102.2.7.6 Application of an opening command on both releases simultaneously (if applicable)

It may happen that both releases (normal and emergency) are energised simultaneously (or virtually simultaneously).

It should be ensured that the operations are not subject to any mechanical, hydraulic or pneumatic interference, particularly if the releases do not operate at the same level.

10.2.102.2.7.7 Protection against pole discrepancy (if applicable)

Protection against pole discrepancy should be checked by either of the following tests:

– with the circuit-breaker open, the closing release of one of the poles shall be energised and a check carried out to see that it closes and then opens;

– with the circuit-breaker closed, the opening release of one of the poles shall be energised and a check carried out to see that the other two poles open.

10.2.102.3 Electrical tests and measurements

10.2.102.3.1 Dielectric tests

Dielectric tests on auxiliary circuits shall be performed to confirm that transportation and storage of the circuit-breaker have not damaged these circuits. However, it is recognised that such circuits contain vulnerable sub-components and the application of the full testing voltage for the full duration can cause damage. In order to avoid this, and to avoid the temporary removal of proven connections, the supplier shall detail the test process that demonstrates that damage has not occurred as well as the method of recording the results from this test process.

For dielectric tests on the main circuit of metal-enclosed switchgear and controlgear, IEC 62271-200 [9] and IEC 62271-203 [10] are applicable.

10.2.102.3.2 Measurement of the resistance of the main circuit

Measurement of the resistance of the main circuit need only be made if interrupting units have been assembled on site. The measurement shall be made with a direct current in accordance with 7.3 of IEC 62271-1.

10.3 Operation

Subclause 10.3 of IEC 62271-1 is applicable.

10.4 Maintenance

Subclause 10.4 of IEC 62271-1 is applicable with the following addition:

In addition, the manufacturer should give information regarding the maintenance of circuit-breakers following

a) short-circuit operations;

b) operations in normal service.

This information should include the number of operations according to items a) and b) after which the circuit-breaker is to be overhauled.

Subclauses 10.4.1 to 10.4.3 of IEC 62271-1 are applicable. The checks required in 10.2.102.1.3 apply.

10.4.101 Resistors and capacitors

When checking resistors and capacitors, allowed variations of the values should be given.

11 Safety

Clause 11 of IEC 62271-1 is applicable with the following addition:

Any known chemical and environmental impact hazards should be identified in the circuit-breaker handbook/manual.

12 Influence of the product on the environment

Clause 12 of IEC 62271-1 is applicable.

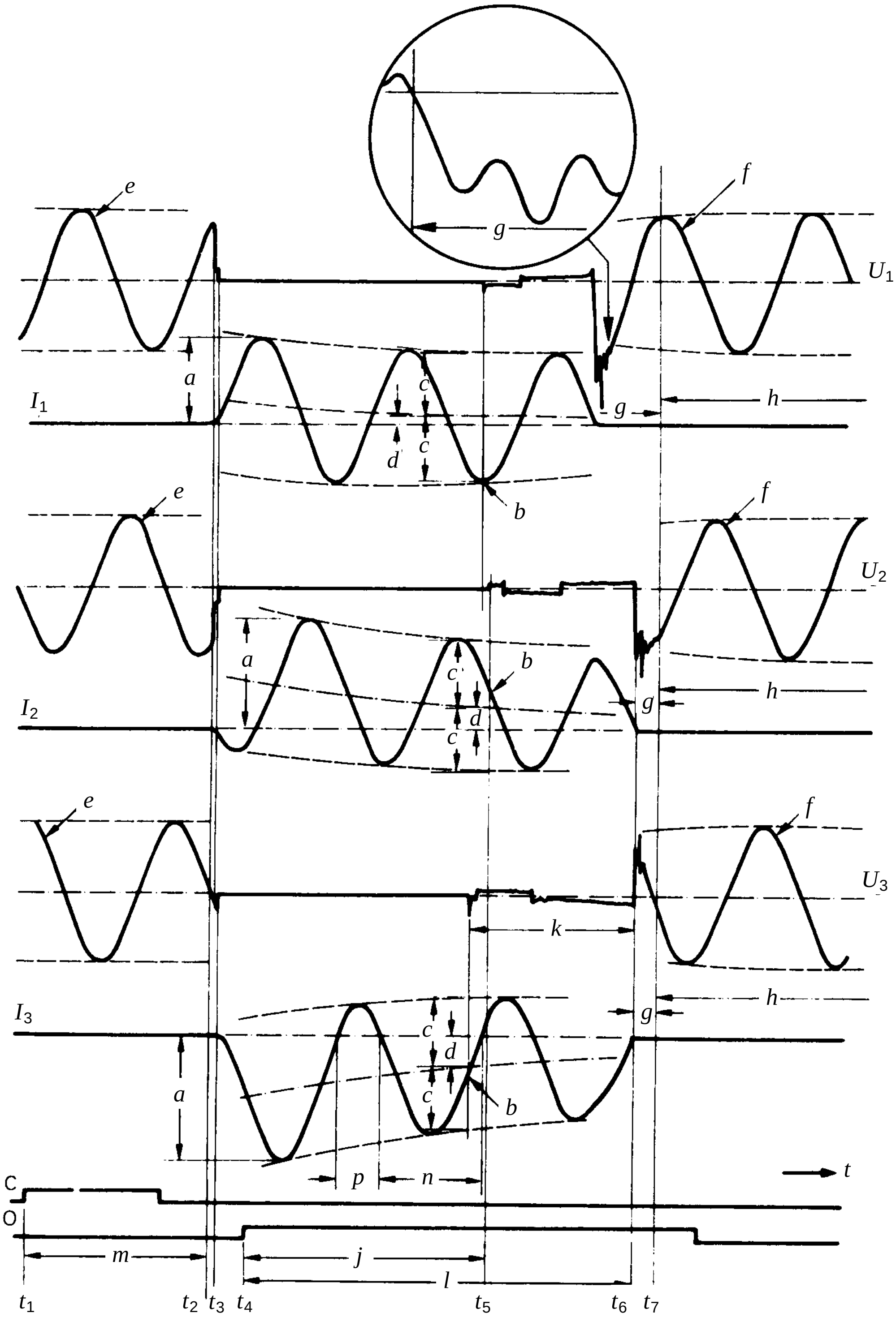


Figure 1 – Typical oscillogram of a three-phase short-circuit make-break cycle

Legend to Figure 1:

U_1 voltage across the terminals of the first pole to clear

I_1 current in the first pole to clear

U_2, U_3 voltage across the terminals of the two other poles

I_2, I_3 current in the two other poles

C closing command, e.g. voltage across the terminals of the closing circuit

O opening command, e.g. voltage across the terminals of the opening release

t_1 the instant of initiation of the closing operation

t_2 the instant when the current begins to flow in the main circuit

t_3 the instant when the current is established in all poles

t_4 the instant of energizing the opening release

t_5 the instant when the arcing contacts have separated (or instant of initiation of the arc) in all poles

t_6 the instant of final arc extinction in all poles

t_7 the instant when the transient voltage phenomena have subsided in the last pole to clear

a (peak) making current

b breaking current

c peak value of the alternating component

d direct current component

e applied voltage

f recovery voltage

g transient recovery voltage

h power frequency recovery voltage

j opening time

k arcing time

l break time

m make time

n major loop

p minor loop

Notes to the following Figures 2 to 7:

NOTE 1 In practice, there will be a time spread between the travel of the contacts of the three poles. For clarity the travel of the contacts in the figures is indicated with a single line for all three poles.

NOTE 2 In practice, there will be a time spread between both the start and end of current flow in the three poles. For clarity, both the start and end of current flow in the figures is indicated with a single line for all three poles.

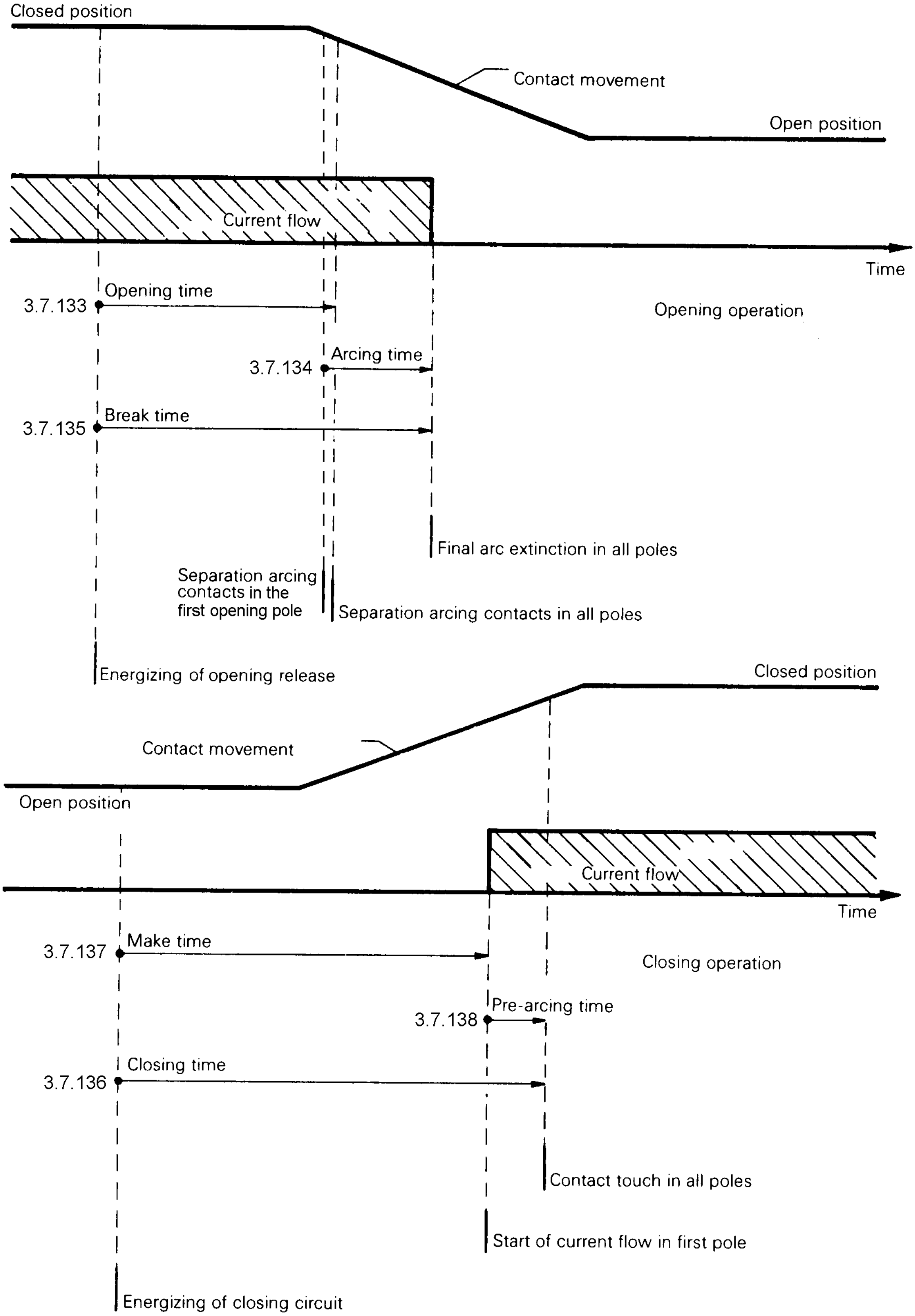


Figure 2 – Circuit-breaker without switching resistors – Opening and closing operations

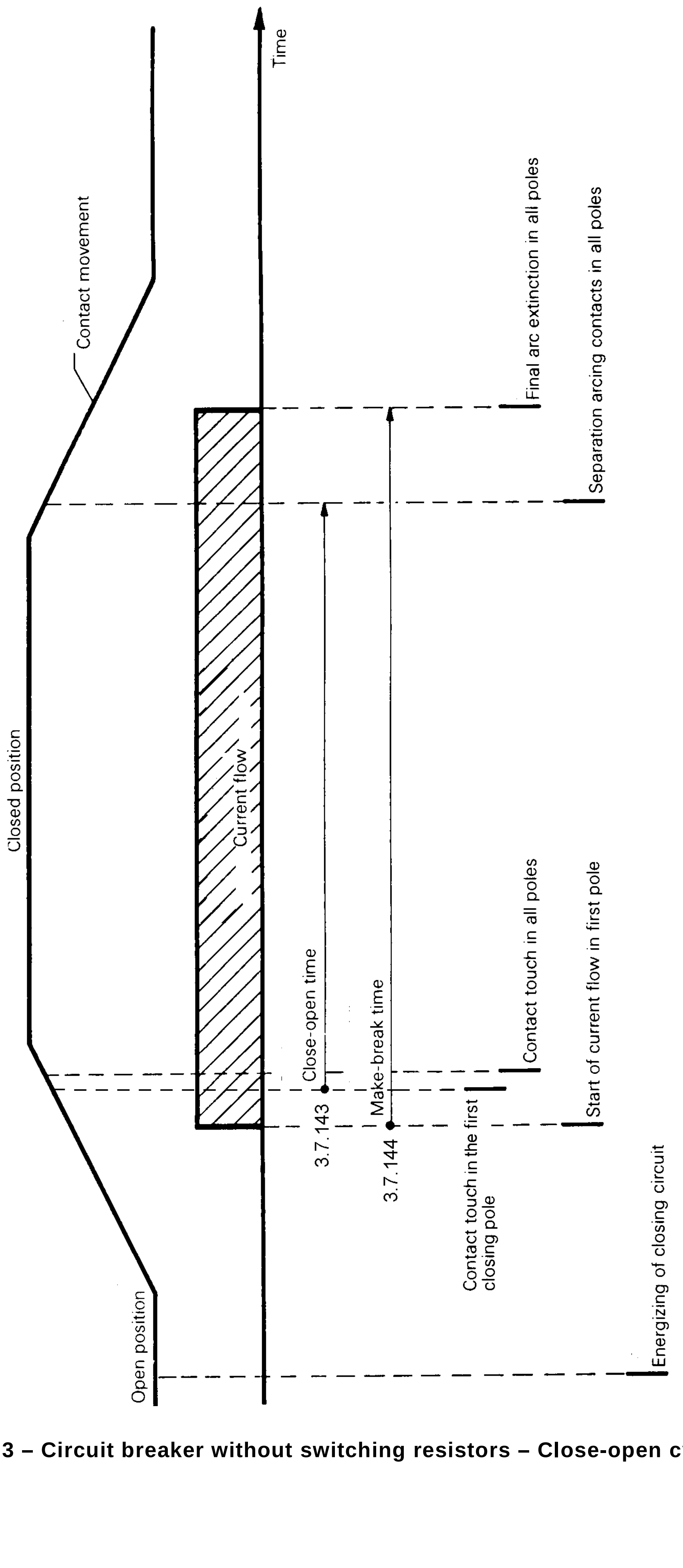


Figure 3 – Circuit breaker without switching resistors – Close-open cycle

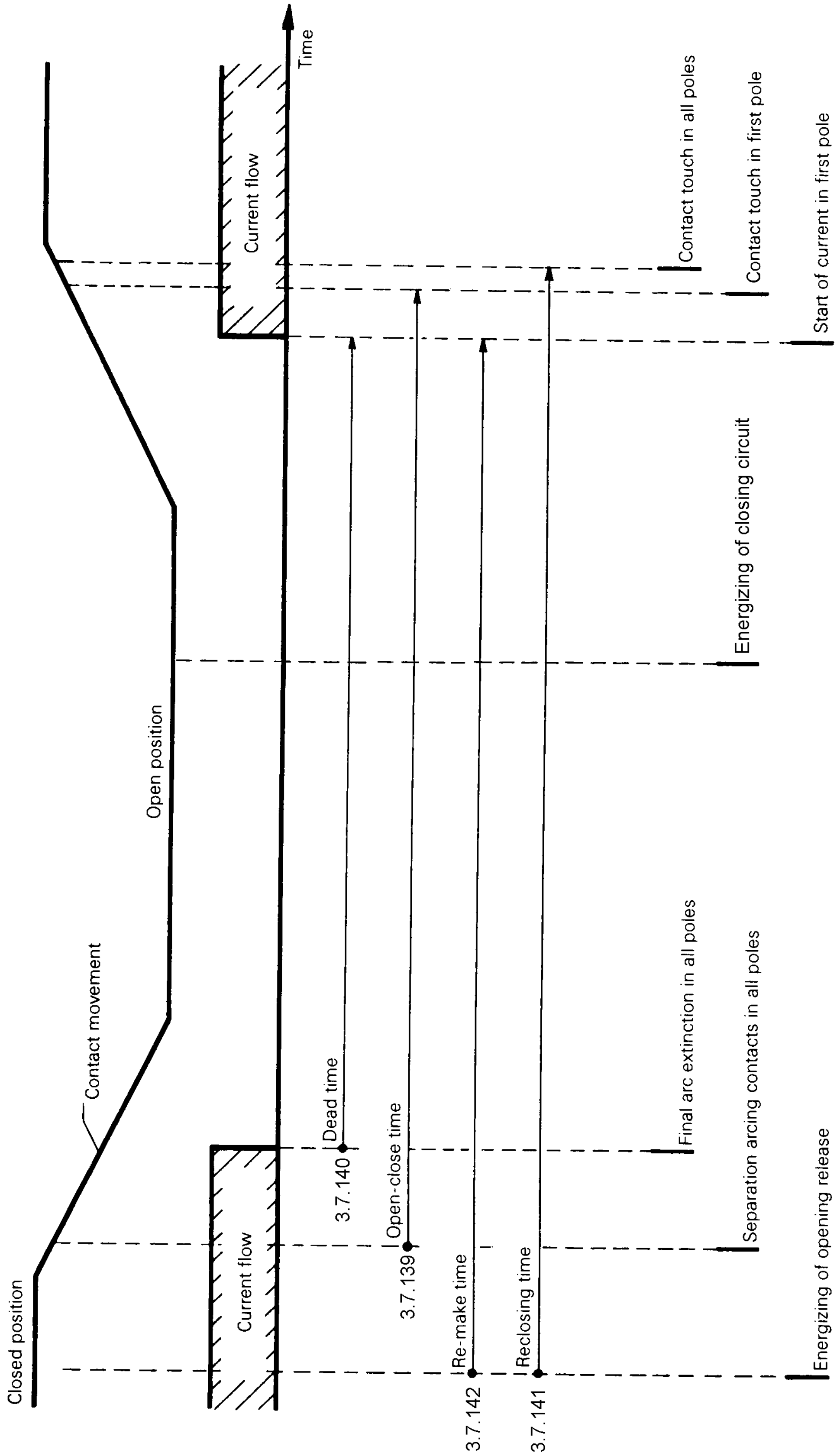


Figure 4 – Circuit-breaker without switching resistors – Reclosing (auto-reclosing)

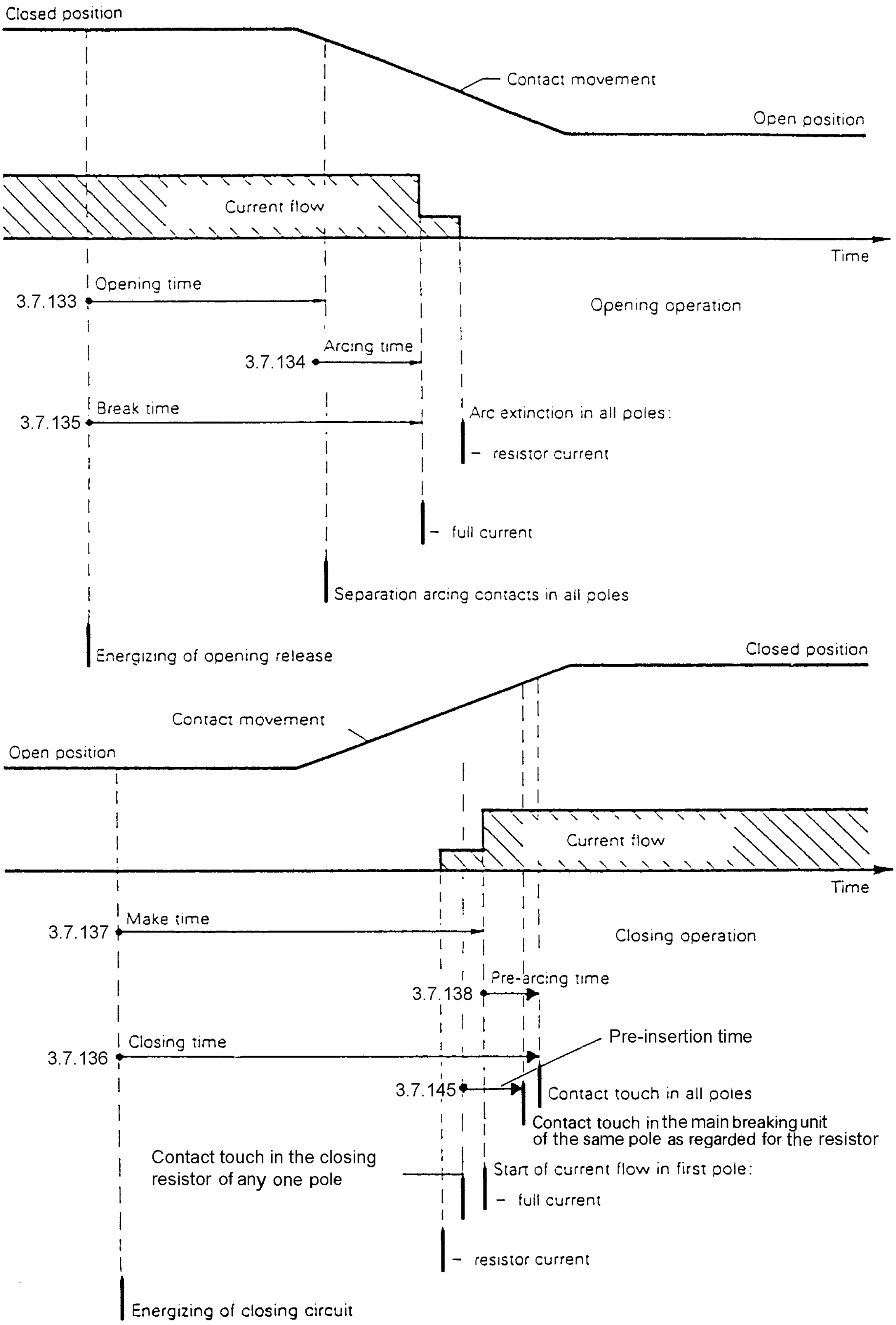


Figure 5 – Circuit-breaker with switching resistors – Opening and closing operations

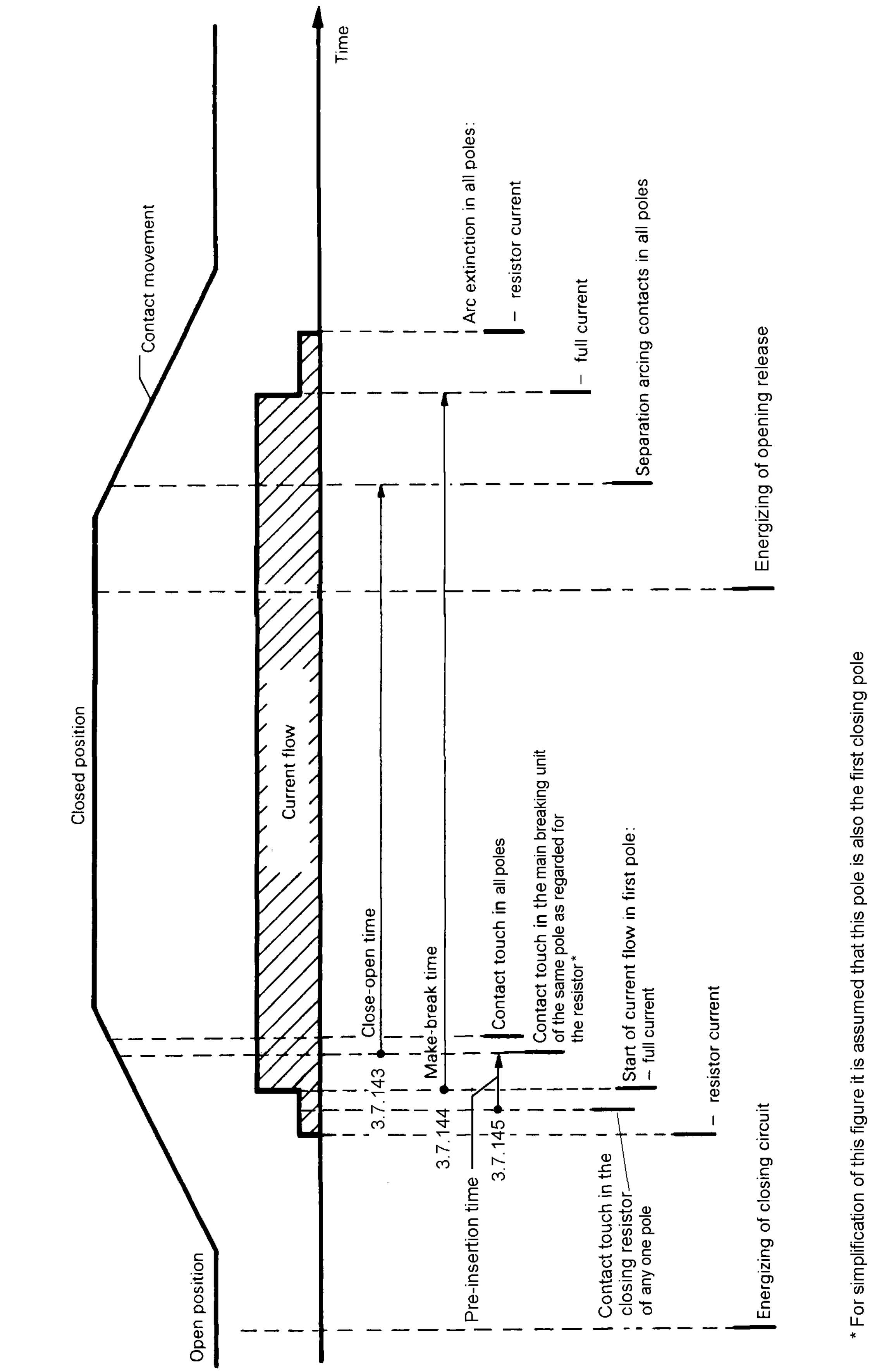


Figure 6 – Circuit-breaker with switching resistors – Close-open cycle

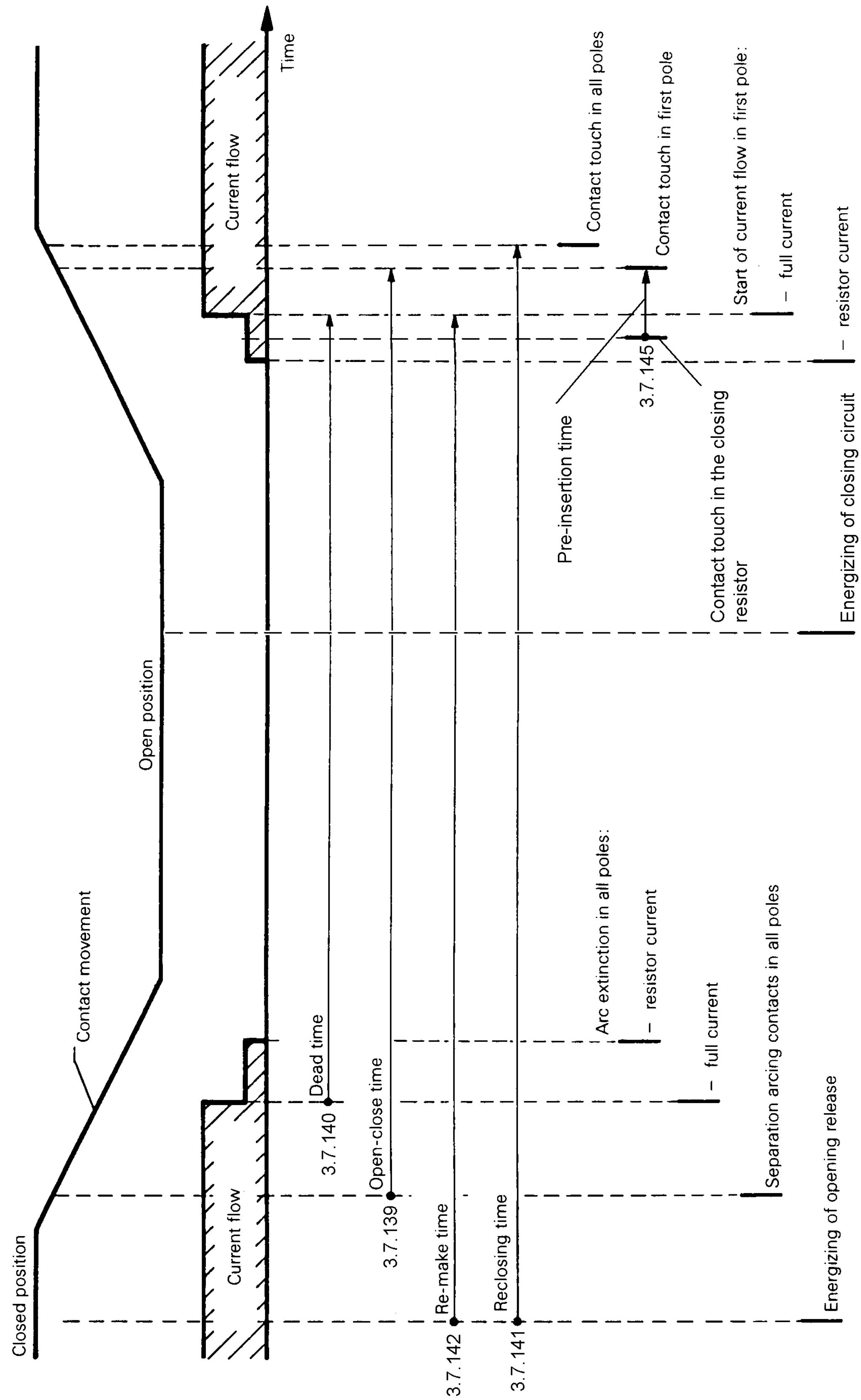
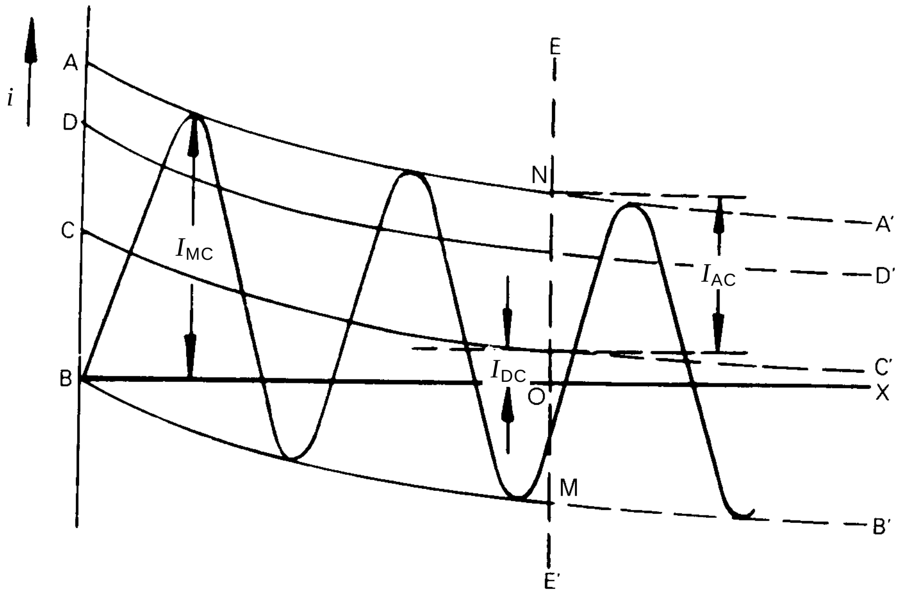


Figure 7 – Circuit-breaker with switching resistors – Reclosing (auto-reclosing)



AA' BB'	envelope of current-wave
BX	normal zero line
CC'	displacement of current-wave zero-line at any instant
DD'	r.m.s. value of the a.c. component of current at any instant, measured from CC'
EE'	instant of contact separation (initiation of the arc)
I_{MC}	making current
I_{AC}	peak value of a.c. component of current at instant EE'
$\frac{I_{AC}}{\sqrt{2}}$	r.m.s. value of the a.c. component of current at instant EE'
I_{DC}	d.c. component of current at instant EE'

$\frac{I_{DC}}{I_{AC}}\times 100=\frac{\overline{ON}-\overline{OM}}{\overline{MN}}\times 100=\left(\frac{2\times\overline{ON}}{\overline{MN}}-1\right)\times 100$ percentage value of the d.c. component

Figure 8 – Determination of short-circuit making and breaking currents, and of percentage d.c. component

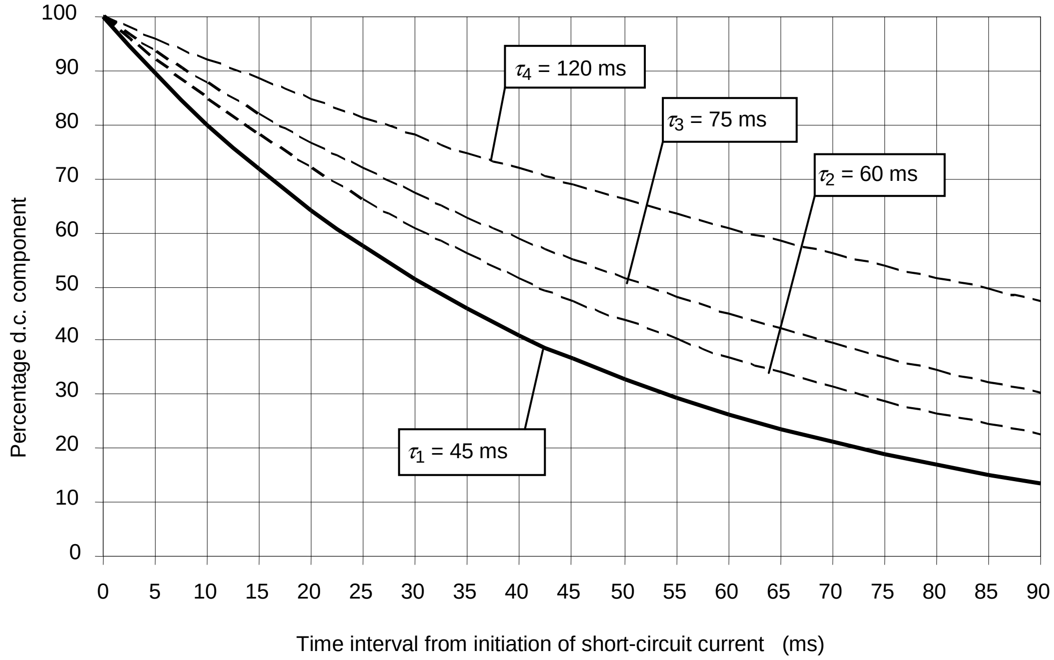


Figure 9 – Percentage d.c. component in relation to the time interval from the initiation of the short-circuit for the ~~standard~~ different time constants ~~τ_1 and for the special case time constants τ_2, τ_3 and τ_4~~

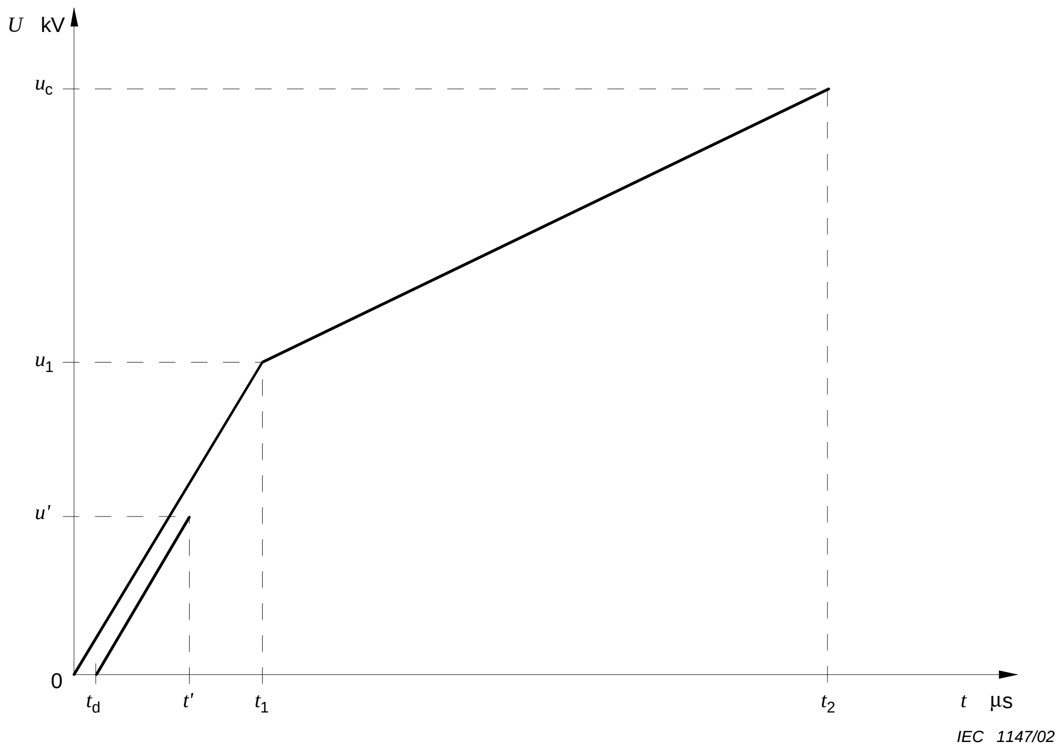


Figure 10 – Representation of a specified four-parameter TRV and a delay line for T100, T60, short-line fault and out-of-phase condition

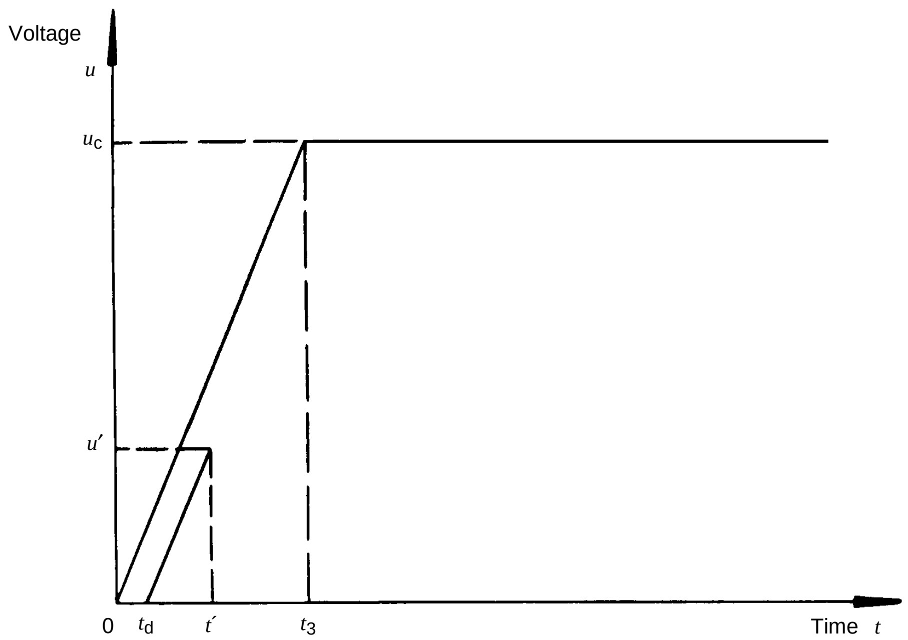
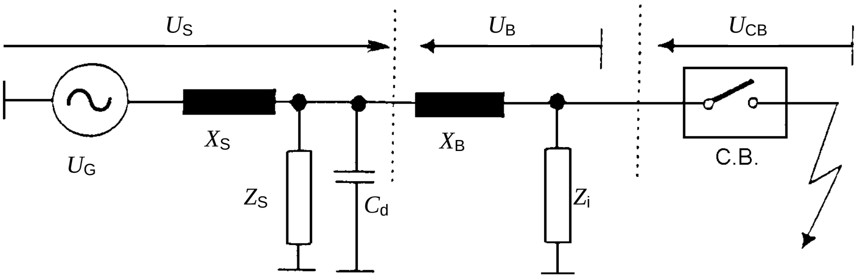


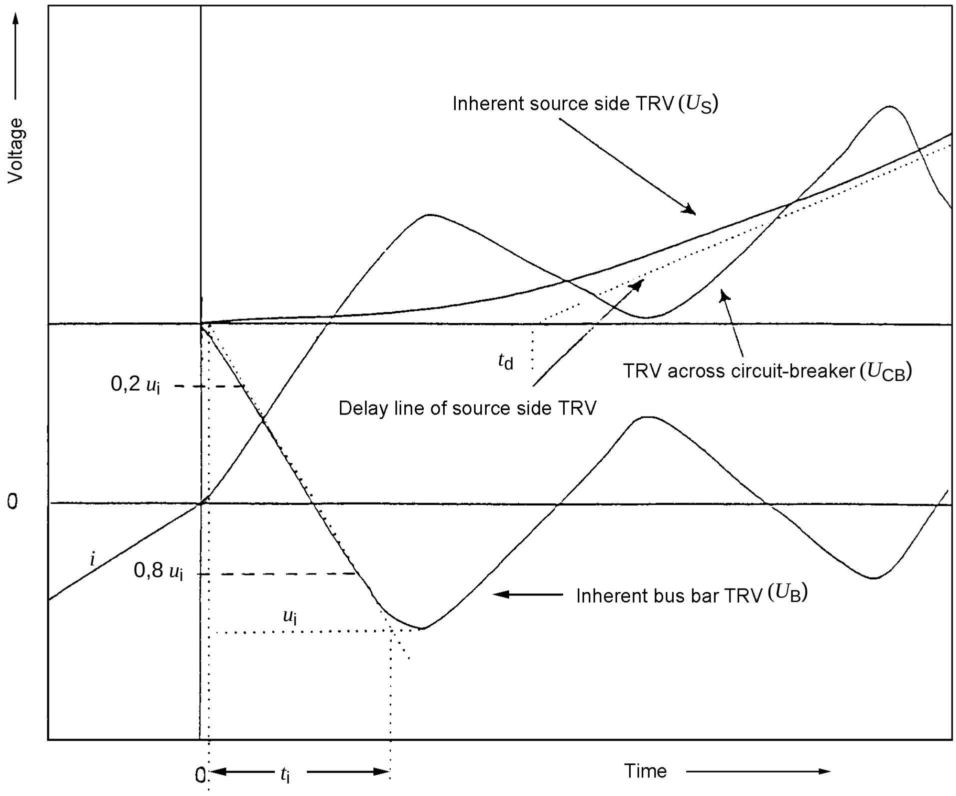
Figure 11 – Representation of a specified TRV by a two-parameter reference line and a delay line



C.B.	circuit-breaker	C_d	time delaying source side capacitance
U_G	supply side voltage	Z_s	source side TRV control components
U_B	bus voltage	Z_i	ITRV controlling components
U_{CB}	voltage across circuit-breaker	X_S	power frequency source side reactance
U_S	source side voltage	X_B	power frequency busbar reactance

NOTE If a lumped inductance is used as X_S, the ITRV controlling components may be connected in parallel to this inductance.

Figure 12a – Basic circuit for terminal fault with ITRV

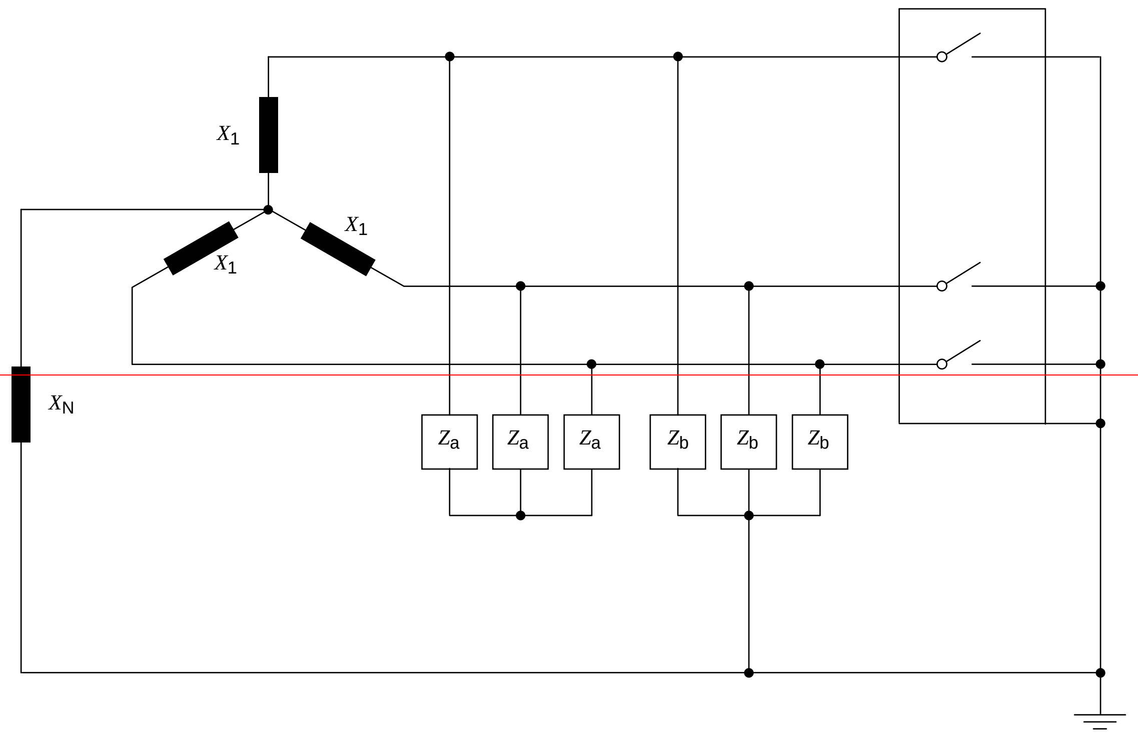


u_i peak voltage of ITRV

t_i time co-ordinate of ITRV

Figure 12b – Representation of ITRV in relationship to TRV

Figure 12 - ITRV circuit and representation of ITRV in relationship to TRV



IEC 1187/06

~~Key~~

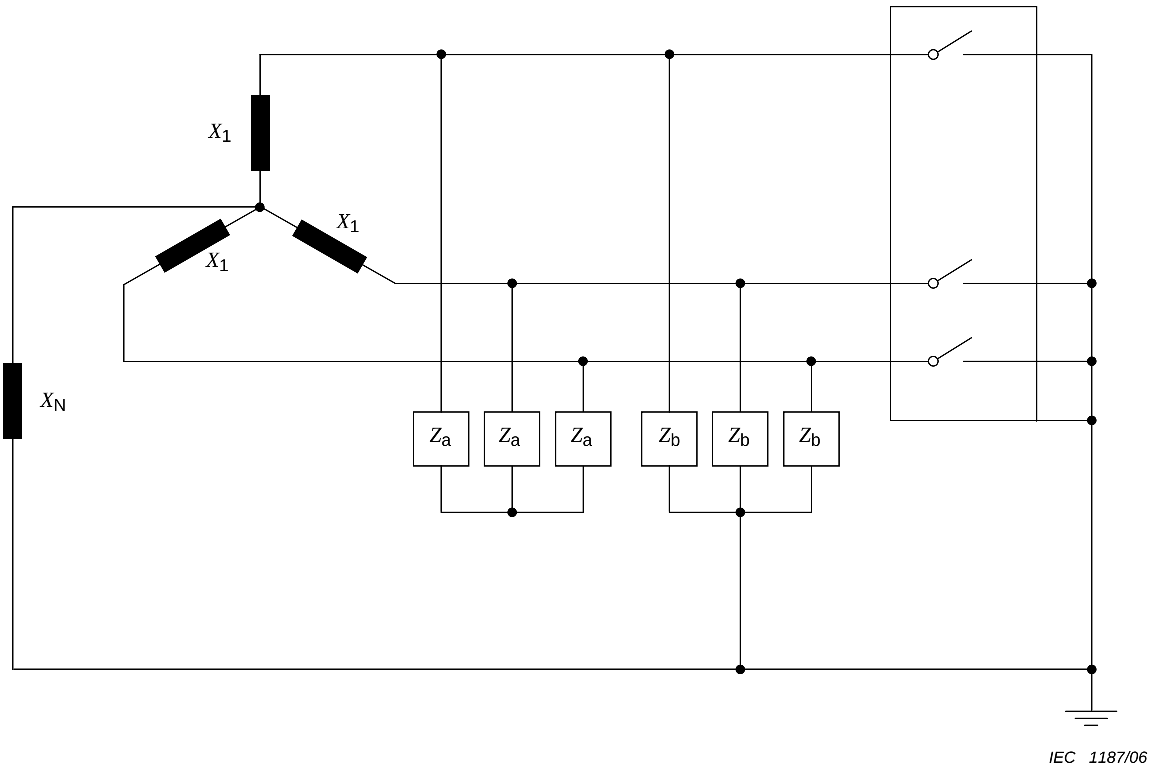
~~X_N~~	~~source neutral impedance~~
~~X_1~~	~~positive sequence short-circuit reactance~~
~~Z_a~~	~~phase-to-phase impedance of TRV circuit~~
~~Z_b~~	~~phase-to-ground impedance of TRV circuit~~

~~X_N much larger than X_1 for first-pole-to-clear factor of 1,5~~

~~X_N 0,75 X_1 for first-pole-to-clear factor of 1,3~~

~~For $Z_0/Z_1 \approx 2$: $Z_a = Z_b = 2Z_1$~~

~~with Z_0 zero sequence component of short-circuit impedance on supply side~~



Key

X_N source neutral impedance

X_1 positive sequence short-circuit reactance

Z_a phase-to-phase impedance of TRV circuit

Z_b phase-to-ground impedance of TRV circuit

X_N much larger than X_1 for first-pole-to-clear factor of 1,5

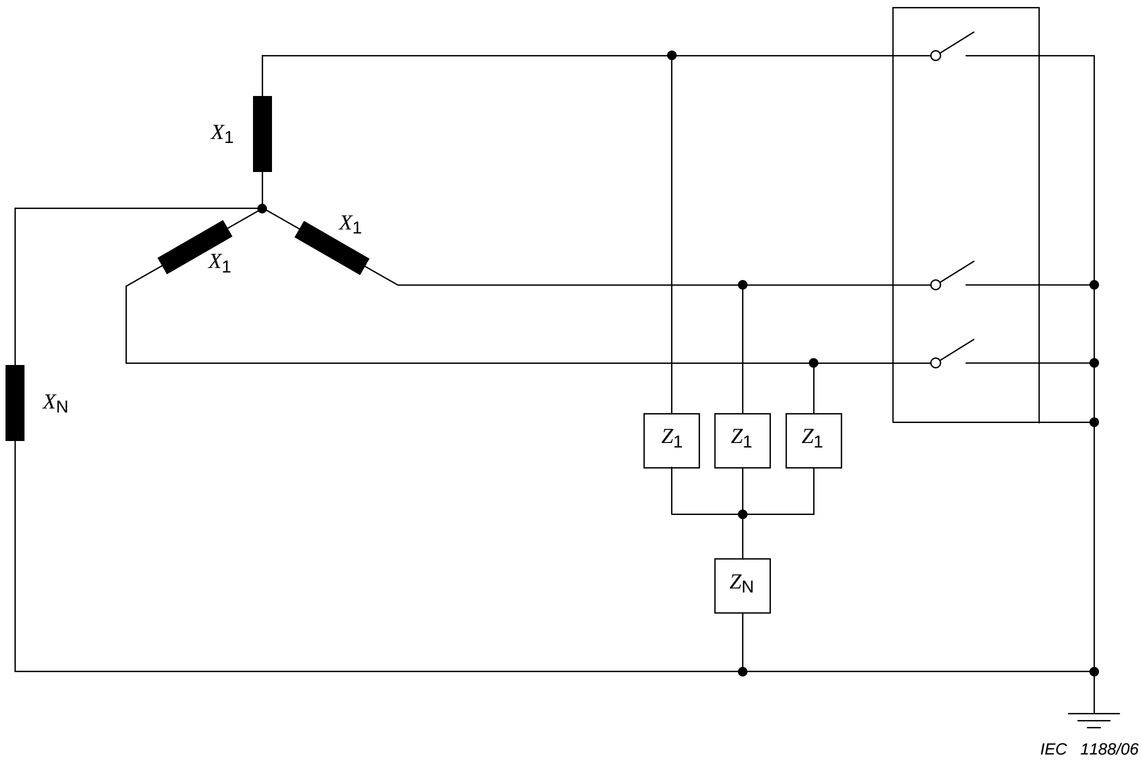
X_N 0,75 X_1 for first-pole-to-clear factor of 1,3

X_N 0,33 X_1 for first-pole-to-clear factor of 1,2

For $Z_0/Z_1 \approx 2$ (for exact values see IEC 62271-306 [4]): $Z_a = Z_b = 2Z_1$

with Z_0 zero sequence component of short-circuit impedance on supply side

Figure 13 – Three-phase short-circuit representation



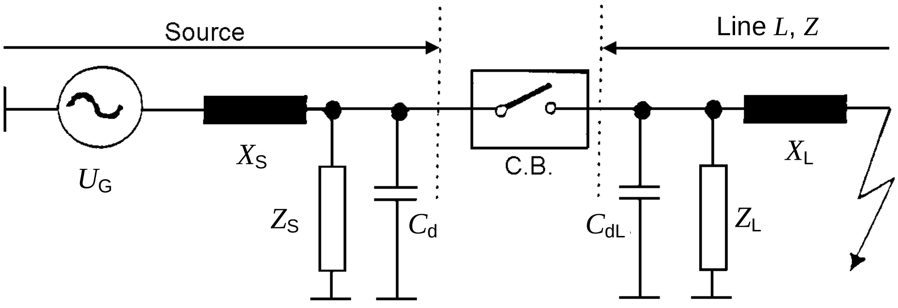
Key

X_N	source neutral impedance
X_1	positive sequence short-circuit reactance
Z_1	phase-to-neutral impedance of TRV circuit
Z_N	neutral impedance of TRV circuit

For $\frac{Z_0}{Z_1} = 2$ $\quad Z_N = \frac{Z_1}{3}$

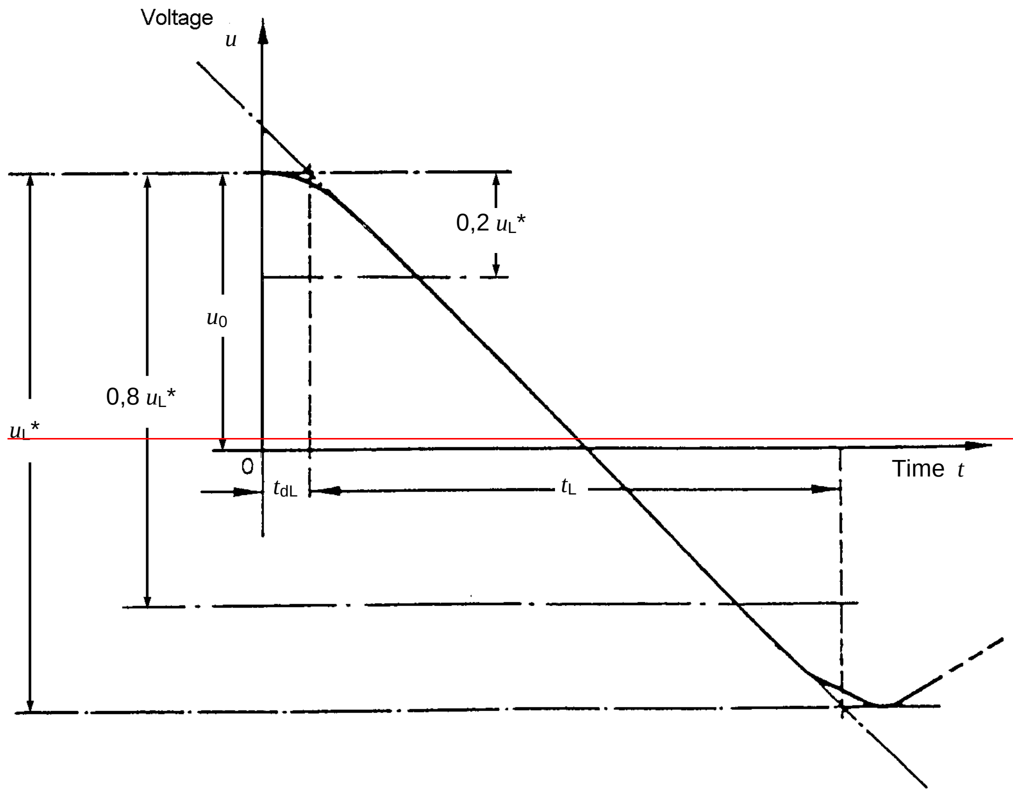
with Z_0 zero sequence of short-circuit impedance on supply side

Figure 14 – Alternative representation of Figure 13



U_G	supply voltage, phase to earth value	X_L	power frequency line side reactance
X_S	power frequency source side reactance	Z_L	line side TRV controlling components
Z_S	source side TRV controlling components	C_{dL}	time delaying line side capacitance
C_d	time delaying source side capacitance	Z	surge impedance of line
C.B.	circuit-breaker	L	length of line to fault

Figure 15 – Basic short-line fault circuit



~~**Figure 16 – Example of a line-side transient voltage with time delay and rounded crest showing construction to derive the values u_L*, t_L and t_{dL}**~~

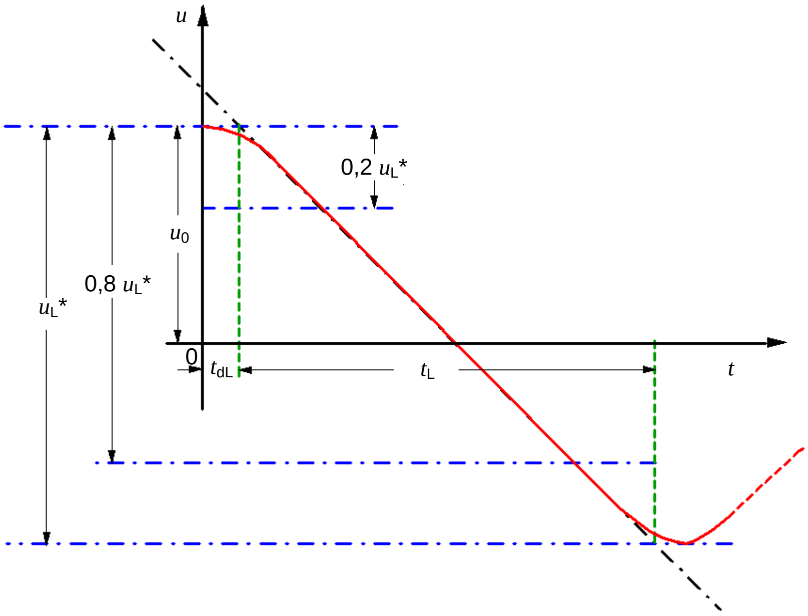


Figure 16a – Example of a line side transient voltage with time delay

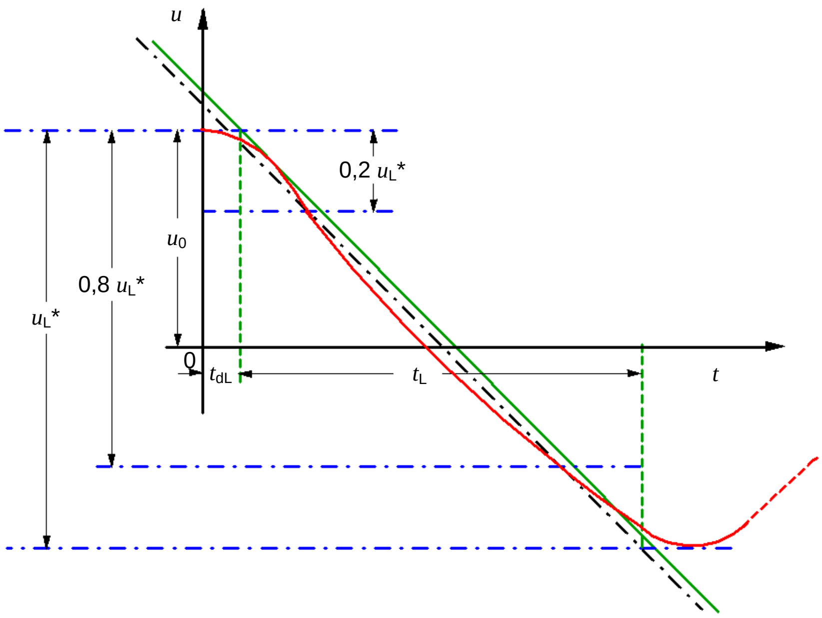
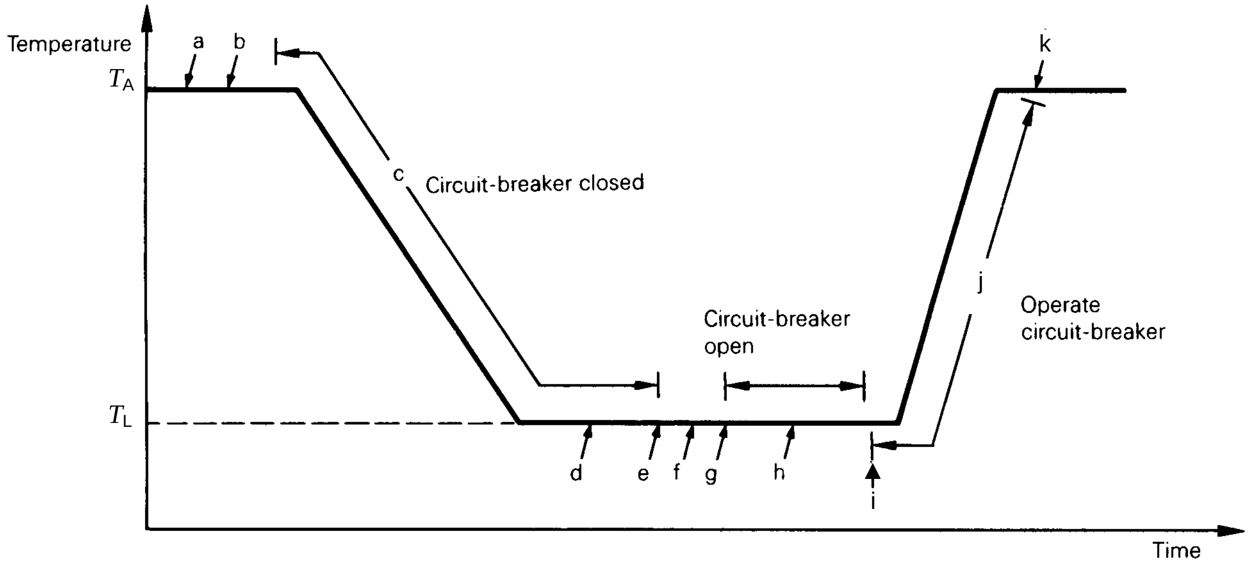
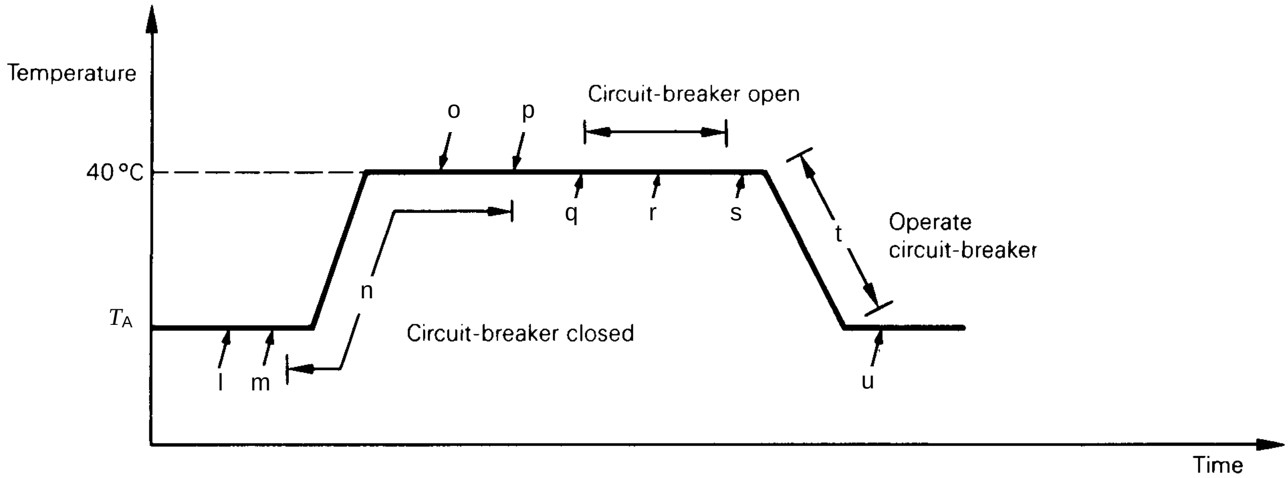


Figure 16b – Example of line transient voltage with time delay with non-linear rate of rise

Figure 16 – Examples of line side transient voltages



a) Low temperature test



b) High temperature test

NOTE Letters a to u identify application points of tests specified in 6.101.3.3 and 6.101.3.4.

Figure 17 – Test sequences for low and high temperature tests

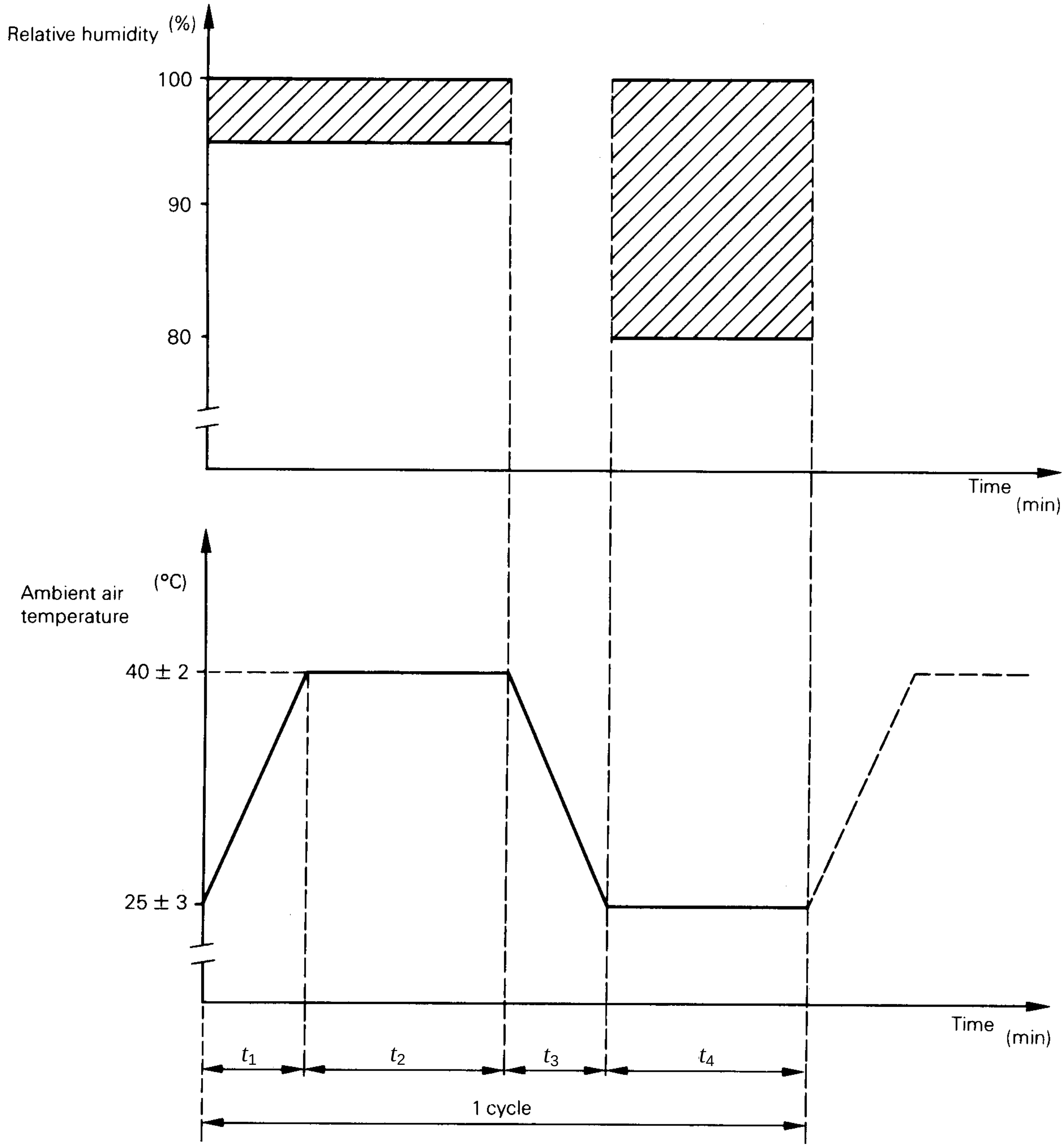
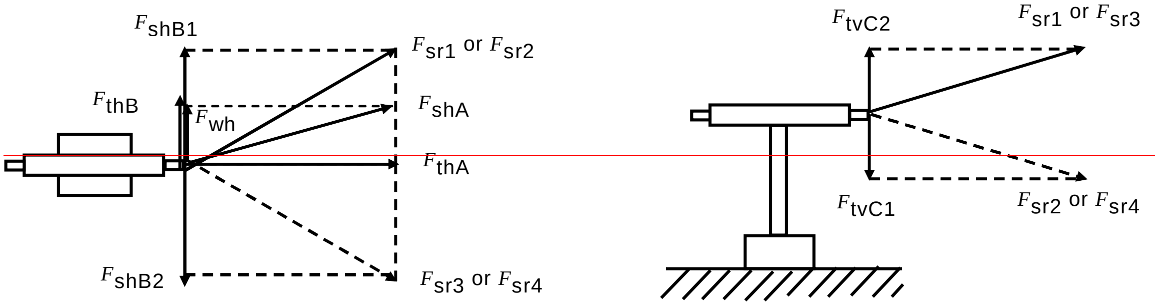


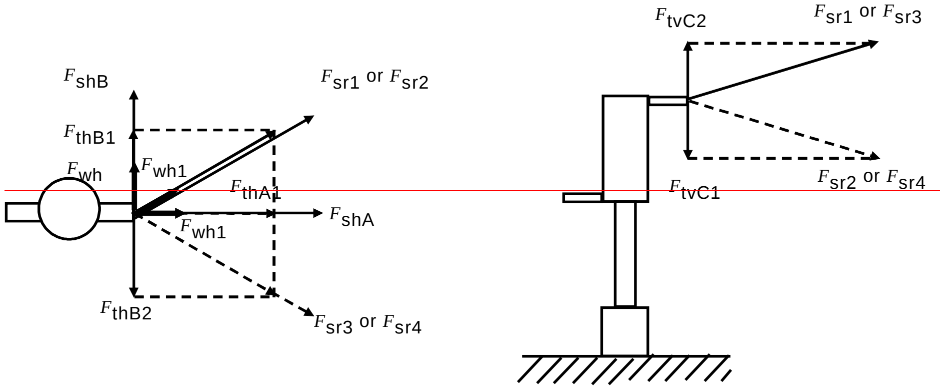
Figure 18 – Humidity test

~~**Circuit-breaker with more than one interrupter unit**~~



~~$F_{shB1} = F_{thB1} + F_{wh}$ and $F_{shB2} = F_{thB2} + F_{wh}$~~ ~~$F_{tv} = F_{sv}$ (see 6.101.6.2)~~

~~**Circuit-breaker with one interrupter unit**~~



~~Test to item 6.101.6.2 a): F_{wh} acts in the direction of the resultant of F_{thB} and F_{thA}~~

~~Test to item 6.101.6.2 b): F_{wh} acts in the direction of F_{thB} or F_{thA}~~

~~F_{thA}~~ ~~tensile horizontal force due to connected conductors (direction A)~~

~~F_{thB}~~ ~~tensile horizontal force due to connected conductors (direction B)~~

~~F_{tv}~~ ~~tensile vertical force due to connected conductors (direction C)~~

~~F_{wh}~~ ~~horizontal force on circuit-breaker due to wind pressure on ice-coated circuit-breaker~~

~~F_{shA}, F_{shB}~~ ~~horizontal forces resulting from F_{thA}, F_{thB} and F_{wh}~~

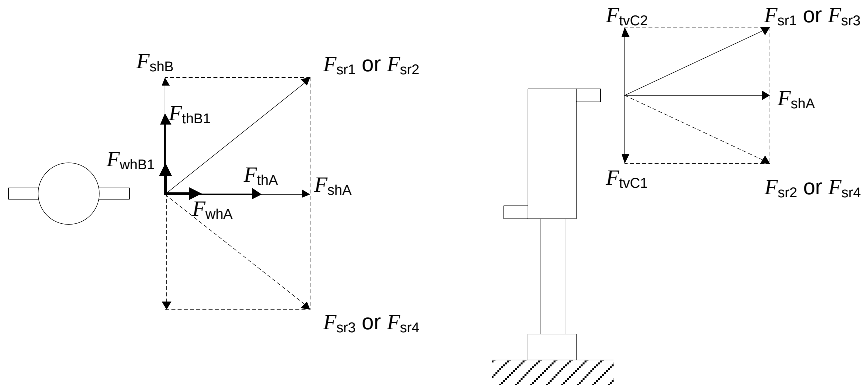
~~F_{sr1}, F_{sr2}, F_{sr3}, F_{sr4}~~ ~~rated static terminal loads (resultant forces)~~

~~NOTE 1 Refer to Figure 20 for directions A, B and C.~~

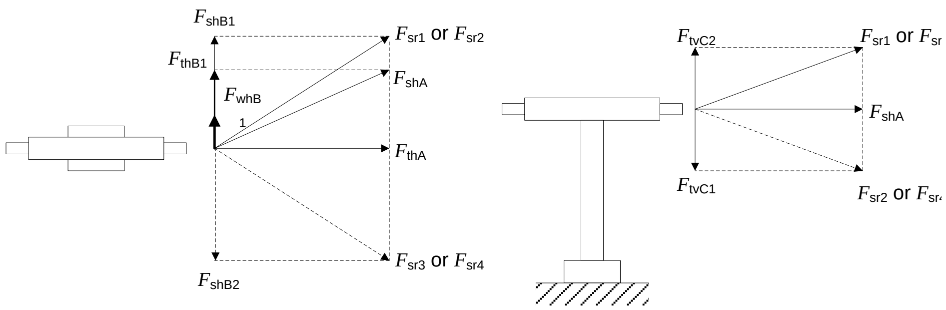
~~NOTE 2 The index letter "s" characterises testing values.~~

	~~**Horizontal**~~	~~**Vertical**~~	~~**Remark**~~
~~Forces due to dead weight, wind and ice on connected conductor~~	~~F_{thA}, F_{thB}~~	~~F_{tv}~~	~~According to Table 14~~
~~Forces due to wind and ice on circuit-breaker*~~	~~F_{wh}~~	~~0~~	~~Calculated by the manufacturer~~
~~* The horizontal force on the circuit-breaker, due to wind, may be moved from the centre of pressure to the terminal and reduced in magnitude in proportion to the longer lever arm. (The bending moment at the lowest part of the circuit-breaker should be the same.)~~			

Circuit-breaker with one interrupter unit



Circuit-breaker with more than one interrupter unit



$F_{shB1} = F_{thB1} + F_{whB1}$ and $F_{shB2} = F_{thB2} + F_{whB2}$ $\qquad$ $F_{tv} = F_{sv}$ (see 6.101.6.2)

Test to item 6.101.6.2 a):
- For circuit breaker with one interrupter unit, F_{wh} acts in the direction of the resultant of F_{thB} and F_{thA}
- For circuit breaker with more than one interrupter unit, F_{wh} acts in the direction of the resultant of F_{thB} in order to get the more severe loading condition

Test to item 6.101.6.2 b): F_{wh} acts in the direction of F_{thB} or F_{thA}

F_{thA} tensile horizontal force due to connected conductors (direction A)

F_{thB} tensile horizontal force due to connected conductors (direction B)

F_{tv} tensile vertical force due to connected conductors (direction C)

F_{wh} horizontal force on circuit-breaker due to wind pressure on ice-coated circuit-breaker

F_{shA}, F_{shB} horizontal forces resulting from F_{thA}, F_{thB} and F_{wh}

F_{sr1}, F_{sr2}, F_{sr3}, F_{sr4} rated static terminal loads (resultant forces)

NOTE 1 Refer to Figure 20 for directions A, B and C.

NOTE 2 The index letter "s" characterises testing values.

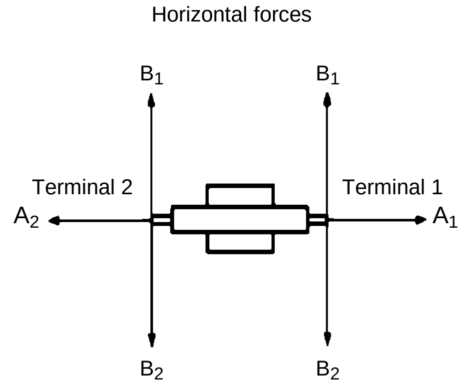
	Horizontal	**Vertical**	**Remark**
Forces due to dead weight, wind and ice on connected conductor	F_{thA}, F_{thB}	F_{tv}	According to Table 14
Forces due to wind and ice on circuit-breaker*	F_{wh}	O	Calculated by the manufacturer

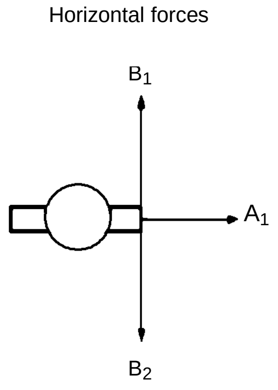
* The horizontal force on the circuit-breaker, due to wind, may be moved from the centre of pressure to the terminal and reduced in magnitude in proportion to the longer lever arm. (The bending moment at the lowest part of the circuit-breaker should be the same.)

Figure 19 – Static terminal load forces

Circuit-breaker with more than one interrupter unit

Circuit-breaker with one interrupter unit

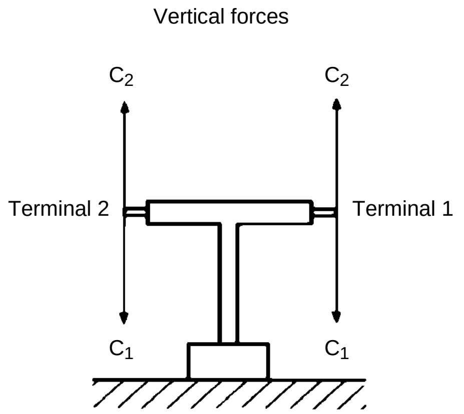


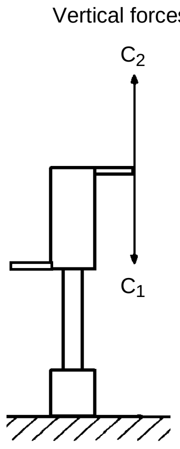


Force directions: A_1, B_1, B_2 for Terminal 1

Force directions: A_2, B_1, B_2 for Terminal 2

Horizontal test forces: F_{shA} and F_{shB} (see Figure 19)





Force directions: C_1, C_2, for Terminal 1

Force directions: C_1, C_2, for Terminal 2

Vertical test forces (both directions): F_{sv} (see Figure 19)

NOTE For circuit-breakers which are symmetrical about the pole unit vertical centreline, only one terminal needs to be tested.

Figure 20 – Directions for static terminal load tests

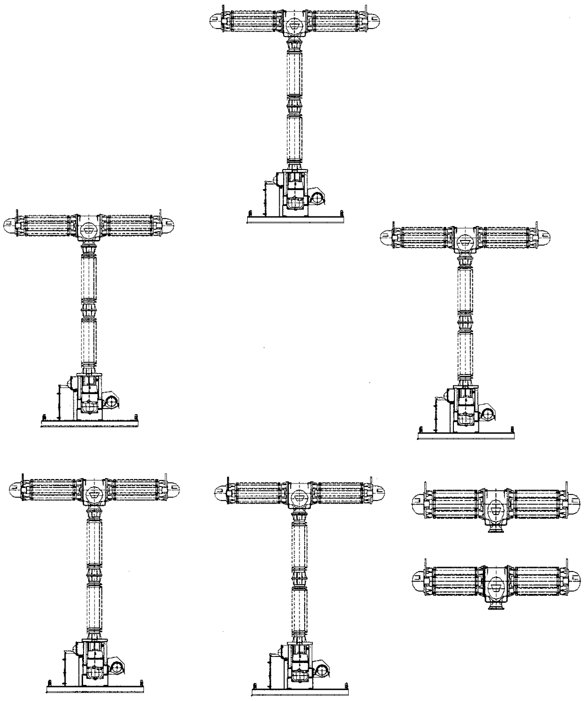


Figure 21 – Permitted number of samples for making, breaking and switching tests, illustrations of the statements in 6.102.2

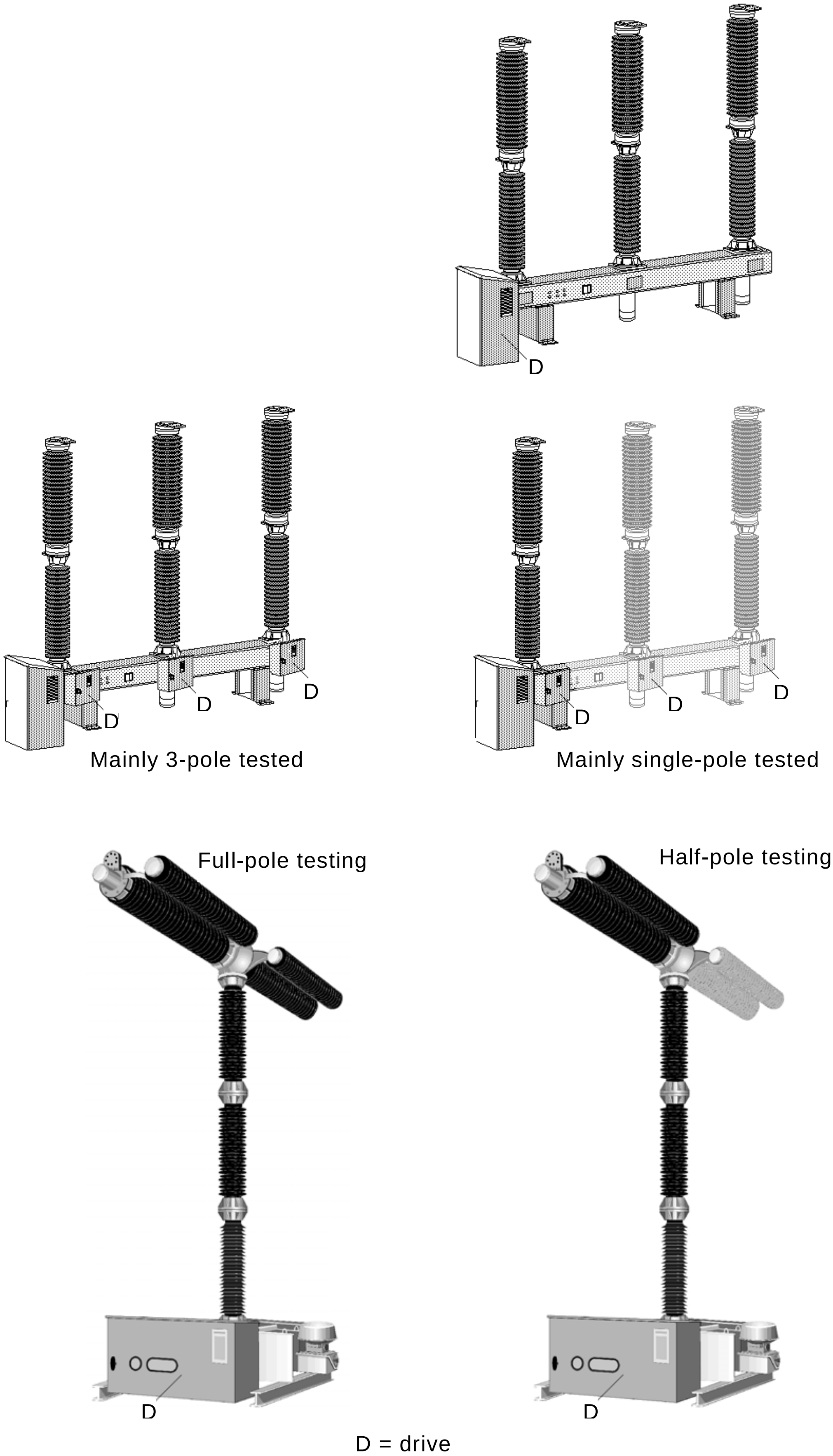


Figure 22 – Definition of a single test specimen in accordance with 3.2.2 of IEC 62271-1

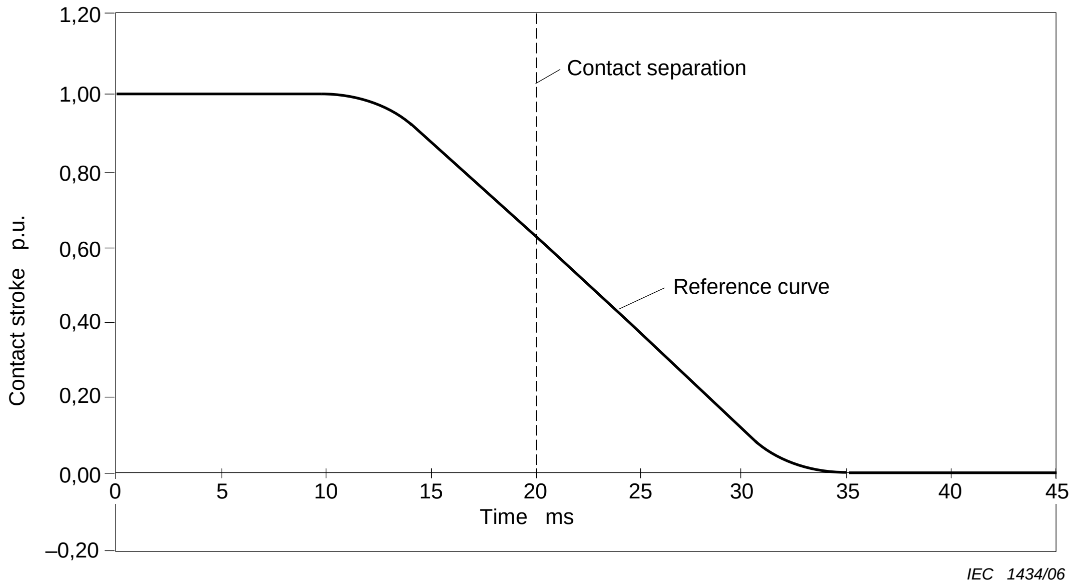


Figure 23a – Reference mechanical characteristics (idealised curve)

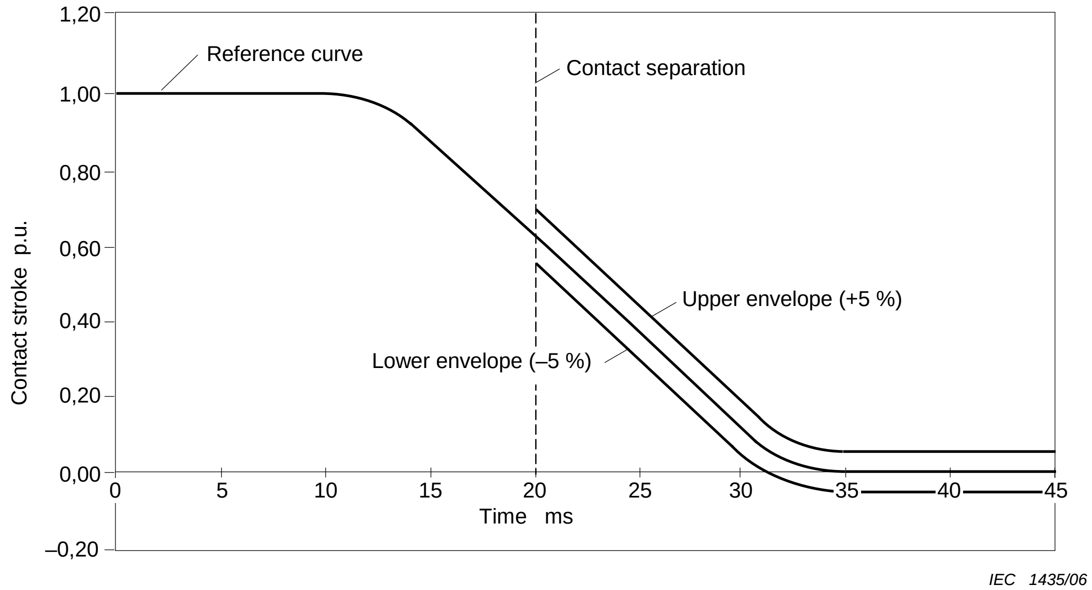


Figure 23b – Reference mechanical characteristics (idealised curve) with the prescribed envelopes centered over the reference curve (+5 %, –5 %), contact separation in this example at time *t* = 20 ms

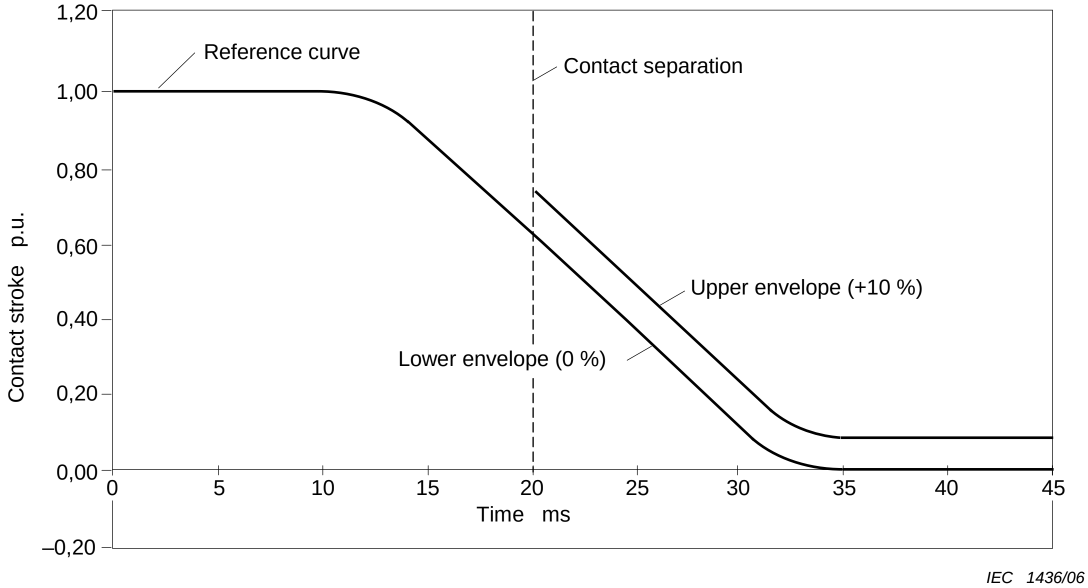


Figure 23c – Reference mechanical characteristics (idealised curve) with the prescribed envelopes fully displaced upward from the reference curve (+10 %, –0 %), contact separation in this example at time *t* = 20 ms

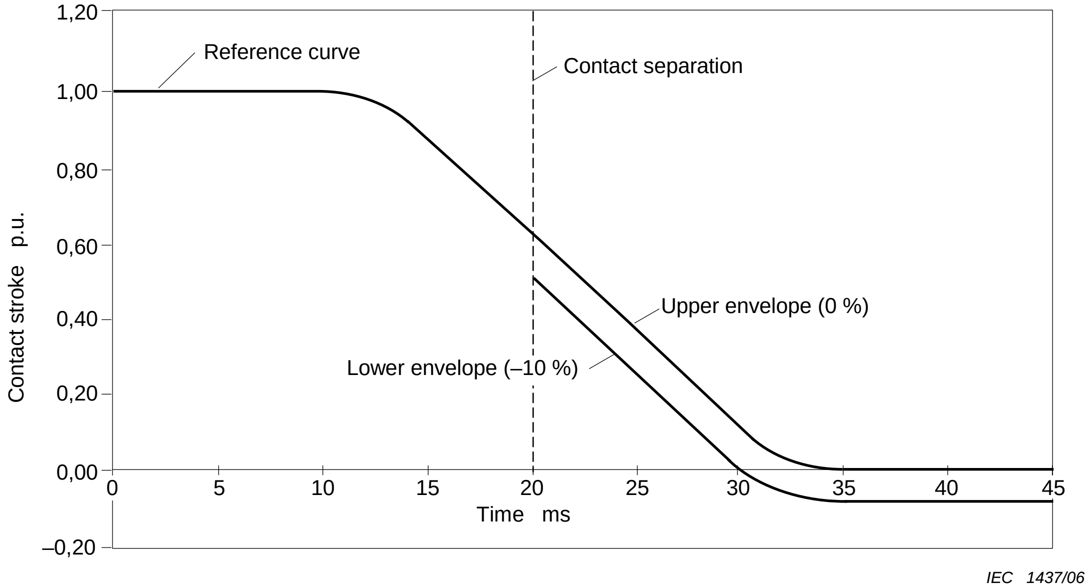
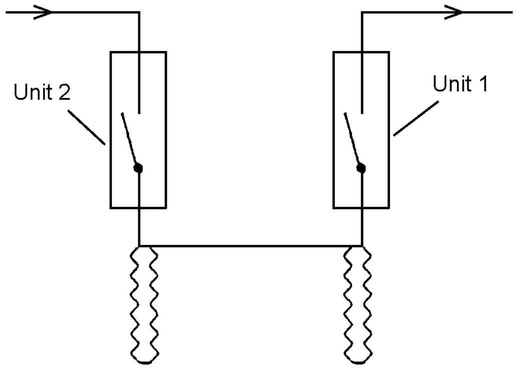


Figure 23d – Reference mechanical characteristics (idealised curve) with the prescribed envelopes fully displaced downward from the reference curve (+0 %, –10 %), contact separation in this example at time *t* = 20 ms

Pole of a circuit-breaker with two separate interrupter units in series



Equivalent testing set-up for unit testing; second interrupter unit is substituted by a conductor of equivalent shape

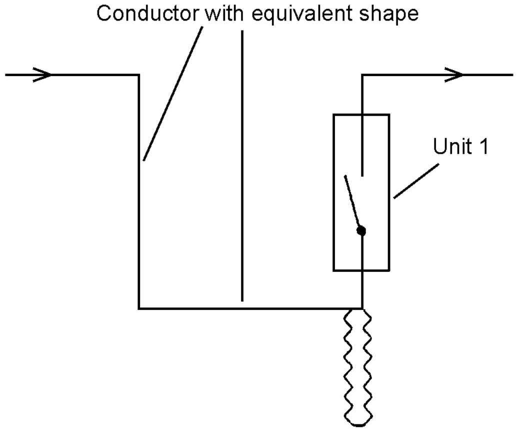


Figure 24 – Equivalent testing set-up for unit testing of circuit-breakers with more than one separate interrupter units

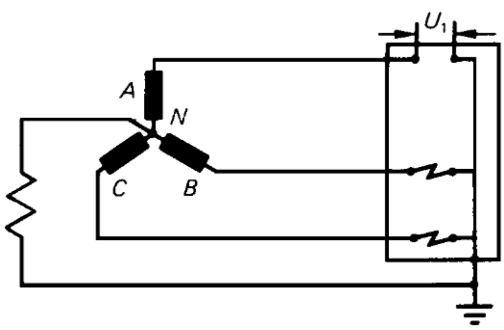


Figure 25a – Preferred circuit

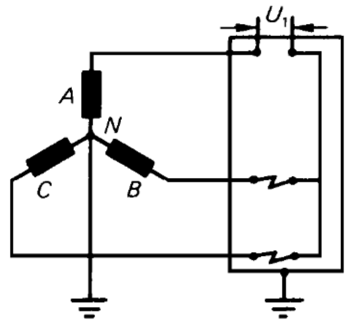


Figure 25b – Alternative circuit

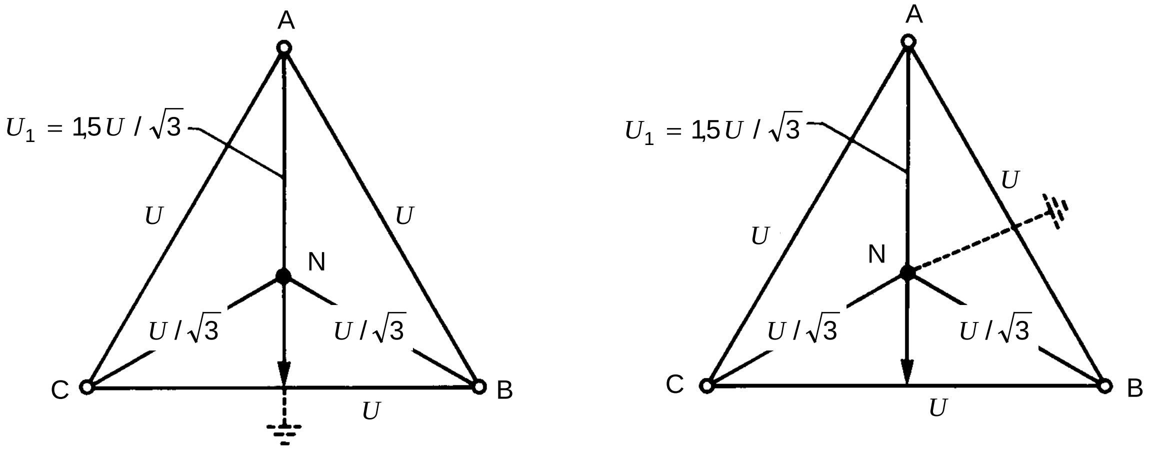


Figure 25 – Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1,5

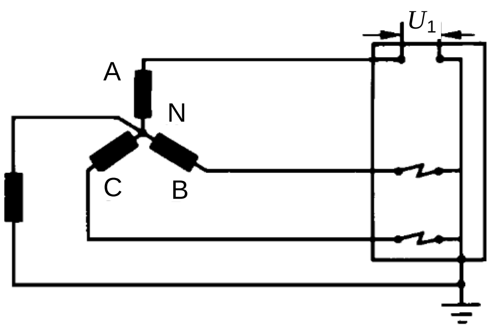


Figure 26a – Preferred circuit

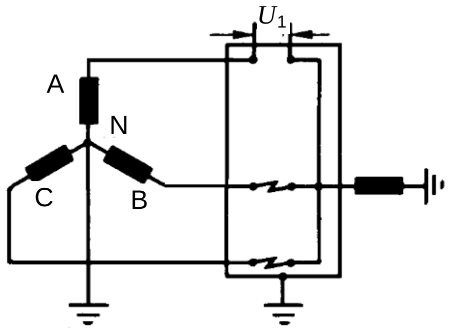
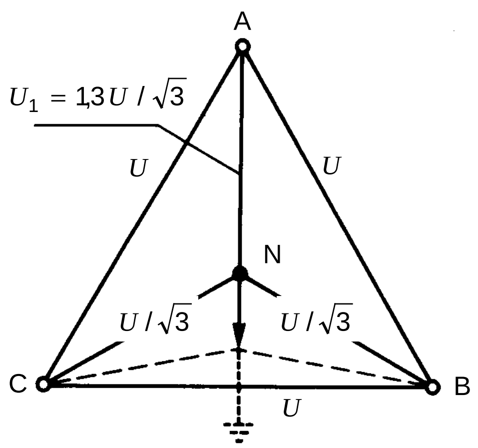


Figure 26b – Alternative circuit



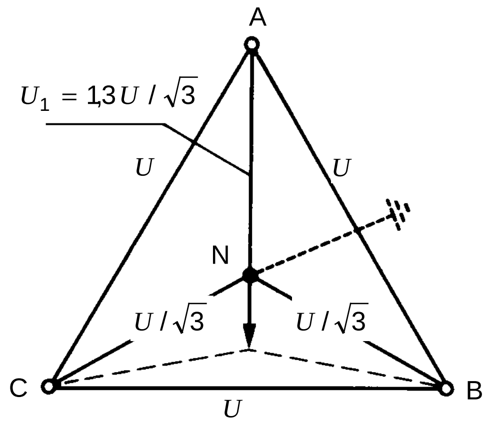


Figure 26 – Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1,3

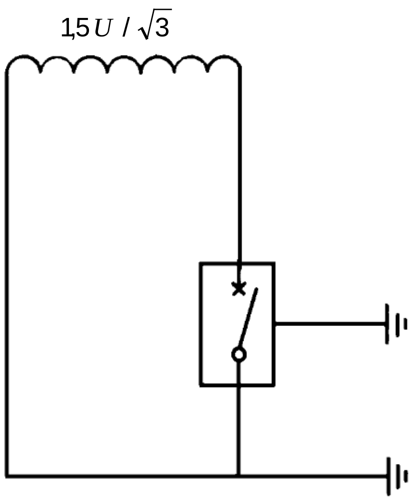


Figure 27a – Preferred circuit

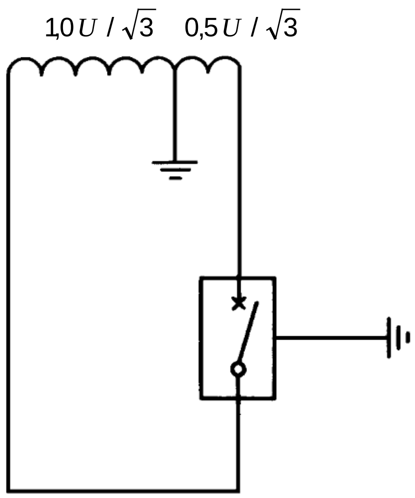


Figure 27b – Alternative circuit not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (e.g. GIS or dead tank circuit-breakers)

Figure 27 – Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1,5

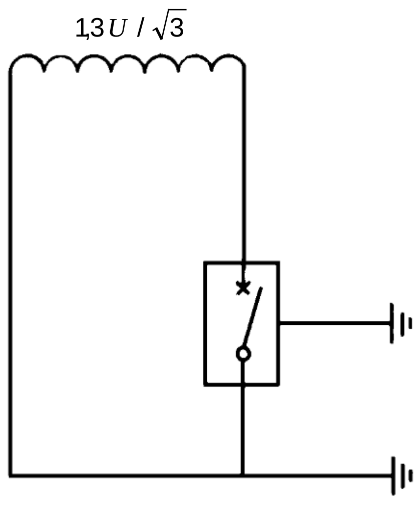


Figure 28a – Preferred circuit

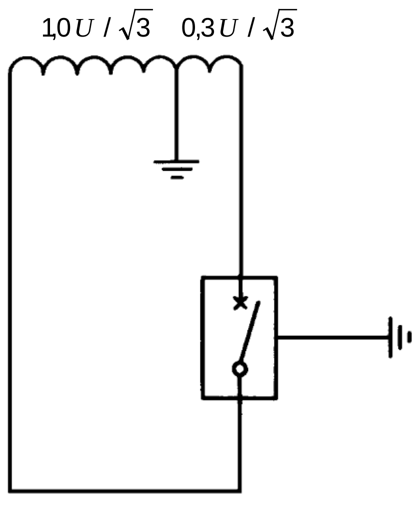
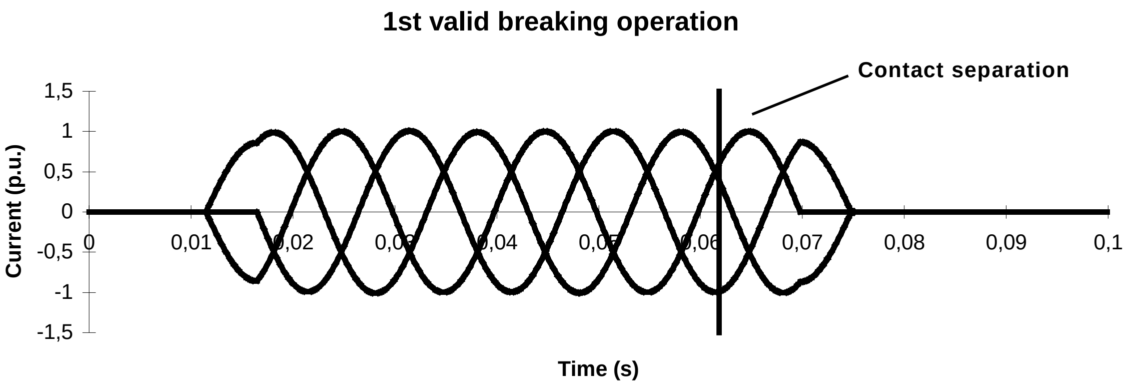
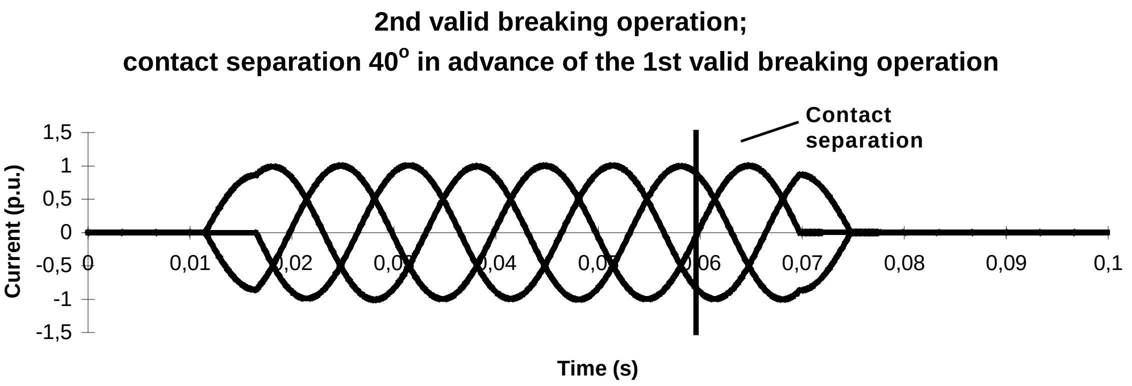


Figure 28b – Alternative circuit, not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (e.g. GIS or dead tank circuit-breakers)

Figure 28 – Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1,3





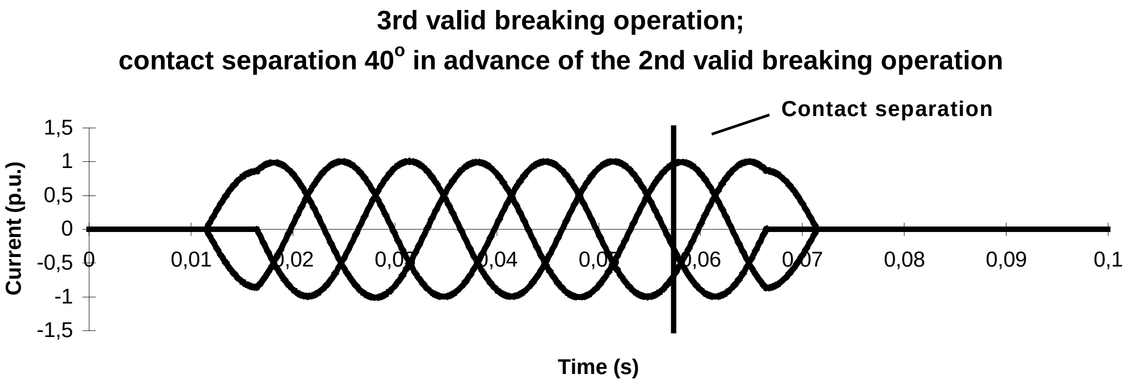
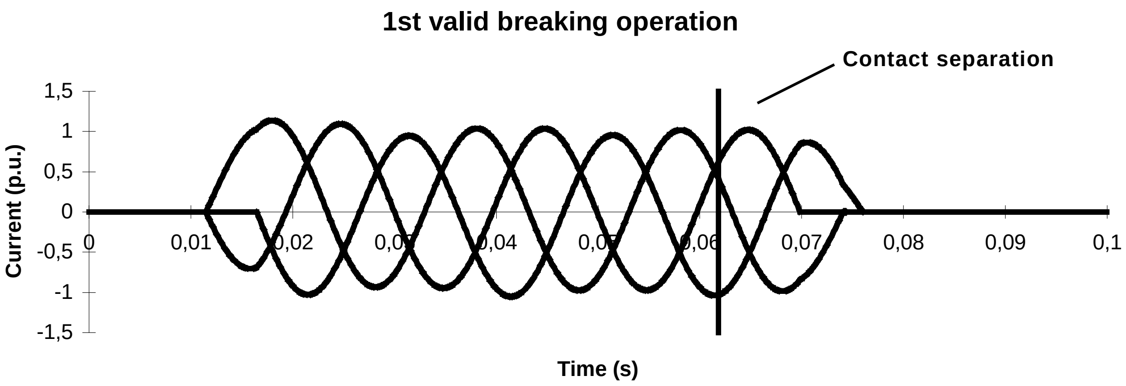
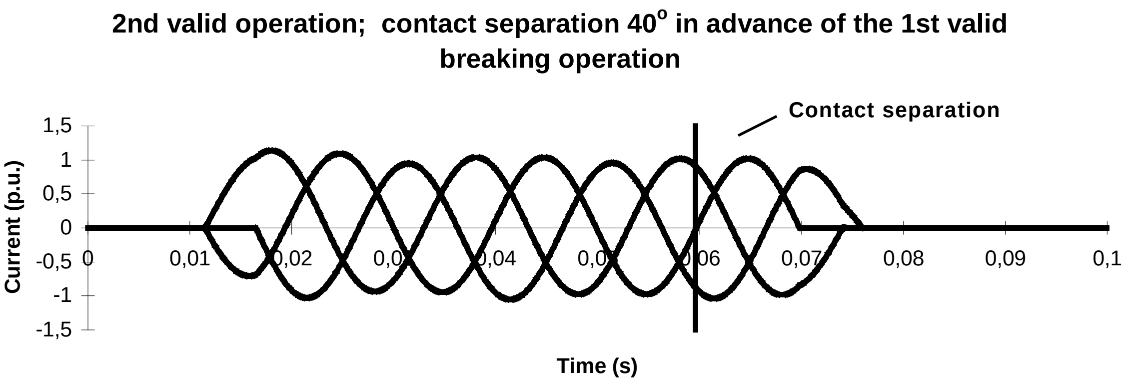


Figure 29 – Example of a graphical representation of the three valid symmetrical breaking operations for three-phase tests in a non-effectively earthed neutral system (first-pole-to-clear factor 1,5)





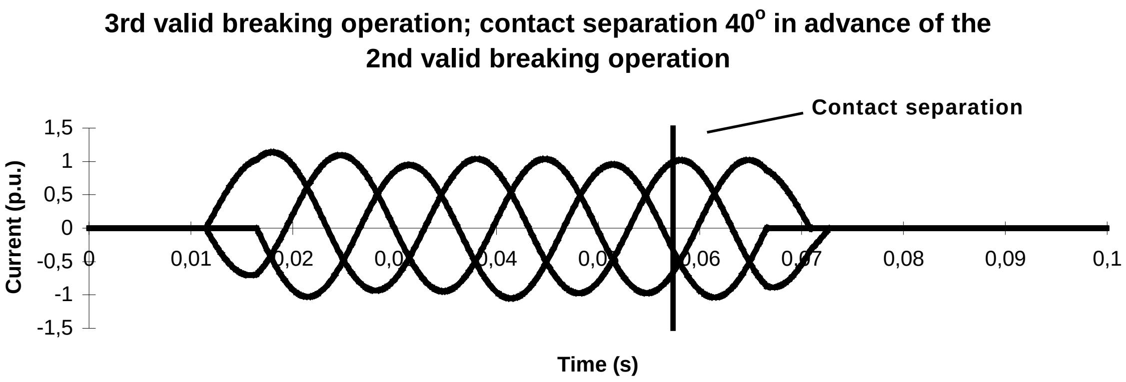
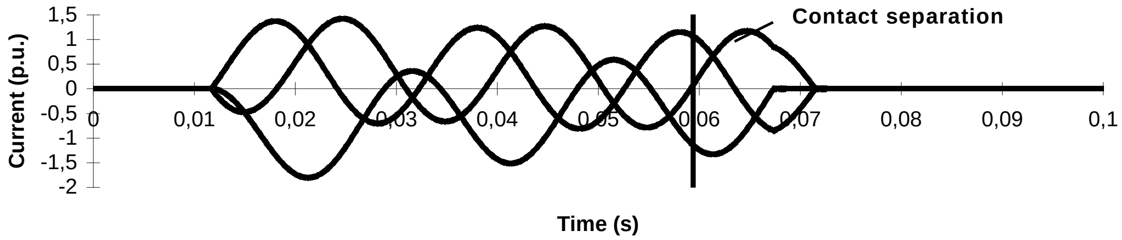
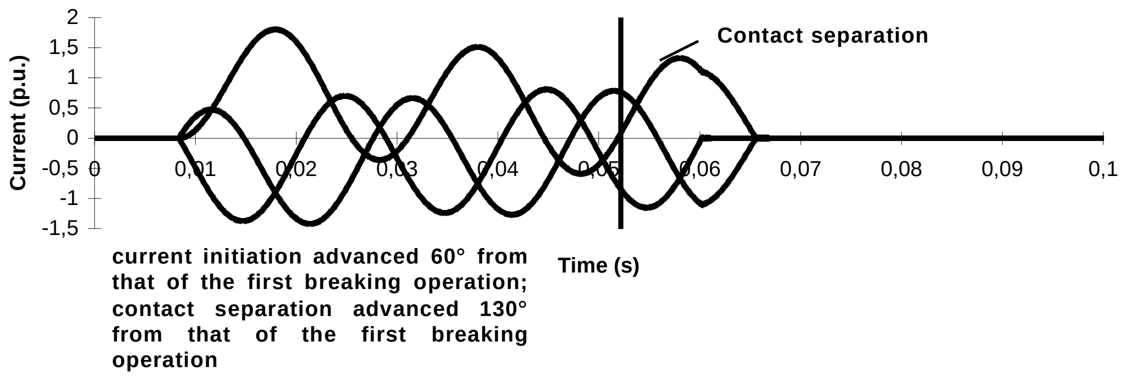


Figure 30 – Example of a graphical representation of the three valid symmetrical breaking operations for three-phase tests in an effectively earthed neutral system (first-pole-to-clear factor 1,3)

1st valid breaking operation; first pole-to-clear on a major loop with the required d.c. level at contact separation



2nd valid breaking operation; one of the last pole-to-clear on an extended major loop with the required d.c. level at contact separation



3rd valid breaking operation; first pole-to-clear on a major loop with the required d.c. level at contact separation

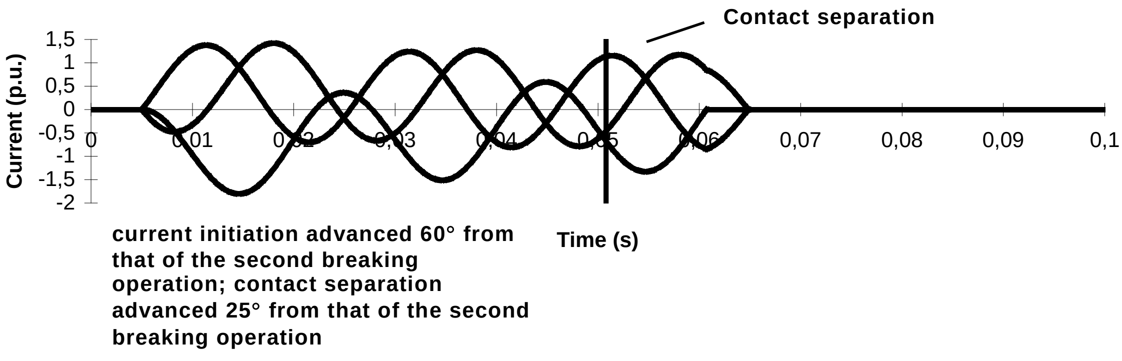


Figure 31 – Graphical representation of the three valid asymmetrical breaking operations for three-phase tests in a non-effectively earthed neutral system (first-pole-to-clear factor 1,5)

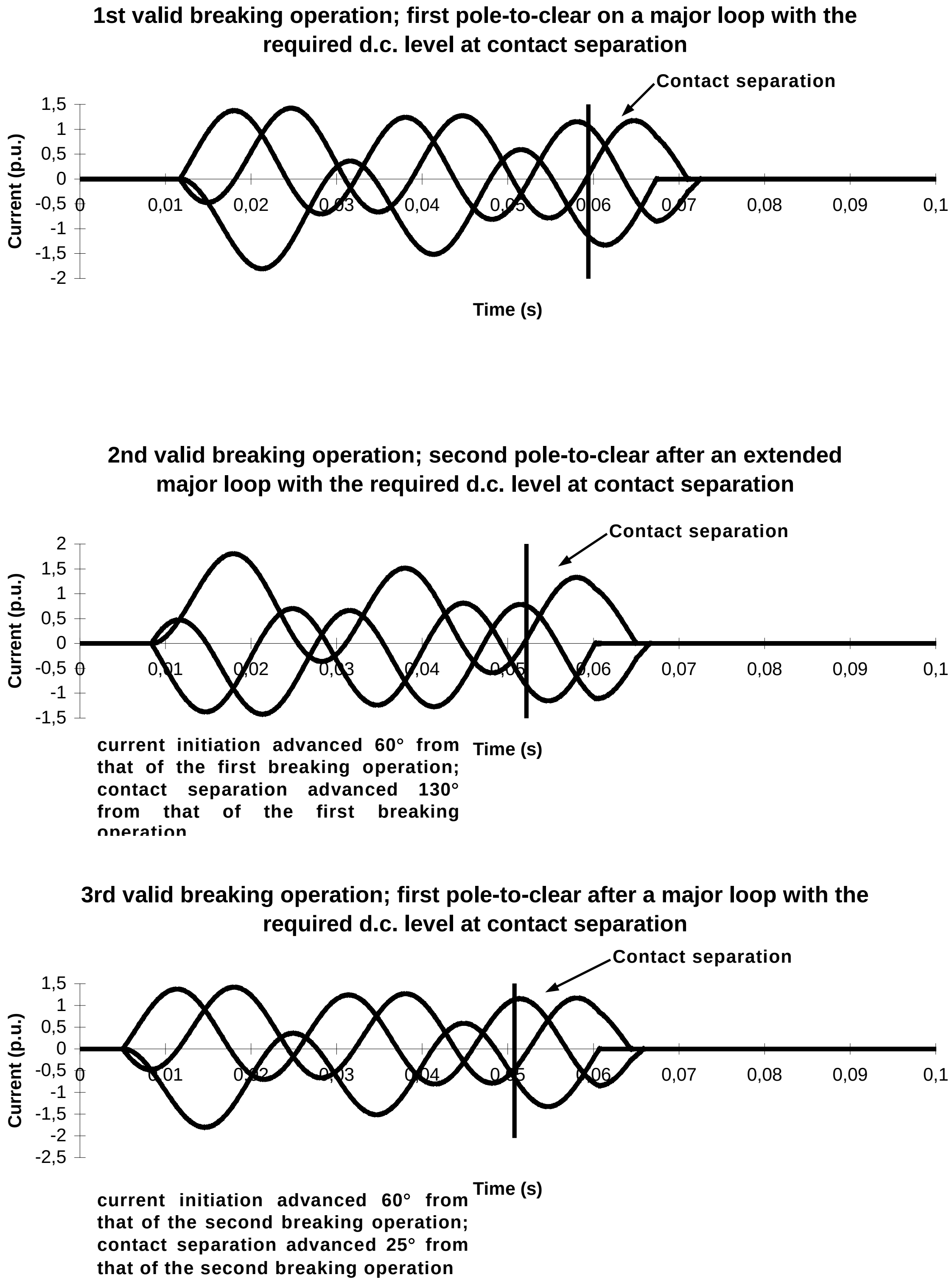
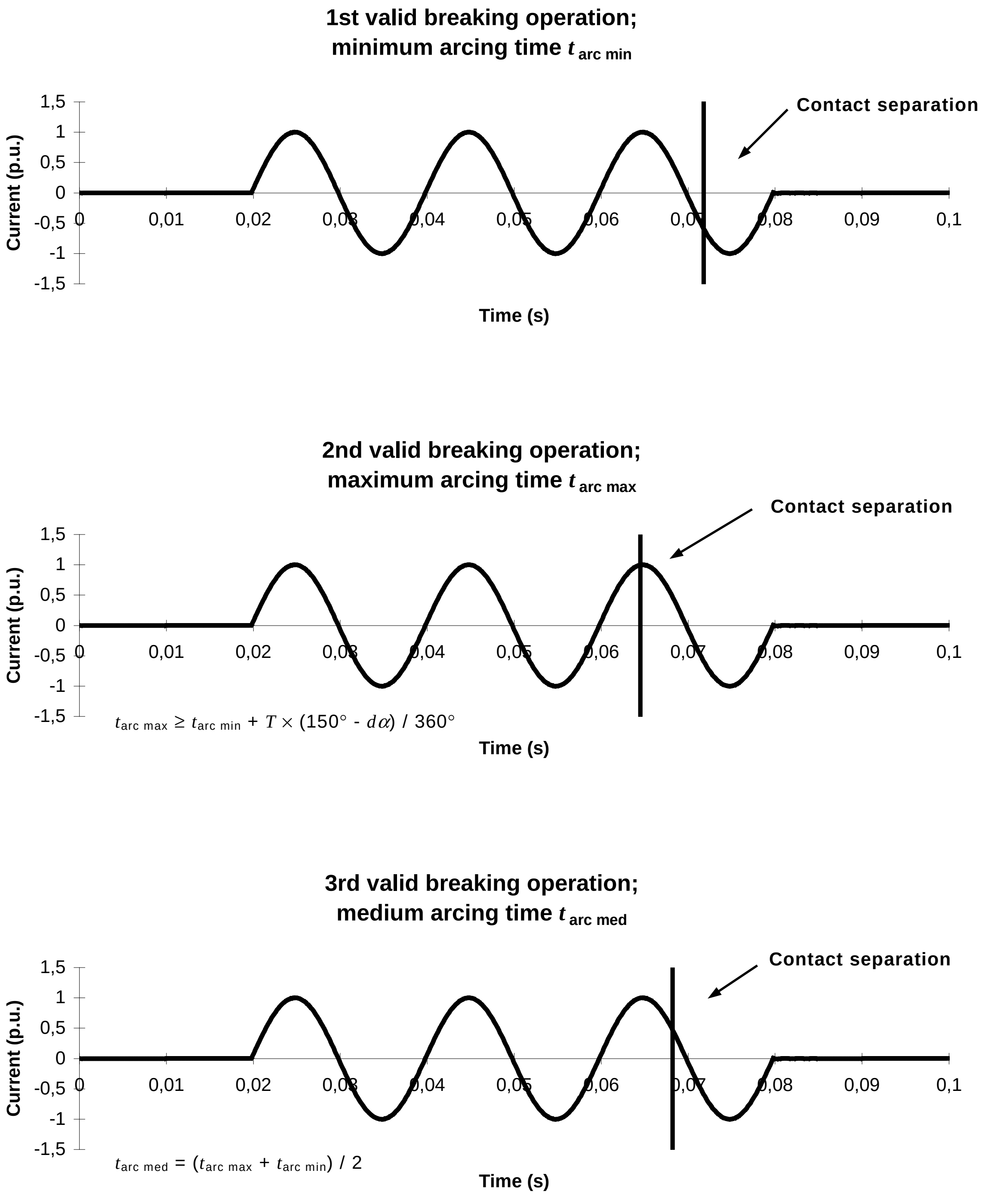


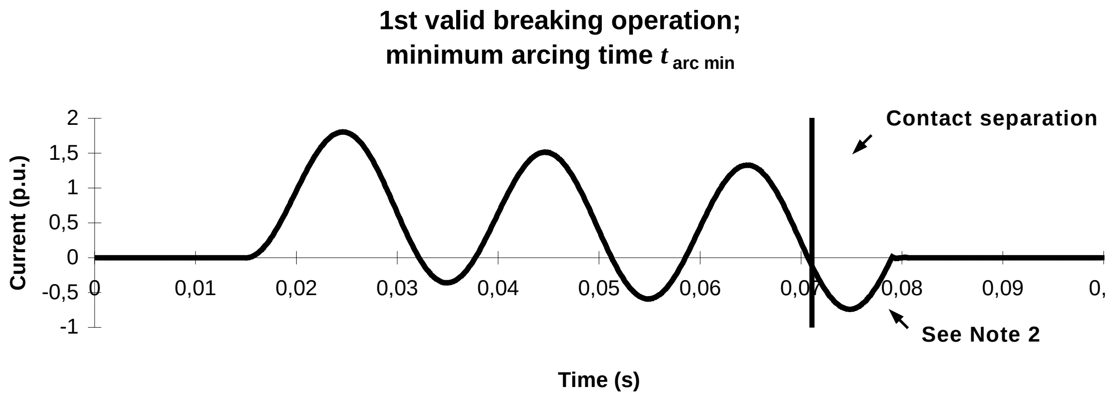
Figure 32 – Graphical representation of the three valid asymmetrical breaking operations for three-phase tests in an effectively earthed neutral system (first-pole-to-clear factor 1,3)

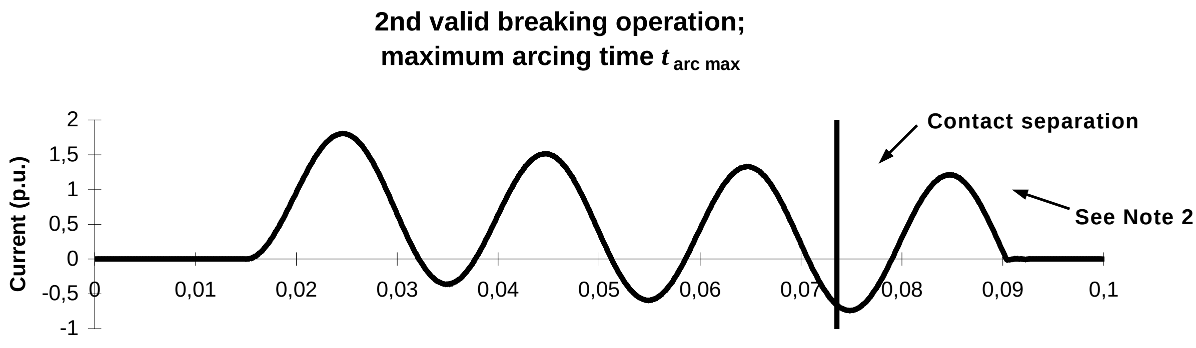


$d\alpha = 18°$

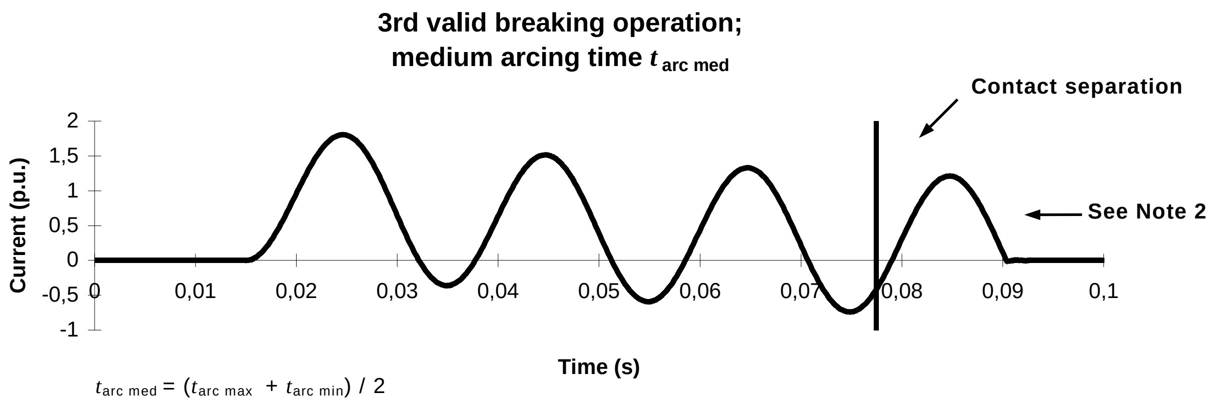
NOTE The polarity of the current may be reversed.

Figure 33 – Graphical representation of the three valid symmetrical breaking operations for single-phase tests in substitution of three-phase conditions in a non-effectively earthed neutral system (first-pole-to-clear factor 1,5)





$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times (30° + d\alpha) / 360°$



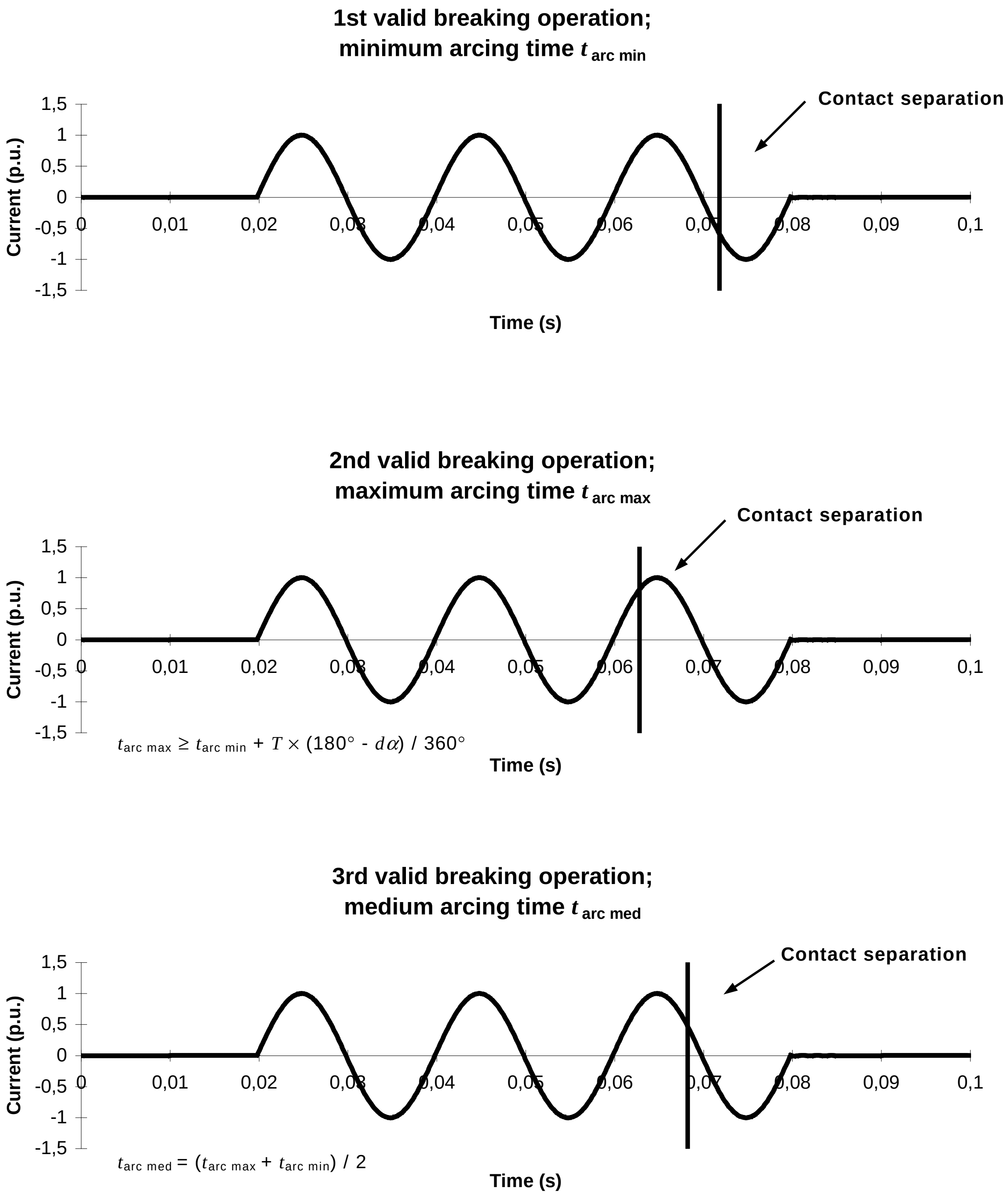
$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}}) / 2$

$d\alpha = 18°$

NOTE 1 The polarity of the current may be reversed.

NOTE 2 The amplitude and the duration of the last current loop must meet the criteria stated in 6.102.10.

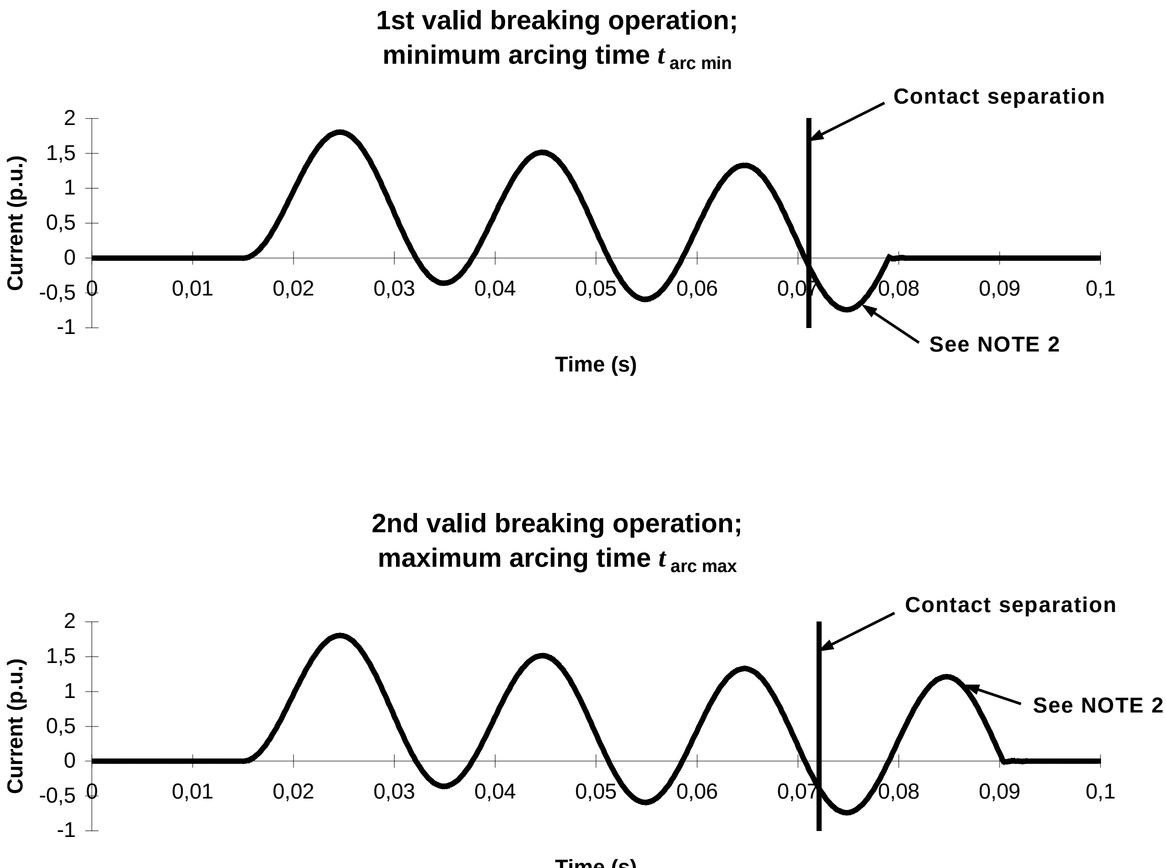
Figure 34 – Graphical representation of the three valid asymmetrical breaking operations for single-phase tests in substitution of three-phase conditions in a non-effectively earthed neutral system (first-pole-to-clear factor 1,5)



$d\alpha$ = 18°

NOTE The polarity of the current may be reversed.

Figure 35 – Graphical representation of the three valid symmetrical breaking operations for single-phase tests in substitution of three-phase conditions in an effectively earthed neutral system (first-pole-to-clear factor 1,2 or 1,3)



$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times d\alpha$ / 360°

$t_{\text{arc med}} = (t_{\text{arc min}} + t_{\text{arc max}})$ / 2

$d\alpha$ = 18°

NOTE 1 The polarity of the current may be reversed.

NOTE 2 The amplitude and the duration of the last current loop must meet the criteria stated in 6.102.10.

Figure 36 – Graphical representation of the three valid asymmetrical breaking operations for single-phase tests in substitution of three-phase conditions in an effectively earthed neutral system (first-pole-to-clear factor 1,2 or 1,3)

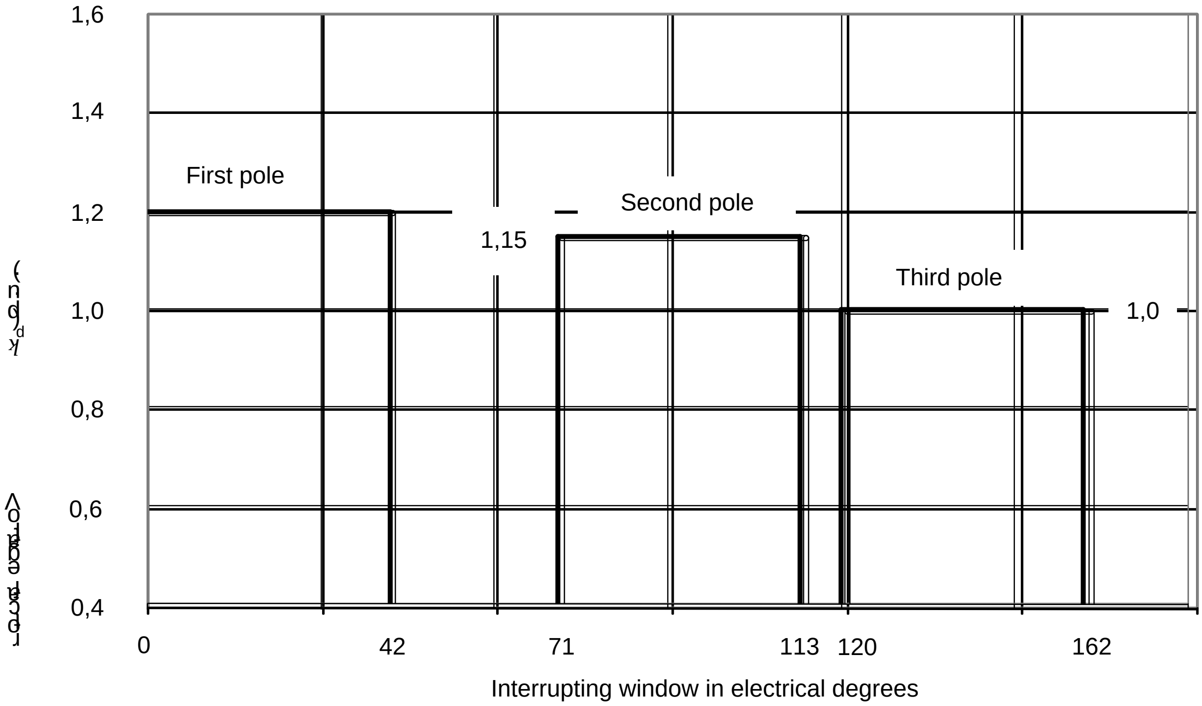


Figure 58 – Graphical representation of the interrupting window and the voltage factor k_p, determining the TRV of the individual pole, for systems with a first-pole-to-clear factor of 1,2

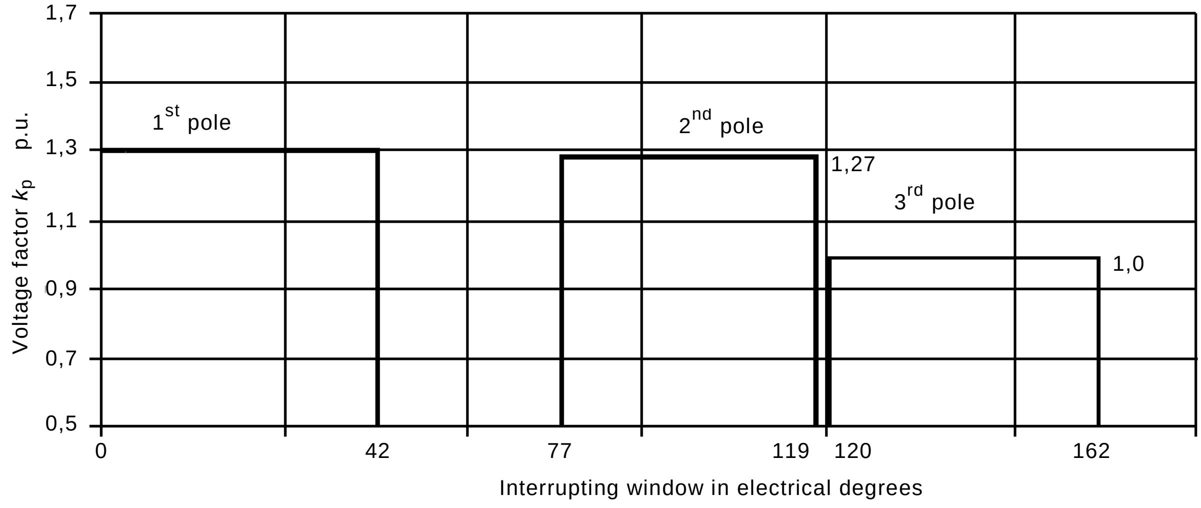


Figure 37 – Graphical representation of the interrupting window and the voltage factor k_p, determining the TRV of the individual pole, for systems with a first-pole-to-clear factor of 1,3

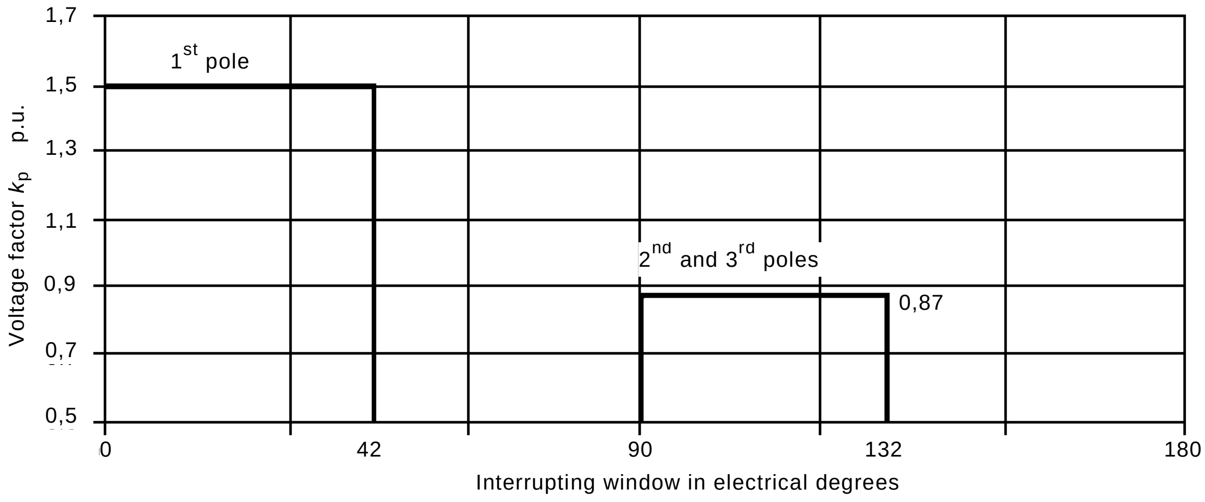


Figure 38 – Graphical representation of the interrupting window and the voltage factor k_p, determining the TRV of the individual pole, for systems with a first-pole-to-clear factor of 1,5

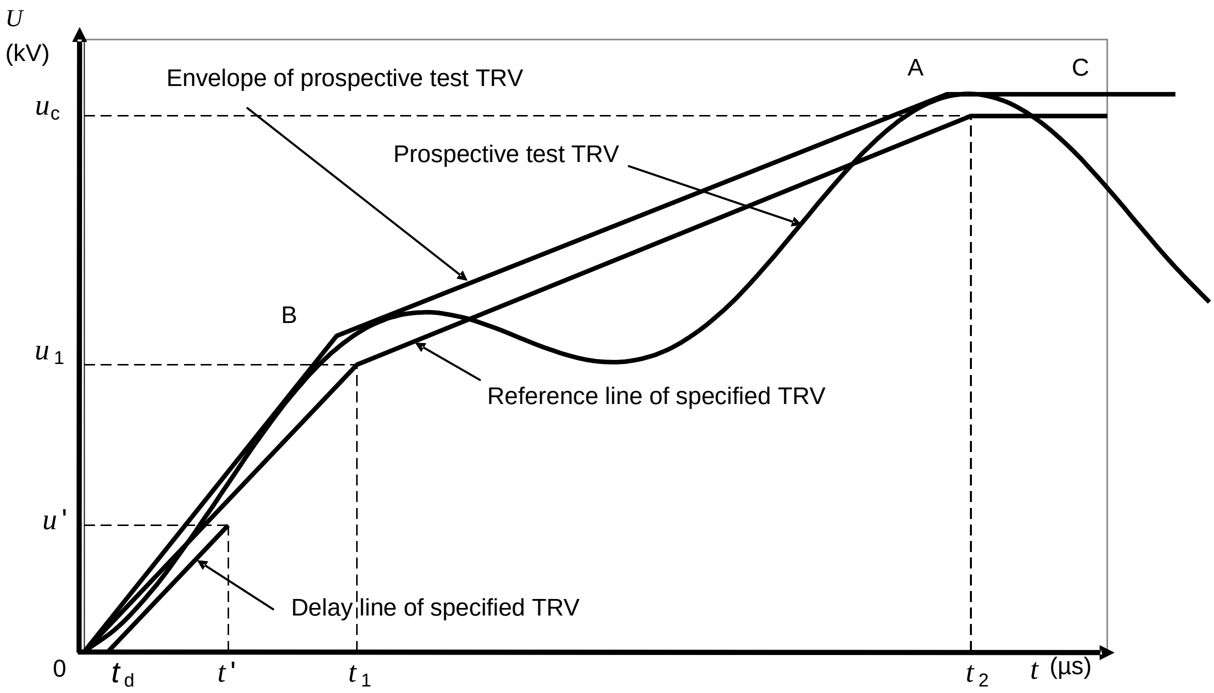


Figure 39 – Example of prospective test TRV with four-parameter envelope which satisfies the conditions to be met during type test – Case of specified TRV with four-parameter reference line

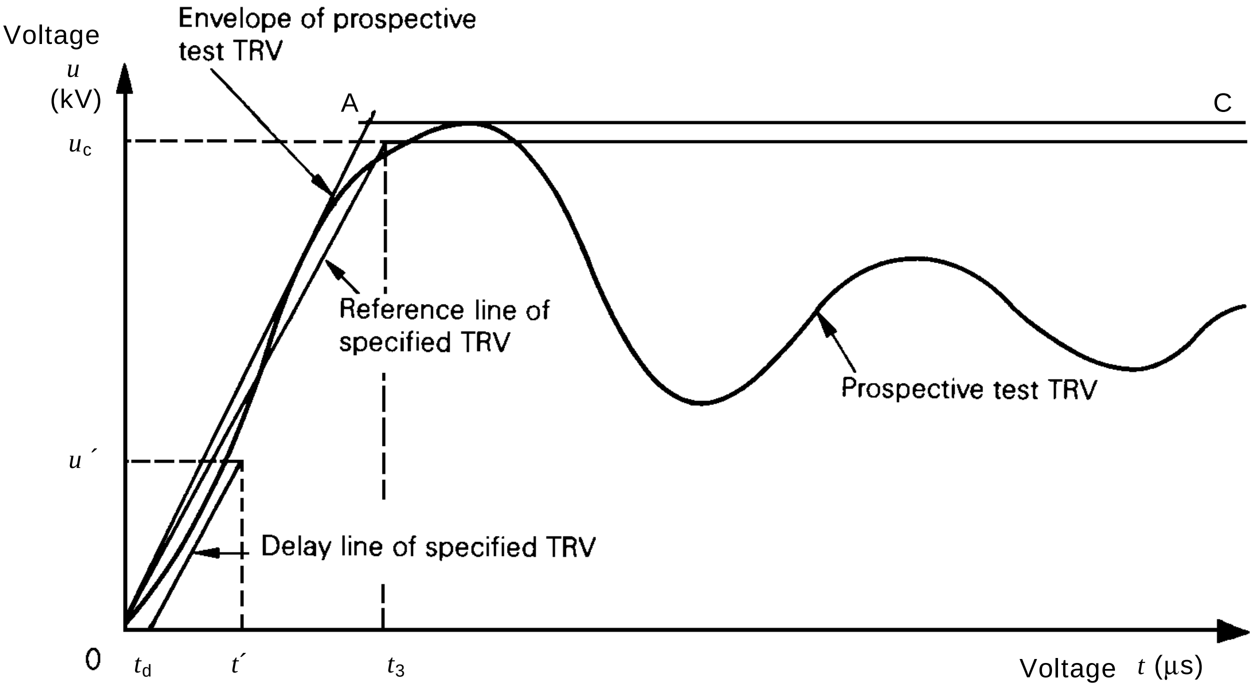


Figure 40 – Example of prospective test TRV with two-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with two-parameter reference line

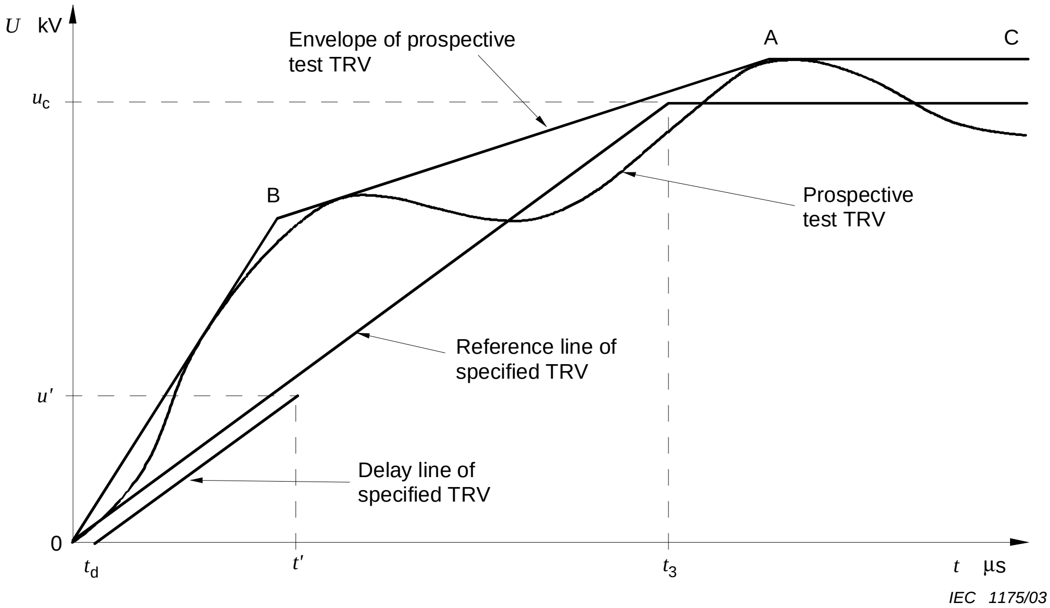


Figure 41 – Example of prospective test TRV with four-parameter envelope which satisfies the conditions to be met during type-test – Case of specified TRV with two-parameter reference line

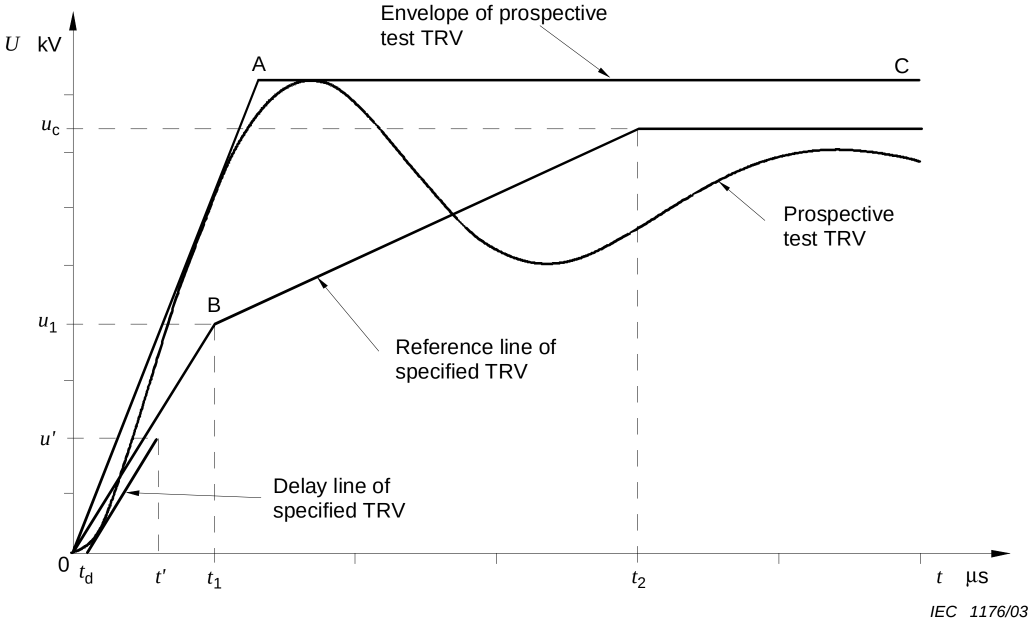
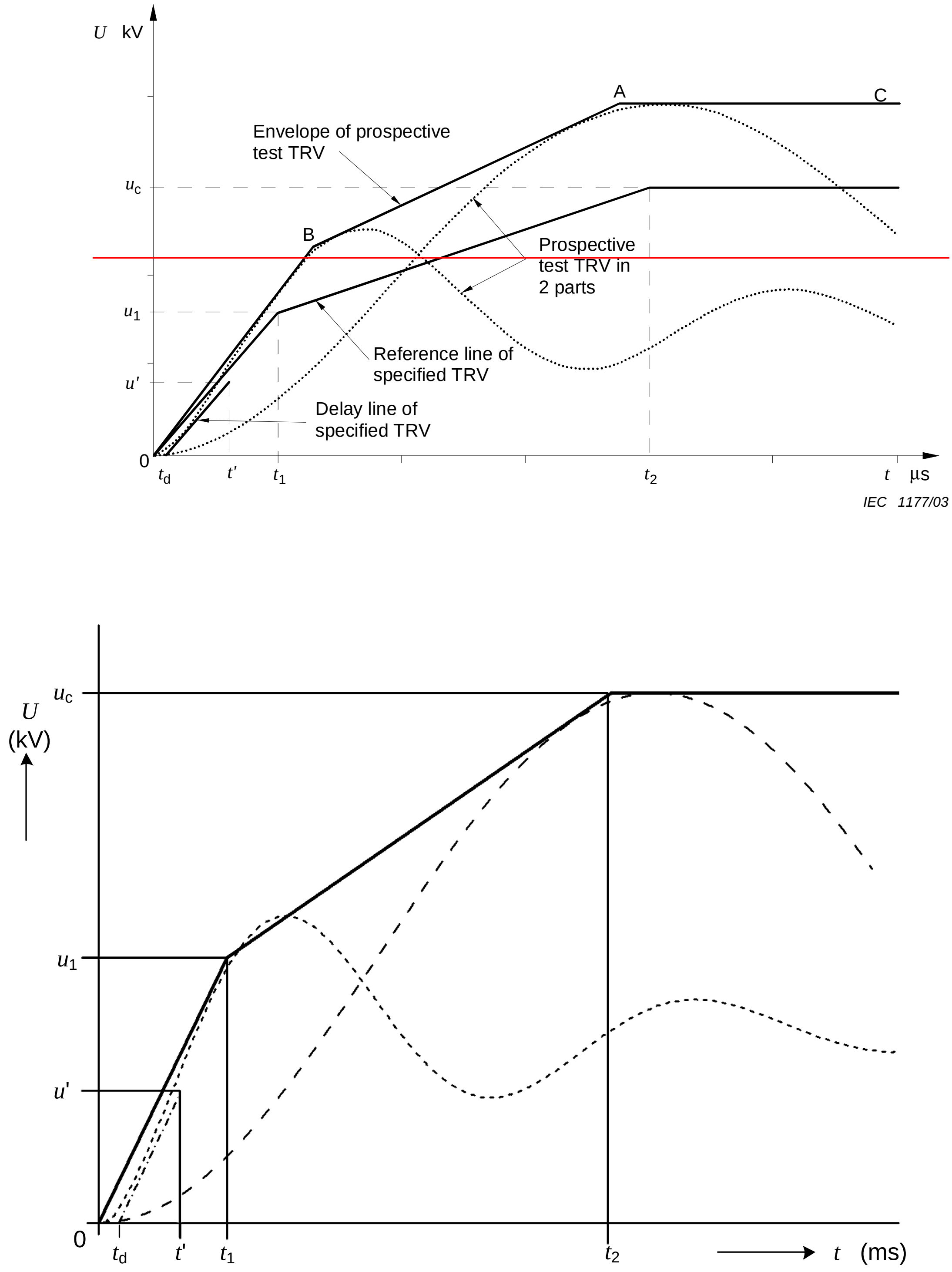


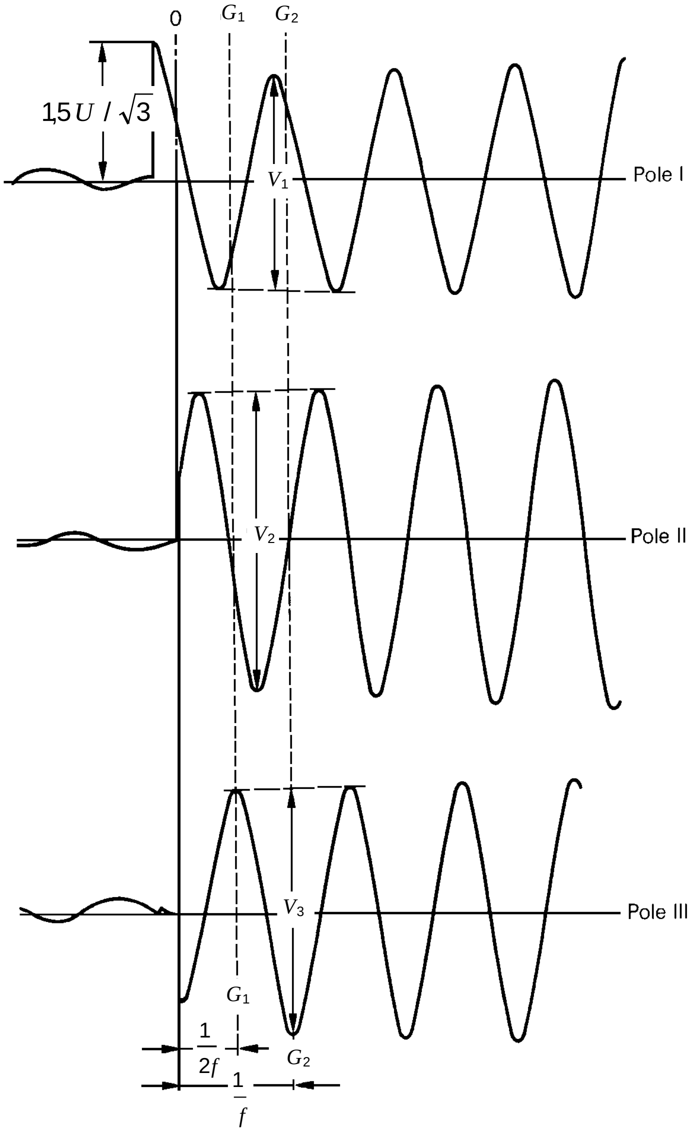
Figure 42 – Example of prospective test TRV with two-parameter envelope which satisfies the conditions to be met during type-test – Case of specified TRV with four-parameter reference line



Key

————	Required 4-parameter envelope
- - - - - -	Test TRV part 1
— — — —	Test TRV part 2
-·-·-·-·-	Delay line

Figure 43 – Example of prospective test TRV-waves and their combined envelope in two-part test



Pole I	= first pole to clear
OO	= instant of final arc-extinction on all phases
G_1G_1	= instant $\frac{1}{2f}$ from OO
G_2G_2	= instant $\frac{1}{f}$ from OO
f	= test frequency
$\frac{V_1}{2\sqrt{2}}$	= value of power frequency recovery voltage of Pole I
$\frac{V_2}{2\sqrt{2}}$	= value of power frequency recovery voltage of Pole II
$\frac{V_3}{2\sqrt{2}}$	= value of power frequency recovery voltage of Pole III

In Pole III a voltage peak occurs exactly at instant G_1G_1. In such event measurement is made at later instant G_2G_2.

Average value of the power frequency recovery voltages of poles I, II and III

$$= \frac{\frac{V_1}{2\sqrt{2}} + \frac{V_2}{2\sqrt{2}} + \frac{V_3}{2\sqrt{2}}}{3}$$

The example illustrates three voltages obtained during a test upon a three-pole circuit breaker in a three-phase test circuit having one of it's neutral points insulated, see Figure 25a or 25b, thus producing momentarily in the first-pole-to-clear a 50 % increase in the recovery voltage, as shown in pole I.

Figure 44 – Determination of power frequency recovery voltage

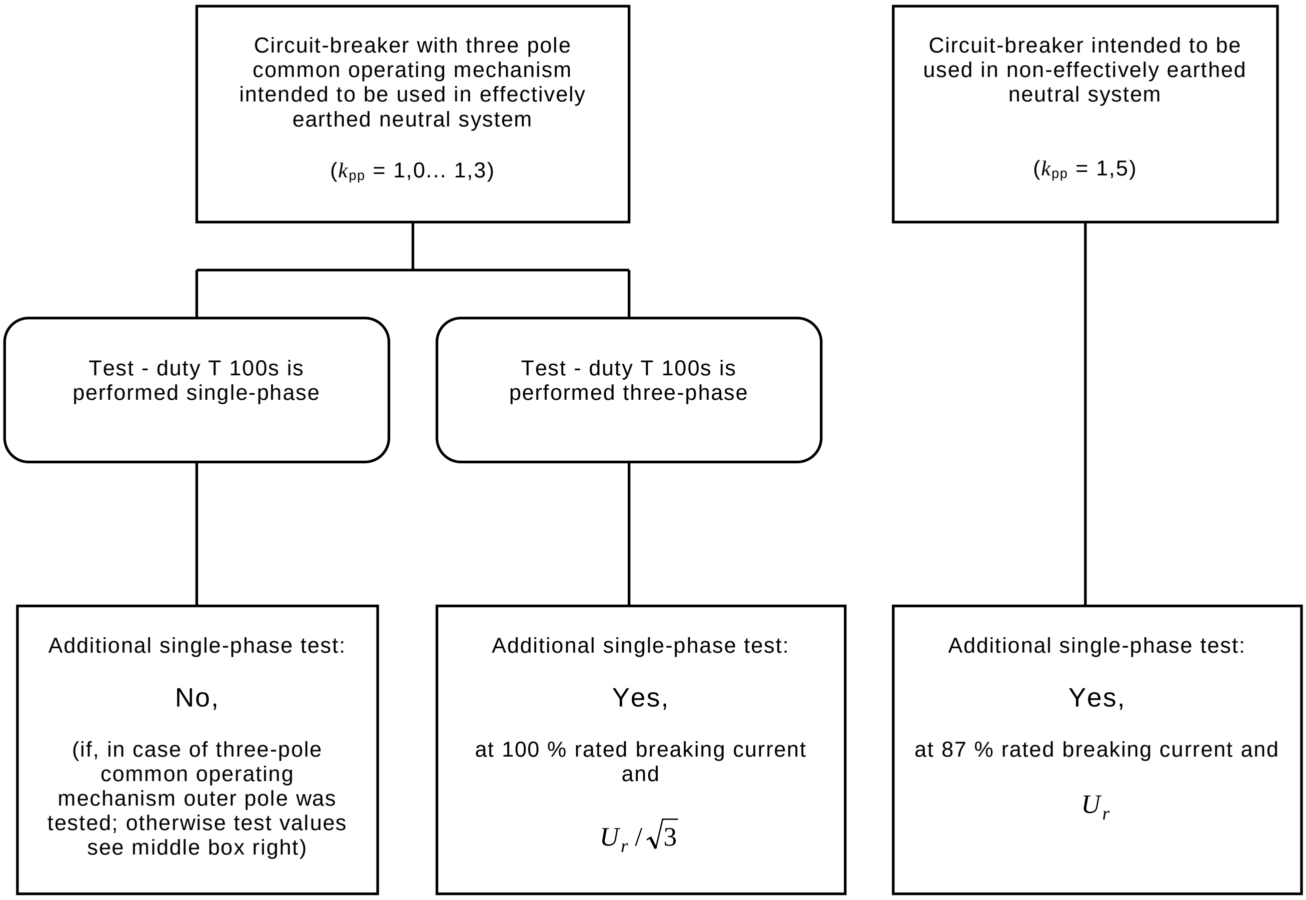
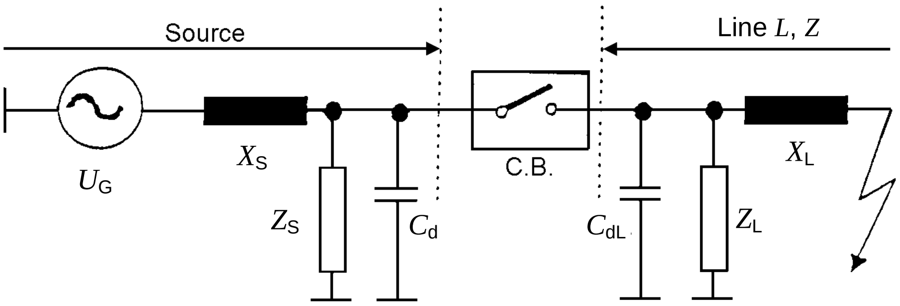


Figure 45 – Necessity of additional single-phase tests and requirements for testing



U_G	supply voltage, phase to earth value	X_L	power frequency line side reactance
X_S	power frequency source side reactance	Z_L	line side TRV controlling components
Z_S	source side TRV controlling components	C_{dL}	time delaying line side capacitance
C_d	time delaying source side capacitance	Z	surge impedance of line
C.B.	circuit-breaker	L	length of line to fault

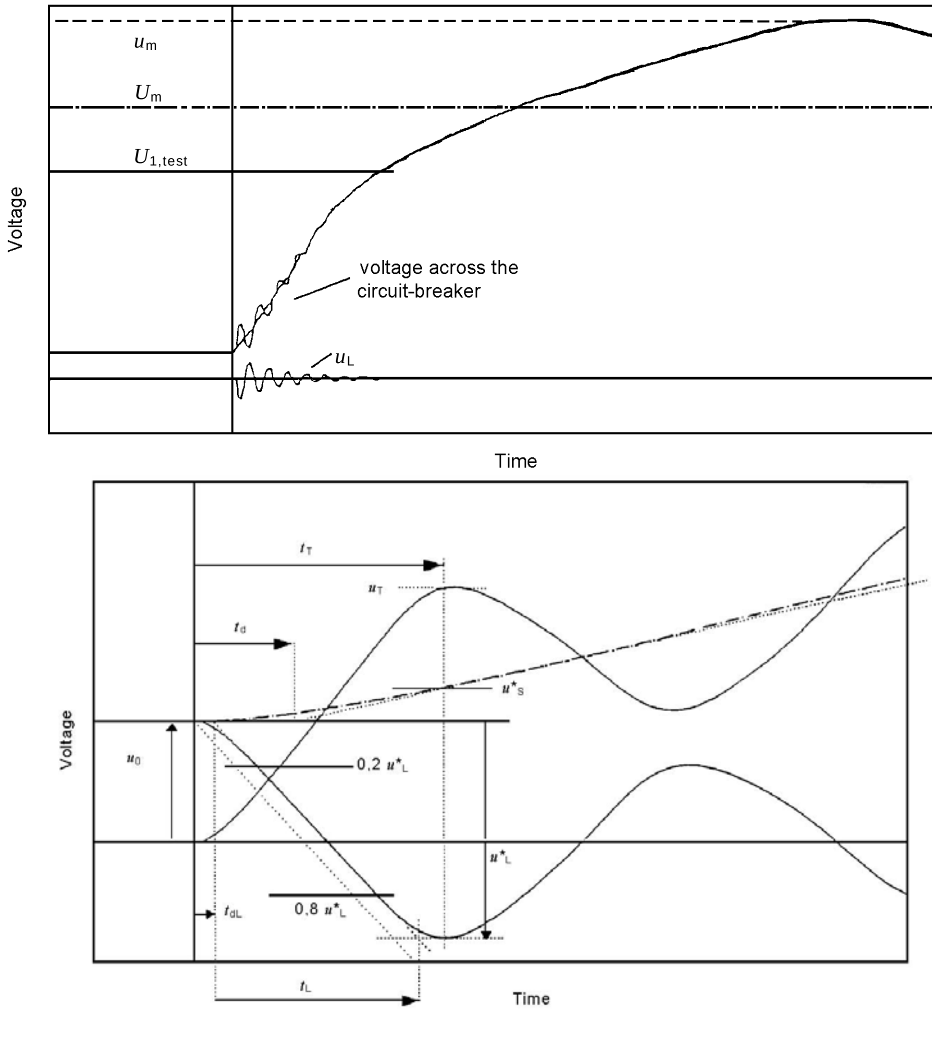
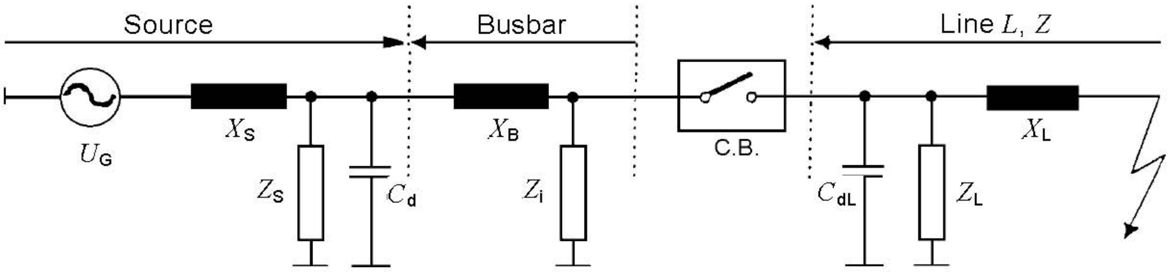
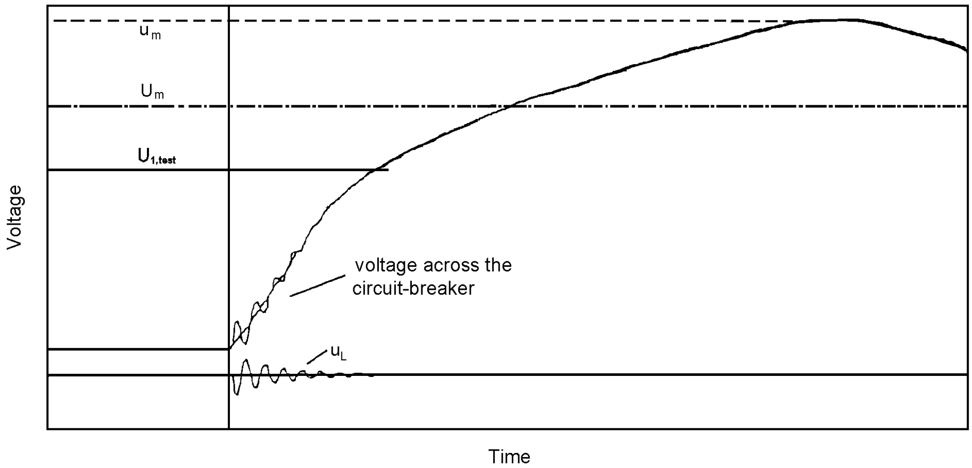


Figure 46 – Basic circuit arrangement for short-line fault testing and prospective TRV-circuit-type a) according to 6.109.3: source side and line side with time delay



U_G	Supply voltage, phase to earth value	Z_i	ITRV controlling components
X_S	Power frequency source side reactance	X_L	Power frequency line side reactance
Z_S	Source side TRV controlling components	Z_L	Line side TRV controlling components
C_d	Time delaying source side capacitance	C_{dL}	Time delaying line side capacitance
C.B.	Circuit-breaker	Z	Surge impedance of line
X_B	Power frequency busbar reactance	L	Length of line to fault



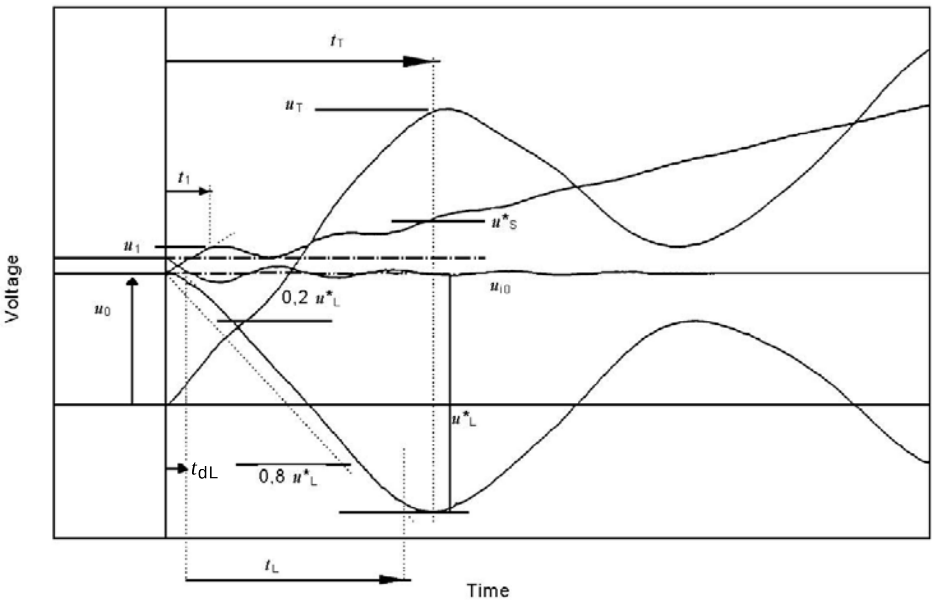
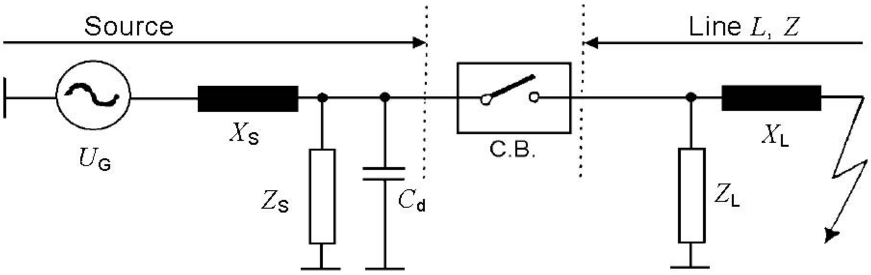
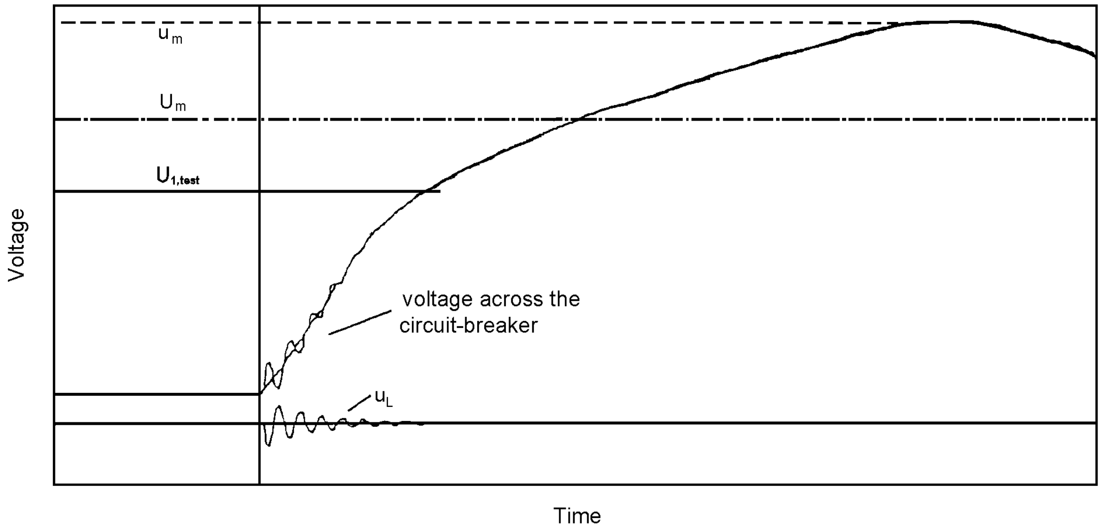


Figure 47 – Basic circuit arrangement for short-line fault testing – circuit type b1) according to 6.109.3: source side with ITRV and line side with time delay



U_G	Supply voltage, phase to earth value	X_L	Power frequency line side reactance
X_S	Power frequency source side reactance	Z_L	Line side TRV controlling components
Z_S	Source side TRV controlling components	Z	Surge impedance of line
C_d	Time delaying source side capacitance	L	Length of line to fault
C.B.	Circuit-breaker		



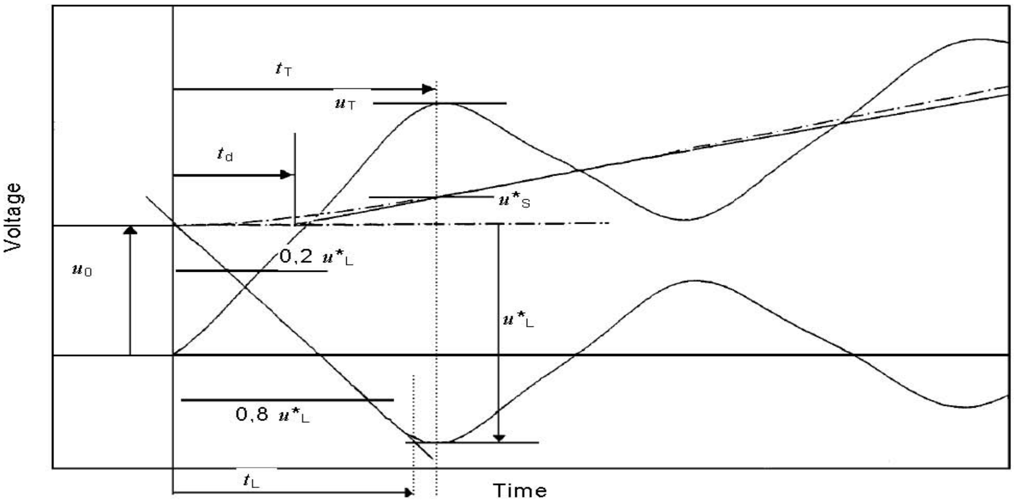


Figure 48 – Basic circuit arrangement for short-line fault testing – circuit type b2) according to 6.109.3: source side with time delay and line side without time delay

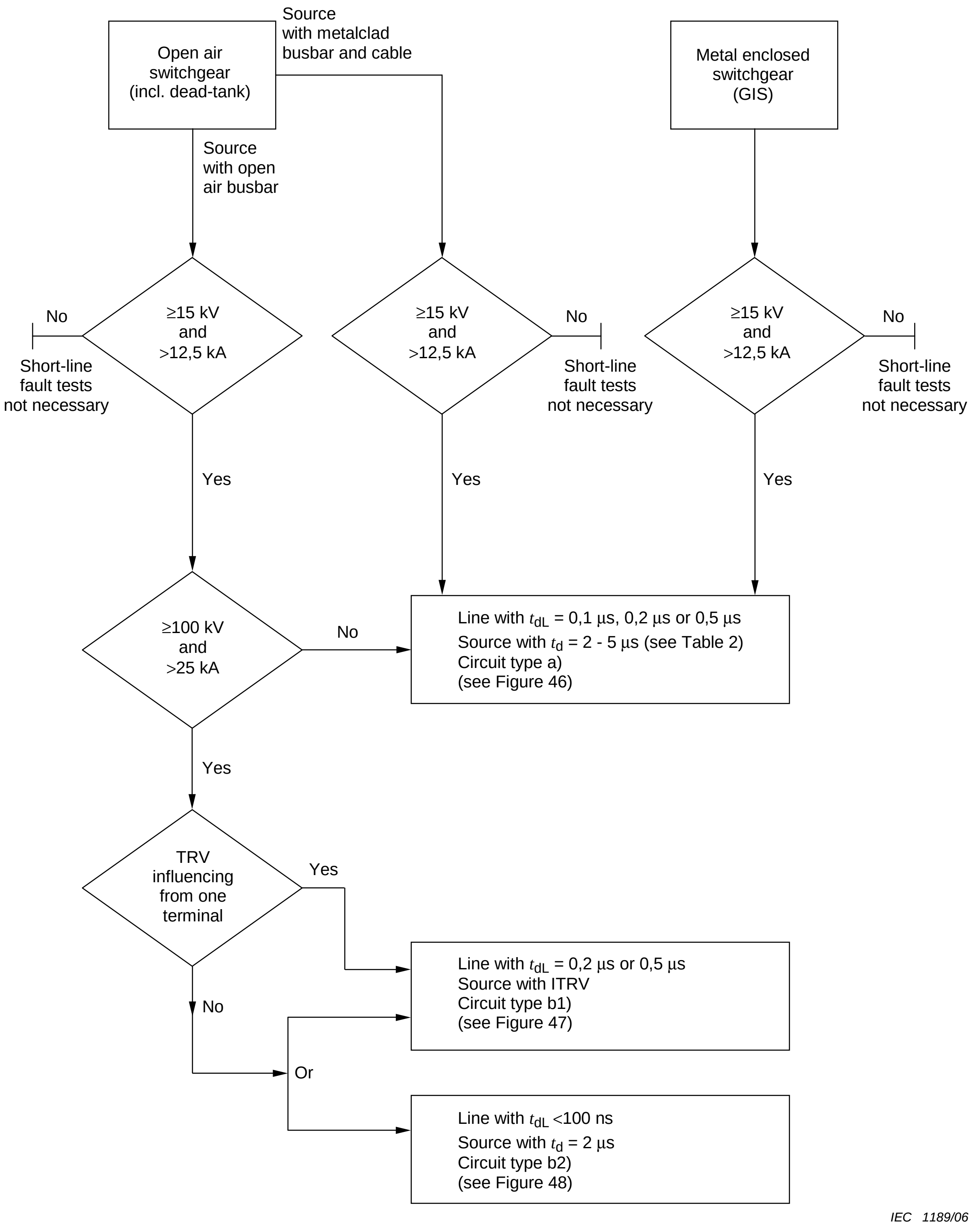


Figure 49 – Flow-chart for the choice of short-line fault test circuits for class S2 circuit-breakers and for circuit-breakers having a rated voltage of 100 kV and above

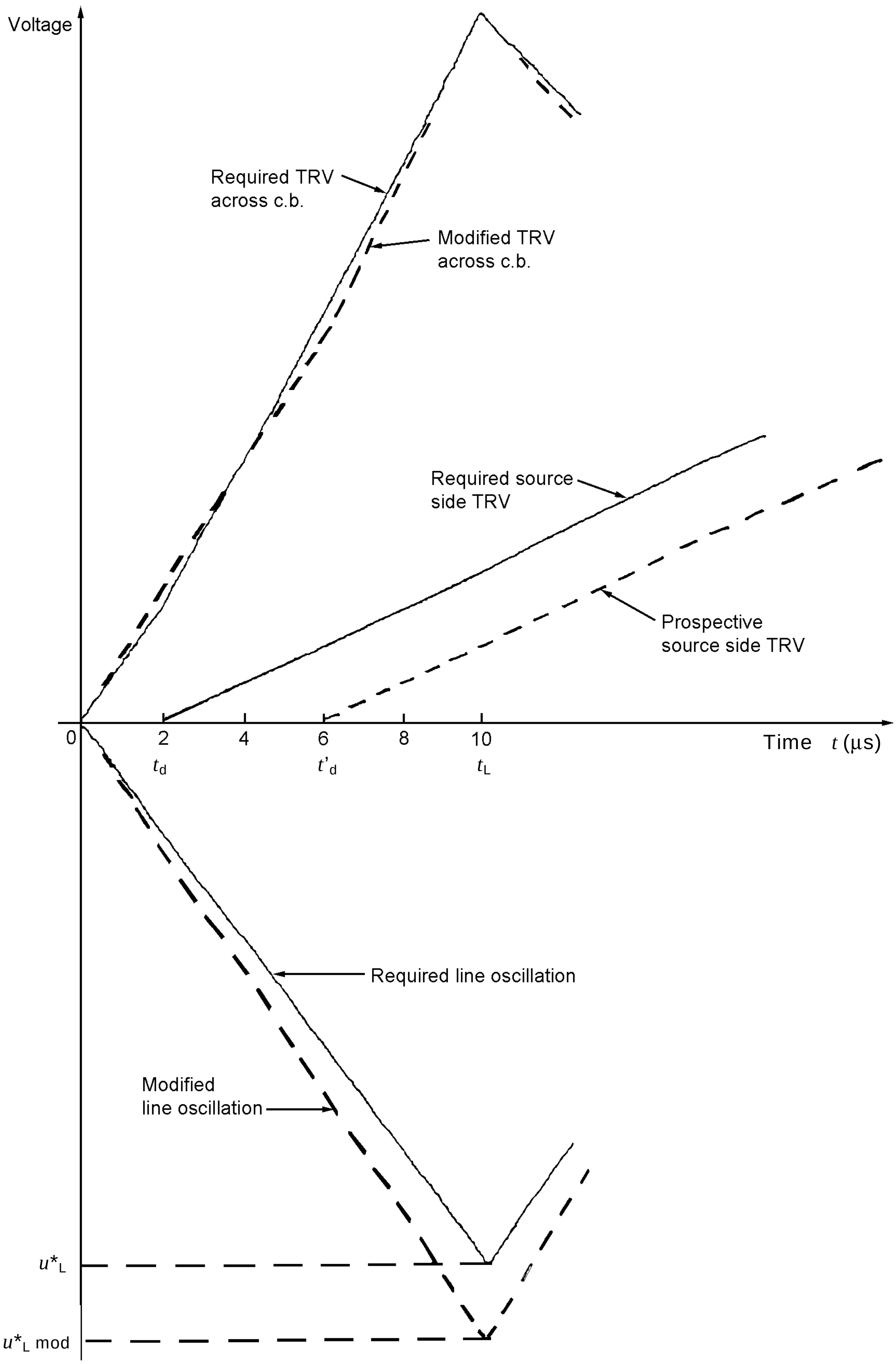
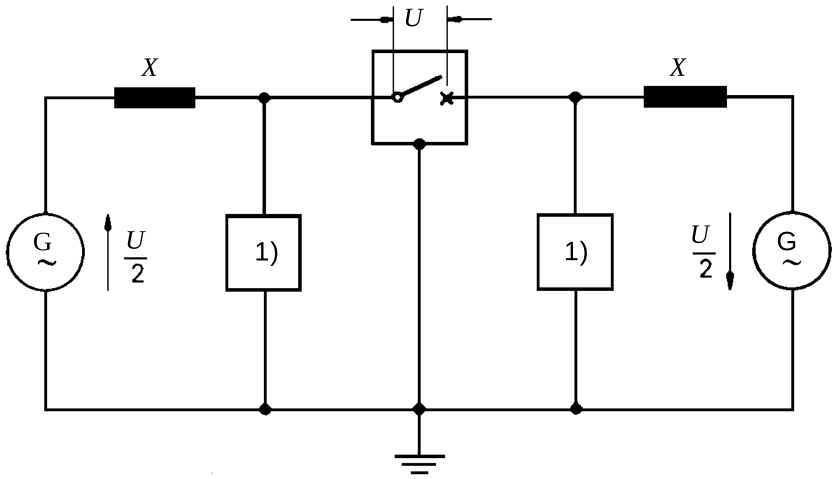
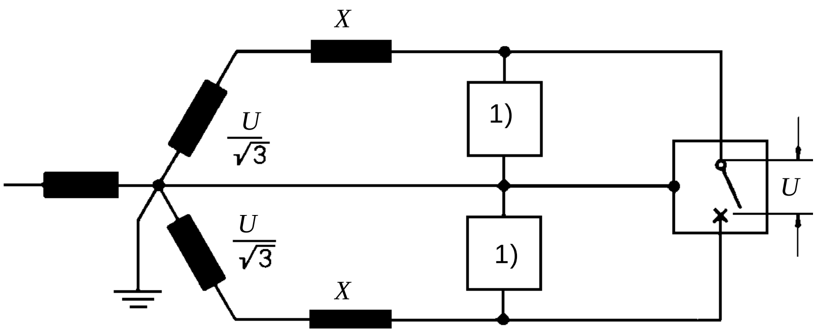


Figure 50 – Compensation of deficiency of the source side time delay by an increase of the excursion of the line side voltage



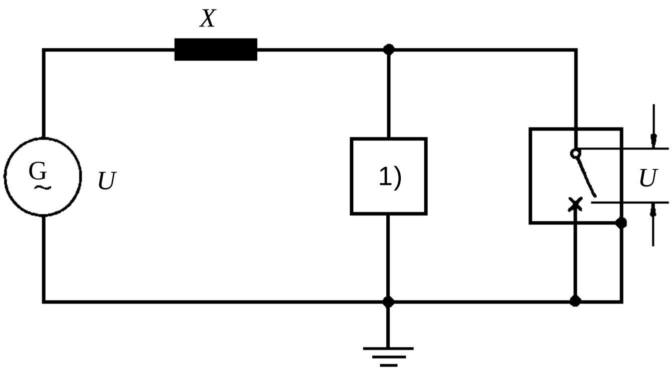
1) The squares represent combinations of capacitances and resistances.

Figure 51 – Test circuit for single-phase out-of-phase tests



1) The squares represent combinations of capacitances and resistances.

Figure 52 – Test circuit for out-of-phase tests using two voltages separated by 120 electrical degrees



1) The square represents combinations of capacitances and resistances.

Figure 53 – Test circuit for out-of-phase tests with one terminal of the circuit-breaker earthed (subject to agreement of the manufacturer)

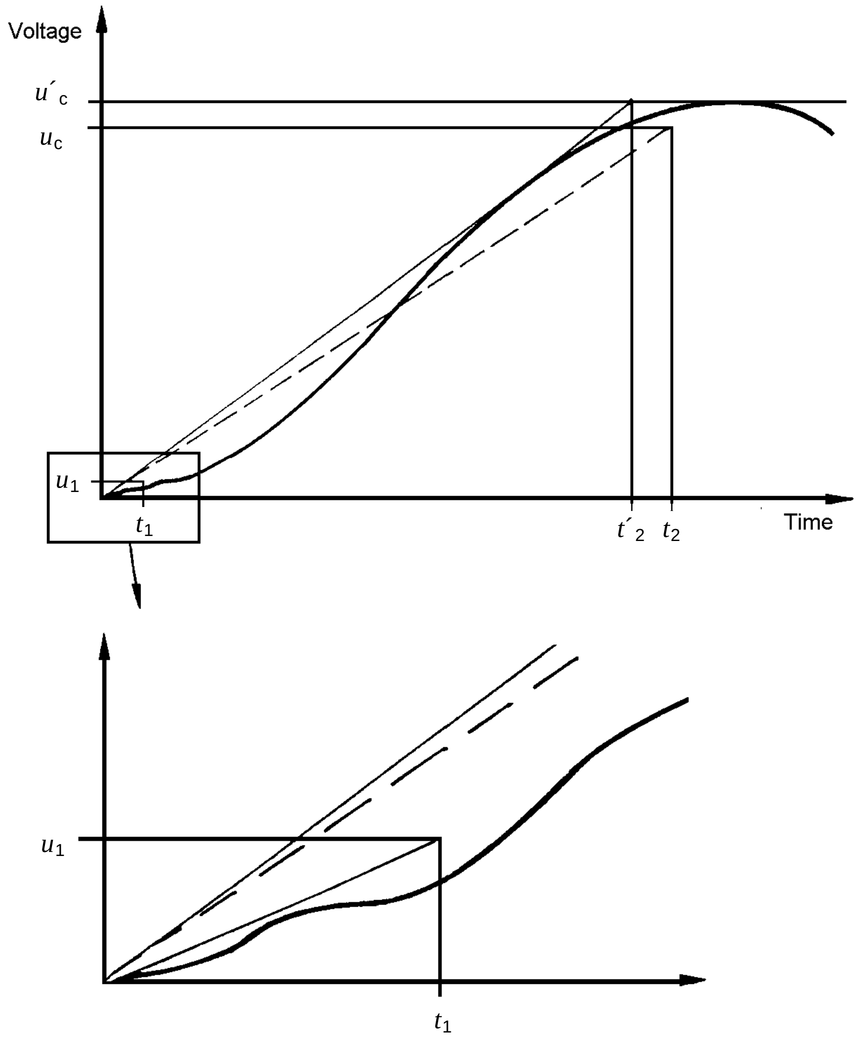
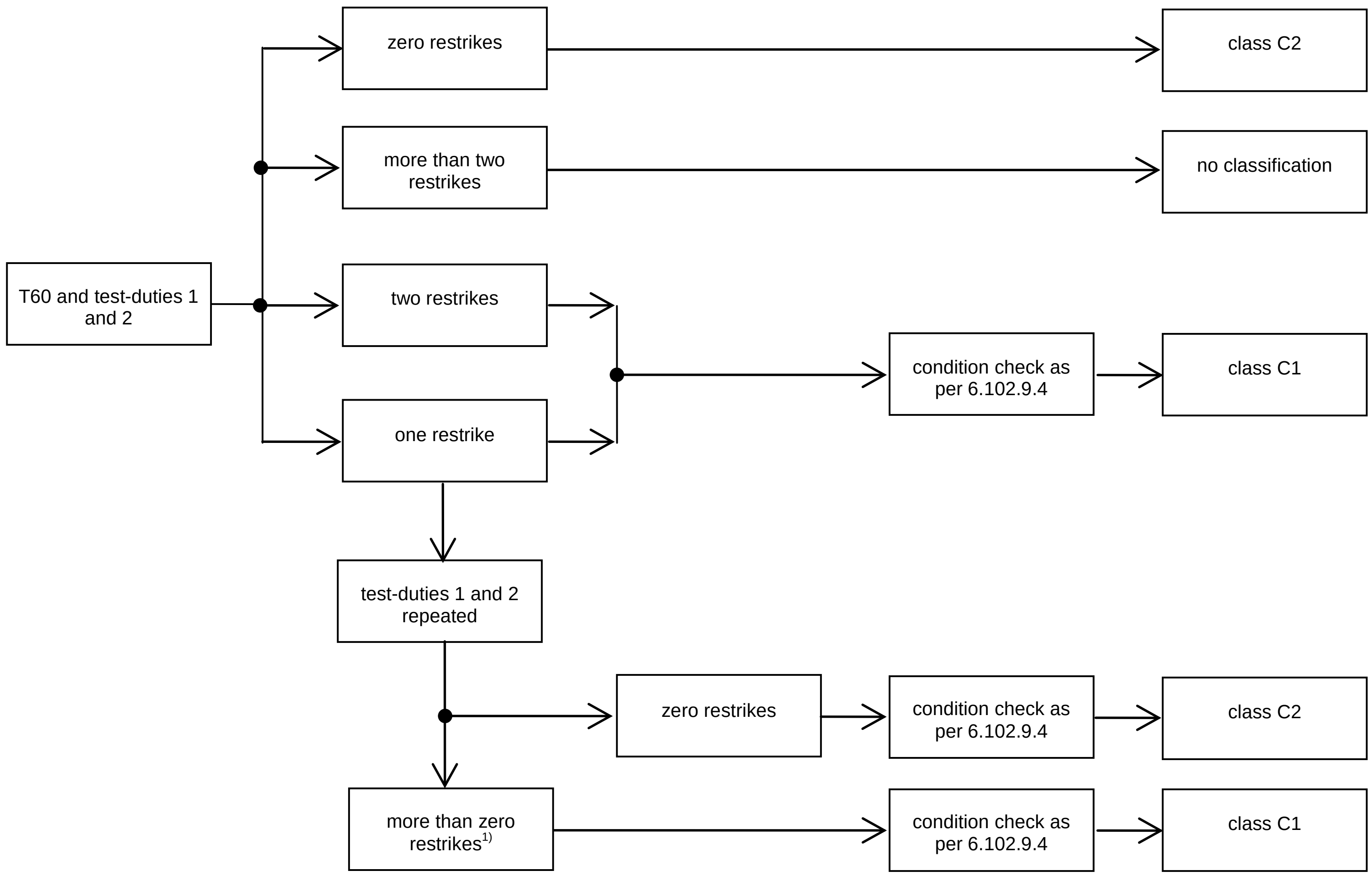
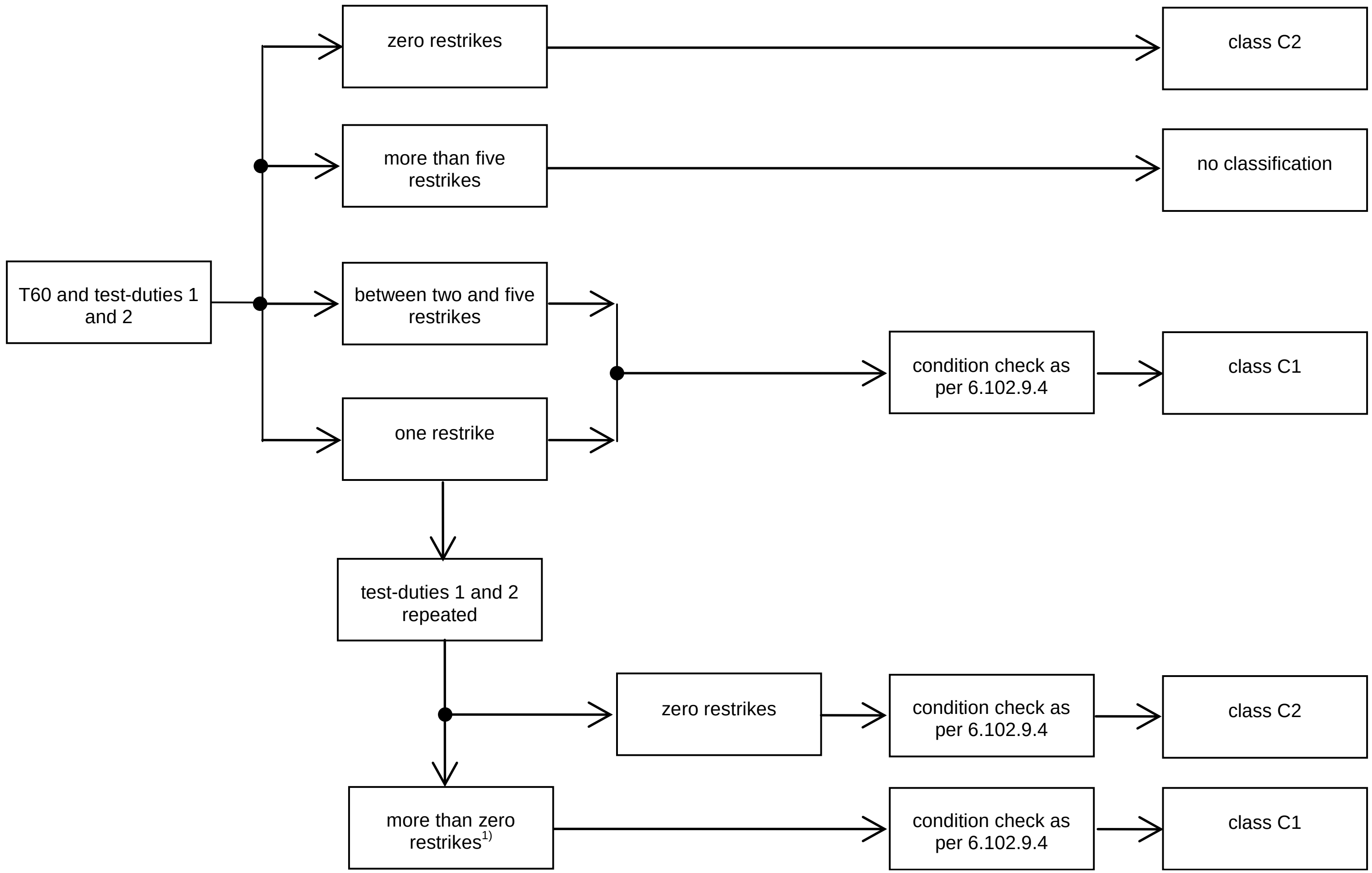


Figure 54 – Recovery voltage for capacitive current breaking tests



[1] Tests can be stopped after one restrike during repetition.

Figure 55 – Reclassification procedure for line and cable-charging current switching tests



[1)] Tests can be stopped after one restrike during repetition.

Figure 56 – Reclassification procedure for capacitor bank current switching tests

Annex A
(normative)

Calculation of transient recovery voltages for short-line faults from rated characteristics

A.1 Basic approach

For rating and testing purposes, it has been decided to consider only a short-line fault occurring from one phase to earth in a system having the neutral earthed and with a first-pole-to-clear factor of 1,0, the severity of this being sufficient to cover other cases, except in special circumstances where the system parameters may be more severe than the standard values.

The simplified single-phase circuit can be represented as shown in Figures 46, 47 and 48.

During the short-circuit, the driving supply voltage U_G is

$$U_G = U_r / \sqrt{3} \tag{A.1}$$

where U_r is the rated voltage of the circuit-breaker.

This voltage U_G drives the current I_L through the circuit consisting of the reactances X_S, X_B (if any) and X_L in series.

The reactances are defined as follows:

– X_S source side reactance;

– X_B busbar reactance on source side;

– X_L line side reactance.

The corresponding inductances are

$$L_S = X_S / \omega \tag{A.2a}$$

$$L_B = X_B / \omega \tag{A.2b}$$

$$L_L = X_L / \omega \tag{A.2c}$$

The r.m.s. value of the voltage drop on the source side, not considering X_B because of its negligible contribution, is

$$U_S = I_L \times X_S = U_G \frac{I_L}{I_{sc}} \tag{A.3}$$

where

I_{sc} is the rated short-circuit breaking current;

I_L is the short-line fault breaking current.

The r.m.s. value of the voltage drop along the line is

$$U_L = I_L \times X_L = U_G (1 - \frac{I_L}{I_{sc}}) \tag{A.4}$$

At the instant when the current is interrupted, the induced voltage drop across the line inductance is:

$$u_0 = U_L \sqrt{2} = L_L \frac{di}{dt} \tag{A.5a}$$

and for a symmetrical current:

$$u_0 = \omega \times L_L \times I_L \sqrt{2} \tag{A.5b}$$

This voltage drop returns to zero by a series of travelling waves reflected back and forth along the line between the circuit-breaker and the location of the fault, generating a transient voltage across the line in the form of a decaying saw-tooth oscillation[2)].

At the instant when the current is interrupted, the induced voltage drop across the source side inductance is:

$$u_x = U_x \sqrt{2} = L_S \frac{di}{dt} \tag{A.6a}$$

and for a symmetrical current:

$$u_x = \omega \times L_S \times I_L \sqrt{2} \tag{A.6b}$$

This voltage drop returns to zero by a series of oscillations. It is superimposed to the driving source voltage, both forming the source side voltage u_S of the circuit-breaker.

The crest value U_m of the total induced voltage at the instant of current interruption is:

$$U_m = u_0 + u_x = (L_L + L_S)\frac{di}{dt} \tag{A.7a}$$

and for a symmetrical current:

$$U_m = \omega(L_L + L_S)I_L\sqrt{2} = U_G\sqrt{2} = U_r\sqrt{2}/\sqrt{3} \tag{A.7b}$$

The voltage at the source side terminals of the circuit-breaker is the difference between the driving supply voltage and the voltage drop across the reactance X_S. The resulting specified transient recovery voltage for short-line faults appearing across the circuit-breaker is the difference between the source side transient voltage u_S and the line side transient voltage u_L as shown in Figure A.1.

The ratio between the voltage u_0 at the instant of breaking and the crest value U_m of the driving voltage is determined by the ratio of voltage drops across the line-side inductance and the source-side inductance, hence

$$u_0/U_m = u_0/(u_0 + u_x) = L_L/(L_L + L_S) = 1 - I_L/I_{SC} \tag{A.8}$$

This relation is shown in Table A.1 for the standard ratios of short-line fault currents.

2) In practice the saw-tooth waveform is in some degree modified by a time delay, due to lumped capacitances present at the terminals of the circuit-breaker (capacitances of voltage transformers, current transformers, etc.); in addition, the top of the oscillation is slightly rounded.

Table A.1 – Ratios of voltage-drop and source-side TRV

U_r	I_L/I_{sc}	u_0/U_m	u_m/U_m	$u_{1,test}$ / u_1
< 100 kV	0,90	0,10	1,49	-
	0,75	0,25	1,41	-
	0,60	0,40	1,32	-
≥ 100 kV	0,90	0,10	1,36	1,033
	0,75	0,25	1,30	1,083
	0,60	0,40	1,24	1,133

A.2 Transient voltage on line side

The peak value u_L* of the first peak of the transient voltage across the line is obtained by multiplying the value u_0 by the peak factor k.

$$u_L^* = ku_0 = kL_L \frac{di}{dt} \tag{A.9}$$

The time t_L is obtained from the rate-of-rise du_L/dt of the transient voltage u_L across the line and the peak value u_L* of the transient voltage across the line:

$$\frac{du_L}{dt} = sI_L = Z\frac{di}{dt} \tag{A.10}$$

then

$$t_L = \frac{u_L^*}{\frac{du_L}{dt}} = \frac{u_L^*}{sI_L} = k\frac{L_L}{Z} \tag{A.11}$$

where

s is the RRRV factor (kV/µs/kA);

Z is the surge impedance of the line;

f is the rated frequency.

The rated line characteristics Z, k and s are given in Table 8 (see 4.105).

NOTE The approximate length of line corresponding to a given short-line fault can be obtained by the equation:

$$L = c \times t_L/2 \tag{A.12}$$

where c is the speed of the travelling wave propagation assumed to be equal to: c = 0,3 km/µs.

A.3 Transient voltage on source side

A.3.1 Rated voltages of 100 kV and above

The course of the source-side transient voltage from the initial value u_0 to the peak value u_m can be derived from Tables 3, 4 and 5. The time coordinates t_1, t_2, t_3 and t_d given in these tables can be used directly. The voltage u_1 in Tables 3, 4 and 5 equalling 0,75 times the induced voltage U_m (instantaneous value of the supply voltage) at the instant of the current interruption results in the higher value $u_{1,test}$:

$$u_{1,test} = u_1 \times (1 + \frac{1}{3} \times (1 - \frac{I_L}{I_{sc}})) \tag{A.13}$$

The actual values of the ratio $u_{1,\text{test}}$ / u_1 are given in Table A.1.

The TRV peak value u_c results in a lower value u_m:

$$u_m = u_0 + k_{af} u_x \tag{A.14}$$

then

$$u_m / U_m = (u_0 + k_{af} u_x) / U_m \tag{A.14a}$$

and using Equation (A.8)

$$u_m / U_m = 1 + (k_{af} - 1) I_L / I_{sc} \tag{A.14b}$$

as given in Table A.1.

The actual rate of rise of the source side TRV du/dt_{SLF} is lowered related to the standard value for short-line fault du/d$t_{SLF,\ stand}$ given in Tables 1, 2, 3 and 4.

$$\left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{SLF} = \left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{SLF,\,stand} \times \frac{I_L}{I_{sc}} \tag{A.15}$$

The time to reach the voltage level U_m is

$$t_m = t_1 \times \frac{k_{af}}{k_{af} - 3/4} \tag{A.16}$$

The peak value u_m of the source-side transient recovery voltage is also the peak value of the transient recovery voltage across the circuit-breaker provided that the voltage oscillation on the line has been damped to zero by the time t_2 (or t_3), as is generally the case. The resulting course of the TRV of the source side is shown in Figure A.3.

The most important part of the resulting transient recovery voltage is up to the first peak value u_L* of the transient voltage across the line which is reached by the time t_T:

– line with time delay (see Figures 46 and 47): $t_T = 2t_{dL} + t_L$ (A.17a)

– line with ~~insignificant~~ a time delay less than 100 ns (see Figure 48): $t_T = t_{dL} + t_L$ (A.17b), where t_{dL} is 0,1 µs.

NOTE In contrast to the usual procedure for defining transient recovery voltages by their envelopes, for the evaluation of the total voltage across the circuit-breaker at the instant, when the line side voltage reaches its first peak u_L*, the actual waveshape is used. This modified procedure is applied because the envelope method would result in an intermediate voltage value in the rising slope of the TRV shortly before the peak, but not in the real crest value of the total voltage across the circuit-breaker, which is relevant for the assessment of the testing conditions. The envelope method is quite satisfactory, provided TRVs are not superimposed by two or more components. However, in the present case where the complete TRV is evaluated across the circuit-breaker, the sum of three different components is considered: the source side TRV, the ITRV of the source side and the line side TRV.

For the calculation of the source-side contribution u_s* at the time t_T two different cases shall be distinguished:

– without ITRV requirements (see Figure A.1)

$$u_s^* = \left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{SLF} \times (t_T - t_d) \tag{A.18}$$

and

$$u_{\mathrm{T}} = u_{\mathrm{L}}^{*} + u_{\mathrm{s}}^{*} \tag{A.19}$$

– with ITRV requirements (see Figure A.2):

$$u_{\mathrm{s}}^{*} = u_{\mathrm{i0}} + \left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{\mathrm{SLF}} \times \left(t_{\mathrm{T}} - t_{\mathrm{d}}\right) \tag{A.20}$$

and again

$$u_{\mathrm{T}} = u_{\mathrm{L}}^{*} + u_{\mathrm{s}}^{*} \tag{A.21}$$

For ITRV requirements (as given in Table 7), the following equations apply:

$$u_{\mathrm{i}} = f_{\mathrm{i}} I_{\mathrm{L}} = k_{\mathrm{i}} L_{\mathrm{B}} \frac{\mathrm{d}i}{\mathrm{d}t} \tag{A.22}$$

where

k_{i} = 1,4 (peak factor);

f_{i} is the multiplying factor according to Table 7.

Then the bus-bar voltage drop u_{i0} becomes

$$u_{\mathrm{i0}} = u_{\mathrm{i}} / k_{\mathrm{i}} \tag{A.23}$$

and the bus-bar inductance

$$L_{\mathrm{B}} = u_{\mathrm{i0}} / (\mathrm{d}i / \mathrm{d}t) \tag{A.24}$$

A.3.2 Rated voltages equal and higher than 15 kV and below 100 kV

Subclause A.3.1 applies except the following:

The course of the source-side transient voltage from the initial value u_0 to the peak value u_{m} can be derived from Table 25. The time coordinates t_3 and t_{d} given in this table can be used directly. The TRV peak value u_{c} results in a lower value u_{m}:

$$u_{\mathrm{m}} = u_0 + k_{\mathrm{af}} u_{\mathrm{x}} \tag{A.25}$$

then

$$u_{\mathrm{m}} / U_{\mathrm{m}} = (u_0 + k_{\mathrm{af}} u_{\mathrm{x}}) / U_{\mathrm{m}} \tag{A.26}$$

A.4 Examples of calculations

As examples of calculations the three basic types of test circuits (see 6.109.3) are calculated. The results are given in A.4.1 to A.4.3:

- source side and line side with time delay (A.4.1);
- source side with ITRV and line side with time delay (A.4.2);
- source side with time delay and line side without time delay (A.4.3).

A.4.1 Source side and line side with time delay (L_{90} and L_{75} for 245 kV, 50 kA, 50 Hz)

Parameters	Equation	Test parameters		
		Unit	L_{90}	L_{75}
Power frequency source side				
Rated voltage U_r	---	kV	245	245
Rated short-circuit current I_{sc}	---	kA	50	50
Rated frequency f_r	---	Hz	50	50
Driving supply voltage U_G	A.1	kV	141,5	141,5
Source side reactance X_S	---	Ω	2,83	2,83
Source side inductance L_S	A.2a	mH	9,01	9,01
Power frequency line side				
Specified line setting	---	%	90	75
Short-line fault breaking current I_L	---	kA	45	37,5
di/dt at the instant of current interruption	---	A/µs	20	16,7
Line side voltage U_L	A.4	kV	14,2	35,4
Line side reactance X_L	---	Ω	0,316	0,944
Line side inductance L_L	A.2c	mH	1,0	3,0
TRV parameters on line side				
Voltage at the instant of current interruption u_0	A.8	kV	20	50
Peak factor k	---	p.u.	1,6	1,6
Peak value of first peak of line side TRV u_L*	A.9	kV	32	80
Time delay t_{dL}	---	µs	0,5	0,5
Rate-of-rise of line side TRV du_L/dt	A.10	kV/µs	9	7,5
Specified line surge impedance Z	---	Ω	450	450
Rise time t_L	A.11	µs	3,56	10,7
TRV parameters on source side				
Time delay t_d	---	µs	2	2
Rate of rise at rated short-circuit breaking current I_{sc} $(du/dt)_{TF}$	---	kV/µs	2	2
Rate of rise at short-line fault breaking current I_L $(du/dt)_{SLF}$	A.15	kV/µs	1,8	1,5
Voltage at instant of current interruption u_X	A.7a	kV	180	150
Voltage $u_{1,test}$ at time t_1	A.13	kV	155	162,5
Time t_m to reach the voltage level U_m	A.16	µs	162	162
Transient peak voltage u_m	A.14	kV	272	260
Transient factor u_m/U_m	A.14a	p.u.	1,36	1,3
Total first peak across the circuit-breaker				
Time coordinate to first peak t_T	A.17a	µs	4,56	11,7
Source side contribution u_s* to TRV at time t_T	A.18	kV	4,6	14,6
First peak voltage u_T	A.19	kV	36,6	94,6

A.4.2 Source side with ITRV, line side with time delay (L_{90} for 245 kV, 50 kA, 50 Hz)

Parameter	Equation	Test parameters	
		Unit	L_{90}
Power frequency source side	Same as in A.4.1		
Power frequency line side	Same as in A.4.1		
TRV parameters on line side	Same as in A.4.1		
TRV parameters on source side	Same as in A.4.1		
ITRV parameters on source side			
Time coordinate t_i	Table 7	µs	0,6
Multiplying factor f_i	Table 7	kV/kA	0,069
Initial peak voltage u_i	A.22	kV	3,1
Busbar voltage drop u_{i0}	A.23	kV	2,21
Bus inductance L_B	A.24	µH	111
Total first peak voltage across the circuit-breaker			
Time coordinate t_T to first peak	A.17a	µs	4,56
Source side contribution u_s* to TRV at time t_T	A.20	kV	6,8
First peak voltage u_T	A.21	kV	38,8

A.4.3 Source side with time delay, line side without time delay (L_{90} for 245 kV, 50 kA, 50 Hz) – Calculation carried out using a simplified method

~~Parameter~~	~~Equation~~	~~Test parameters~~	
		~~Unit~~	~~L_{90}~~
~~**Power frequency source side (bus inductance neglected)**~~	~~Same as in A.4.1~~		
~~**Power frequency line side**~~	~~Same as in A.4.1~~		
~~**TRV parameters on line side**~~	~~Same as in A.4.1~~		
~~**TRV parameters on source side**~~	~~Same as in A.4.1~~		
~~**Total first peak voltage across the circuit-breaker**~~			
~~Time coordinate t_T to first peak~~	~~A.17b~~	~~µs~~	~~3,66~~
~~Source side contribution u_s* to TRV at time t_T~~	~~A.18~~	~~kV~~	~~3,0~~
~~First peak voltage u_T~~	~~A.19~~	~~kV~~	~~35,0~~

Parameter	Equation	Test parameters	
		Unit	L_{90}
Power frequency source side (bus inductance neglected)	Same as in A.4.1		
Power frequency line side	Same as in A.4.1		
TRV parameters on line side	Same as in A.4.1 except for given value t_{dL}		
Time delay t_{dL}	---	µs	< 0,1
TRV parameters on source side	Same as in A.4.1		
Total first peak voltage across the circuit-breaker			
Time coordinate t_T to first peak	A.17b	µs	3,66
Source side contribution u_S^* to TRV at time t_T	A.18	kV	3,0
First peak voltage u_T	A.19	kV	35,0

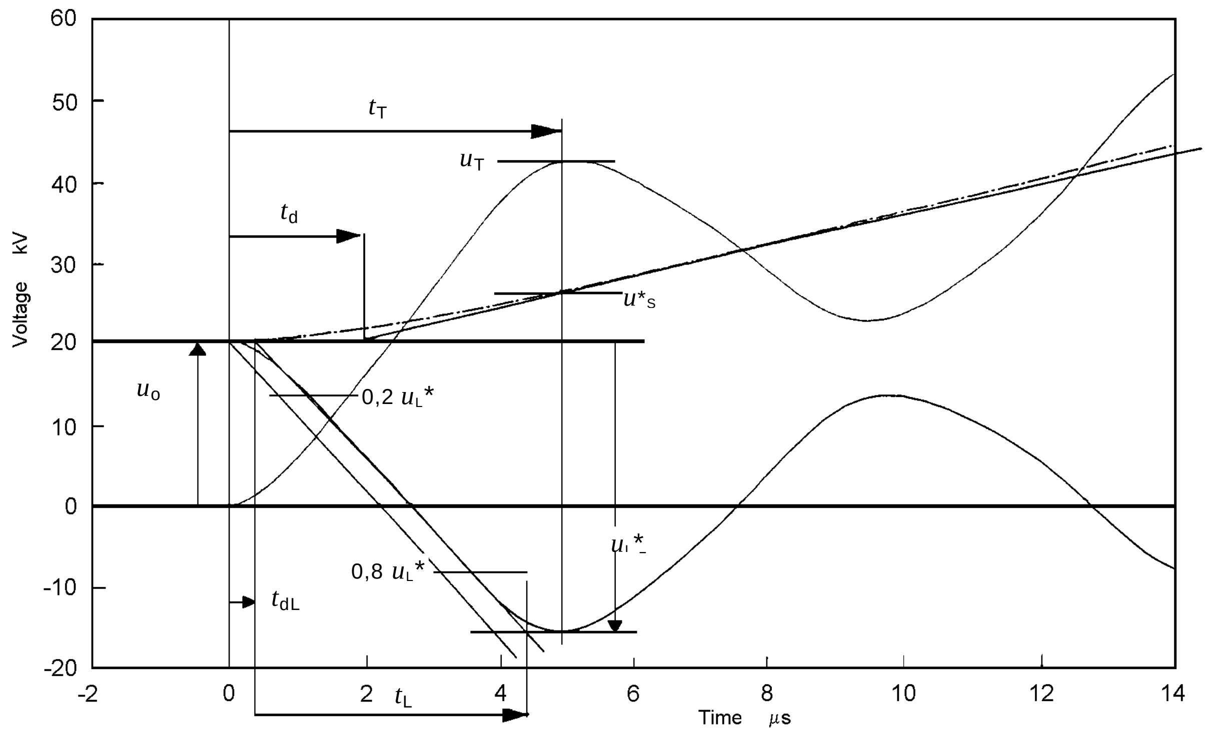


Figure A.1 – Typical graph of line and source side TRV parameters – Line side and source side with time delay

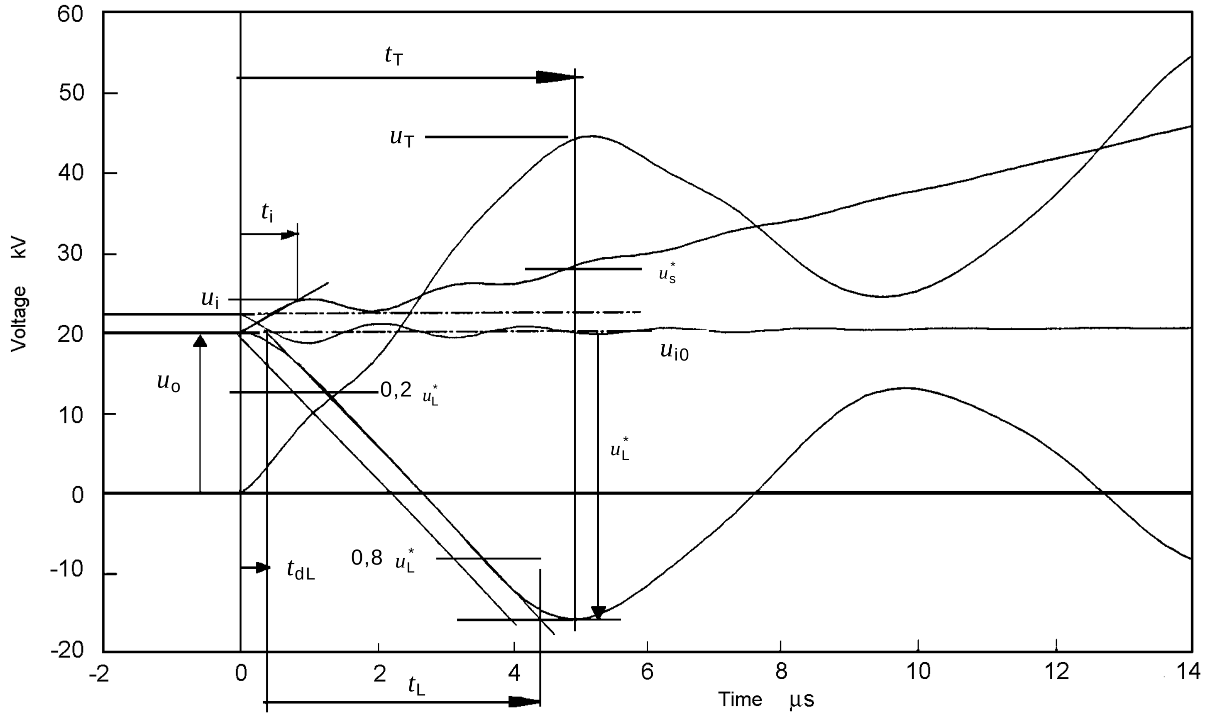


Figure A.2 – Typical graph of line and source side TRV parameters – Line side and source side with time delay, source side with ITRV

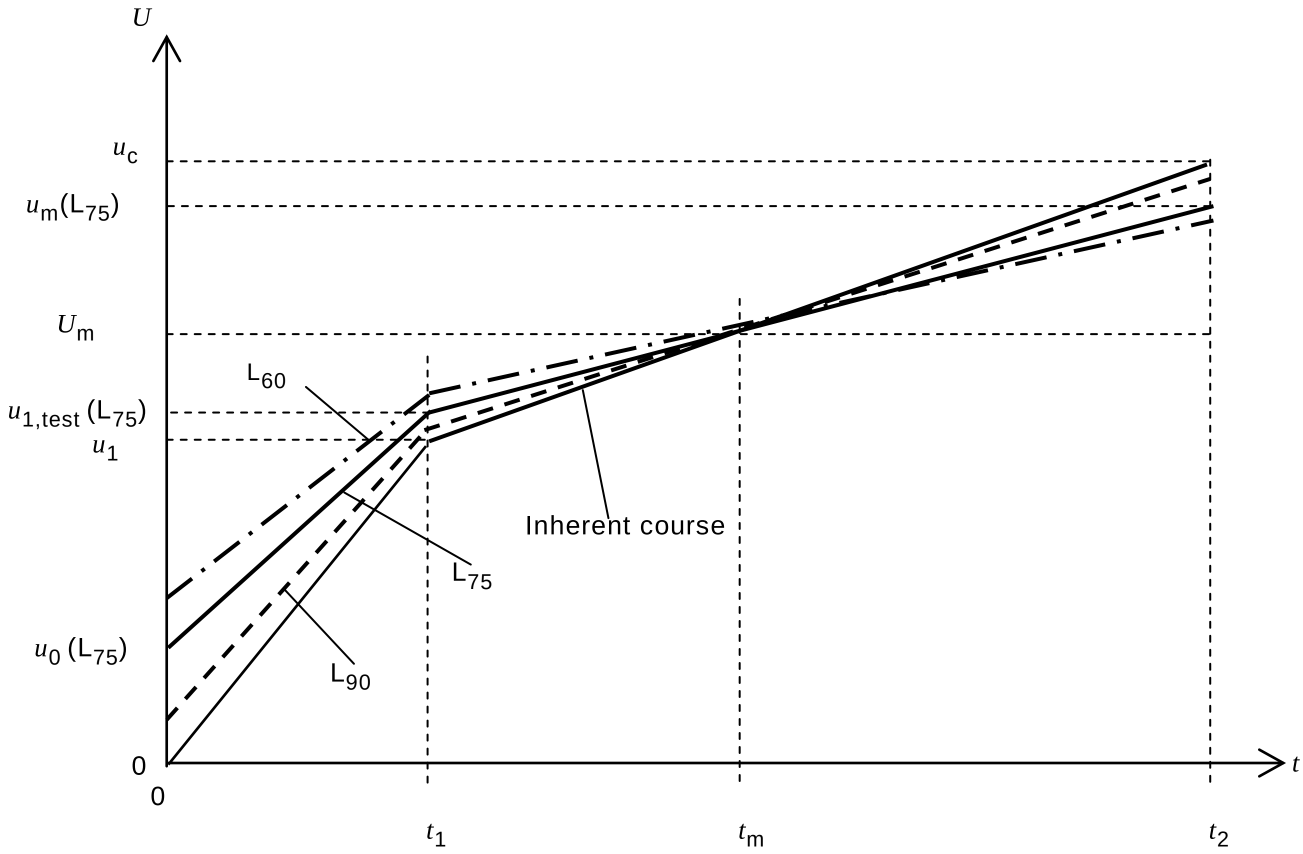


Figure A.3 – Actual course of the source side transient recovery voltage for short-line fault L_{90}, L_{75} and L_{60}

Annex B
(normative)

Tolerances on test quantities during type tests

During type tests, the following types of tolerances may normally be distinguished:

– tolerances on test quantities which directly determine the stress of the test object;
– tolerances concerning features or the behaviour of the test object before and after the test;
– tolerances on test conditions;
– tolerances concerning parameters of measurement devices to be applied.

In the following Table B.1, only tolerances on test quantities are considered.

A tolerance is defined as the range of the test value specified in this standard within which the measured test value should lie for a test to be valid. In certain cases (see 6.105.5 and Table 12) the test may remain valid even if the measured value falls outside the tolerance.

Any deviation of the measured test value and the true test value caused by the uncertainty of the measurement are not taken into account in this respect.

The basic rules for application of tolerances on test quantities during type tests are as follows:

a) testing stations shall aim wherever possible for the test values specified;
b) the tolerances on test quantities specified shall be observed by the testing station. Higher stresses of the circuit-breaker exceeding those tolerances are permitted only with the consent of the manufacturer. Lower stresses render the test invalid;
c) where, for any test quantity, no tolerance is given within this standard, or the standard to be applied, the type test shall be performed at values not less severe than specified. The upper stress limits are subject to the consent of the manufacturer;
d) if, for any test quantity, only one limit is given, the other limit shall be considered to be as close as possible to the specified value.

NOTE The term “tolerances on test quantities” must not be mixed up with the width of the band of test parameters which may be open at one side, for example, the test current for LC2, CC2 and BC2.

Table B.1 – Tolerances on test quantities for type tests

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.2	Dielectric tests				
6.2.6.1 and 6.2.7.1	Power-frequency voltage tests	Test voltage (r.m.s. value)	Rated short-duration power-frequency withstand voltage	± 1 %	IEC 62271-1, IEC 60060-1
		Frequency	--	45 Hz to 65 Hz	IEC 60060-1
		Wave shape	Peak value / r.m.s. value = √2	± 5 %	
6.2.6.2 and 6.2.7.3	Lightning impulse voltage tests	Peak value	Rated lightning impulse withstand voltage	± 3 %	
		Front time	1,2 µs	± 30 %	
		Time to half-value	50 µs	± 20 %	
6.2.7.2	Switching impulse voltage tests	Peak value	Rated switch impulse withstand voltage	± 3 %	
		Front time	250 µs	± 20 %	
		Time to half-value	2 500 µs	± 60 %	
6.2.11	Voltage test as condition check using standard switching impulse voltage				
		Peak value of switching impulse voltage	See 6.2.11	± 3 %	IEC 60060-1
		Front time	250 µs	± 20 %	
		Time of half-value	2 500 µs	± 60 %	
	Using TRV circuit of T10	Peak value of switching impulse voltage	See 6.2.11	± 3 %	
		Time to peak	Standard value for T10 (see Table 14)	$^{+200}_{-10}$ %	
6.3	Radio interference voltage tests	Test voltage	See 6.3 of IEC 62271-1	± 1 %	IEC 60060-1
6.4	Measurement of the resistance of the main circuit	DC test current I_{DC}	--	50 A ≤ I_{DC} ≤ rated normal current	IEC 62271-1

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.5	Temperature-rise tests	Ambient air velocity	--	≤ 0,5 m/s	IEC 62271-1
		Test current frequency	Rated frequency	$^{+2}_{-5}$ %	
		Test current	Rated normal current	$^{+2}_{0}$ % These limits shall be kept only for the last two hours of the testing period.	
		Ambient air temperature T	--	+ 10 °C < T < 40 °C	
6.6	Short-time withstand current and peak withstand current tests	Test frequency	Rated frequency	± 10 %	IEC 62271-1
		Peak current (in one of the outer phases)	Rated peak withstand current	$^{+5}_{0}$ %	
		Average of a.c. component of three-phase test current	Rated short-time withstand current	± 5 %	
		AC component of test current in any phase/average	1	± 10 %	
		Short-circuit current duration	Rated short-circuit duration	See tolerances for I^2t	
		Value of I^2t	Rated value I^2t	$^{+10}_{0}$ %	
6.101.3	Low and high temperature tests	Deviation of ambient air temperature over height of test object	--	≤ 5 K	
		Ambient air temperature for recording characteristics before test	20 °C	± 5 K	
		Minimum and maximum ambient air temperature during tests	According to class of circuit-breaker (see IEC 62271-1)	± 3 K	
6.101.4	Humidity test	Minimum temperature of a cycle	25 °C	± 3 K	
		Maximum temperature of a cycle	40 °C	± 2 K	
6.101.6	Guide for static terminal load test	Forces	As specified in 6.101.6	$^{+10}_{0}$ %	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.102	Miscellaneous provisions for making, breaking and switching tests	Maximum arcing time to be controlled Medium arcing time to be controlled	Specified test value	± 0,5 ms ± 1 ms	
6.103	Test circuits for short circuit making and breaking tests	Power factor (average)	--	≤ 0,15	
		Power factor of any phase / average	--	± 25 %	
		Frequency	Rated frequency	± 8 %	
6.104	Short-circuit test quantities				
6.104.1	Applied voltage before short-circuit making tests	Applied voltage	See 6.104.1	$^{+10}_{\ 0}$ %	
		Applied phase voltage / average (three-phase)	1	± 5 %	
6.104.3	Short-circuit breaking current	AC component of any phase / average	1	± 10 %	
		AC component of the prospective current at final arc extinction in last-pole-to-clear	Specified breaking current for the relevant test-duty	≥ 90 % NOTE For test duty T100a, the tolerances on the last current loop shape (amplitude and duration) are given in 6.102.10.2.1.2 b) and in 6.106.6.1.	
6.104.4	DC component of short-circuit breaking current	DC component in T10, T30, T60, T100s	--	≤ 20 %	
		DC component at current zero in T00a	For direct tests: 6.106.6.2 (single-phase) and 6.106.6.1 (three-phase)	≤ 110% of specified value and ≥ 95% of the specified value	
		Average d.c. component at current zero	For direct tests: 6.106.6.2 (single-phase) and 6.106.6.1 (three-phase)	≤ 100% of specified value and ≥ 95% of the specified value	
6.104.5	Transient recovery voltage (TRV) for terminal fault tests	Peak value of TRV: - for circuit-breakers ≤ 52 kV - for circuit-breakers > 52 kV	 See Tables 24 and 25 See Tables 24, 25, 26 and 27	 $^{+10}_{\ 0}$ % $^{+5}_{\ 0}$ %	
		Rate of rise of TRV: - for circuit-breakers ≤ 52 kV - for circuit-breakers > 52 kV	 See Tables 24 and 25 See Tables 24, 25, 26 and 27	 $^{+15}_{\ 0}$ % [1)] $^{+8}_{\ 0}$ %	
		Time delay t_d	See Tables 24, 25, 26 and 27	± 20 %	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.104.7	Power frequency recovery voltage (RV)	Power frequency recovery voltage	Specified values according to 6.104.7	± 5 %	
		RV of any pole at the end of the time / average	1	± 20 %	
6.106	Basic short-circuit test-duty	Breaking current in T10	10 % of rated short-circuit breaking current	± 20 %	
		Breaking current in T30	30 % of rated short-circuit breaking current	± 20 %	
		Breaking current in T60	60 % of rated short-circuit breaking current	± 10 %	
		Breaking current in T100s	100 % of rated s.-c. breaking current	$^{+5}_{0}$ %	
		Breaking current in T100a	100 % of rated s.-c. breaking current	±10%	
		Peak short-circuit current in T100s and T100a	Rated short-circuit making current	$^{+10}_{0}$ %	
6.107	Critical current tests	Breaking current	See 6.107.2	± 20 %	
		DC component of breaking current	≤ 20 %	Upper limit 25 %	
~~6.108~~	~~Single-phase and double earth fault tests~~	~~Breaking current~~	~~See Figure 45~~	~~$^{+5}_{0}$ %~~	
		~~DC component of breaking current~~	~~≤ 20 %~~	~~Upper limit 25 %~~	
		~~Peak value of TRV:~~	~~See 6.108.2 and Tables 24, 25, 26 and 27~~		
		~~– for circuit-breakers ≤ 52 kV~~		~~$^{+10}_{0}$ %~~	
		~~– for circuit-breakers > 52 kV~~		~~$^{+5}_{0}$ %~~	
		~~Rate of rise of TRV~~	~~See 6.108.2 and Tables 24, 25, 26 and 27~~		
		~~– for circuit-breakers ≤ 52 kV~~		~~$^{+15}_{0}$ %~~	
		~~– for circuit-breakers > 52 kV~~		~~$^{+8}_{0}$ %~~	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.108	Single-phase and double earth fault tests	Breaking current	See Figure 45	$^{+5}_{0}$ %	
		DC component of breaking current	≤ 20 %		
		Peak value of TRV: – for circuit-breakers ≤ 52 kV – for circuit-breakers > 52 kV	See 6.108.2 and Tables 24, 25, 26 and 27	 $^{+10}_{0}$ % $^{+5}_{0}$ %	
		Rate-of-rise of TRV – for circuit-breakers ≤ 52 kV – for circuit-breakers > 52 kV	See 6.108.2 and Tables 24, 25, 26 and 27	 $^{+15}_{0}$ % $^{+8}_{0}$ %	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
~~6.109~~	~~Short-line fault tests~~	~~DC component of breaking current~~	~~≤ 20 %~~	~~Upper limit 25 %~~	
		~~Breaking current L_{90}~~	~~90 % of rated short-circuit breaking current~~	~~90 % to 92 %~~	
		~~Breaking current L_{75}~~	~~75 % of rated short-circuit breaking current~~	~~71 % to 79 %~~	
		~~Breaking current L_{60}~~	~~60 % of rated short-circuit breaking current~~	~~55 % to 65 %~~	
		~~Surge impedance~~	~~450 Ω~~	~~± 3 %~~	~~See NOTE~~
		~~Peak value of line side voltage~~		$\cancel{{}^{+20}_{\ 0}\ \%}$	
		~~Rate of rise of line side voltage~~	~~See Table 8 and Annex A~~	$\cancel{{}^{+5}_{\ 0}\ \%}$	
		~~Time delay t_{dL}~~		$\cancel{{}^{\ 0}_{-10}\ \%}$	
6.109	Short-line fault tests	DC component of breaking current	≤ 20 %		
		Breaking current L_{90}	90 % of rated short-circuit breaking current	90 % to 92 %	
		Breaking current L_{75}	75 % of rated short-circuit breaking current	71 % to 79 %	
		Breaking current L_{60}	60 % of rated short-circuit breaking current	55 % to 65 %	
		Surge impedance Z		± 3 %	See NOTE
		Peak value of line side voltage		${}^{+20}_{\ 0}\ \%$	
		Rate of rise of line side voltage	See Table 8 and Annex A	${}^{+5}_{\ 0}\ \%$	
		Time delay t_{dL}		${}^{\ 0}_{-10}\ \%$	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
~~6.110~~	~~Out-of-phase making and breaking tests~~	~~Power factor~~	~~--~~	~~≤ 0,15~~	
		~~DC component of breaking current~~	~~≤ 20 %~~	~~Upper limit 25 %~~	
		~~Applied voltage and power frequency recovery voltage~~	~~As specified in 6.110.2~~	~~± 5 %~~	
		~~Peak value of TRV:~~			
		~~– for circuit-breakers ≤ 52 kV~~	~~See Tables 1 and 2~~	$^{+10}_{\ 0}$ ~~%~~	
		~~– for circuit-breakers > 52 kV~~	~~See Tables 1, 2, 3, 4 and 5~~	$^{+5}_{\ 0}$ ~~%~~	
		~~Rate of rise of TRV:~~			
		~~– for circuit-breakers ≤ 52 kV~~	~~See Tables 1 and 2~~	$^{+15}_{\ 0}$ ~~%~~	
		~~– for circuit-breakers > 52 kV~~	~~See Tables 1, 2, 3, 4 and 5~~	$^{+8}_{\ 0}$ ~~%~~	
		~~Instant of closing in OP2~~	~~At crest of applied voltage in one pole~~	~~± 15°~~	
		~~Breaking current for OP1~~	~~30 % of rated out-of-phase breaking current~~	~~± 20 % of specified value~~	
		~~Breaking current for OP2~~	~~100 % of rated out-of-phase breaking current~~	~~-~~ $^{+10}_{\ 0}$ ~~%~~	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.110	Out-of-phase making and breaking tests	Power factor	--	≤ 0,15	
		DC component of breaking current	≤ 20 %		
		Applied voltage and power frequency recovery voltage	As specified in 6.110.2	± 5 %	
		Peak value of TRV:			
		– for circuit-breakers ≤ 52 kV	See Tables 1 and 2	$^{+10}_{\ 0}$ %	
		– for circuit-breakers > 52 kV	See Tables 1, 2, 3, 4 and 26	$^{+5}_{\ 0}$ %	
		Rate of rise of TRV:			
		– for circuit-breakers ≤ 52 kV	See Tables 1 and 2	$^{+15}_{\ 0}$ %	
		– for circuit-breakers > 52 kV	See Tables 1, 2, 3, 4 and 26	$^{+8}_{\ 0}$ %	
		Instant of making in OP2	At crest of applied voltage in one pole	± 15°	
		Breaking current for OP1	30 % of rated out-of-phase breaking current	± 20 % of specified value	
		Breaking current for OP2	100 % of rated out-of-phase breaking current	$^{+10}_{\ 0}$ %	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
~~6.111~~	~~Capacitive current switching tests~~	~~Power frequency voltage variation:~~ ~~– for LC1, CC1 and BC1~~ ~~– for LC2, CC2 and BC2~~		~~≤ 2 %~~ ~~≤ 5 %~~	
		~~Voltage decay of recovery voltage 300 ms after arc extinction~~		~~≤ 10 %~~	
		~~R.m.s value / r.m.s. value of fundamental component~~	~~--~~	~~≤ 1,2~~	
		~~Test voltage~~	~~As specified in 6.111.7~~	$^{+3}_{0}$ ~~%~~	
		~~Frequency of the recovery voltage~~	~~Rated frequency~~	~~± 2 %~~	
		~~Breaking current / rated capacitive breaking current~~	~~LC1, CC1, BC1~~ ~~LC2, CC2, BC2~~	~~10 % to 40 %~~ ~~≥ 100 %~~	
		~~Damping factor of inrush current~~	~~Circuit-breakers < 52 kV~~	~~≥ 0,75~~	
			~~Circuit-breakers ≥ 52 kV~~	~~≥ 0,85~~	
		~~Back-to-back current switching: peak value of inrush making current~~	~~BC2~~	~~± 10 %. The tolerance on the inherent value of back-to-back making inrush current shall be~~ $^{+10}_{0}$ ~~%.~~	
		~~Back-to-back current switching: frequency of inrush making current~~	~~BC2~~	~~As close as possible to the required value. Shall not be lower than 77 % of service condition and not be higher than 6000 Hz.~~	
	~~Capacitive current switching tests with specified TRV~~	~~Waveshape of the recovery voltage~~	~~Theoretical test voltage waveshape of the corresponding single-phase direct test (1-cos curve)~~	$^{+6}_{0}$ ~~% of the peak value of the test voltage (i.e. approximately 3 % of the peak recovery voltage~~ u_c ~~shown in Figure 54)~~	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.111	Capacitive current switching tests	Power frequency voltage variation: – for LC1, CC1, BC1 – for LC2, CC2, BC2		≤ 2 % ≤ 5 %	
		Voltage decay of recovery voltage 300 ms after arc extinction		≤ 10 %	
		R.m.s value / r.m.s. value of fundamental component	--	≤ 1,2	
		Test voltage	As specified in 6.111.7	$^{+3}_{0}$ %	
		Frequency of the recovery voltage	Rated frequency	± 2 %	
		Breaking current / rated capacitive breaking current	LC1, CC1, BC1 LC2, CC2, BC2	10 % to 40 % ≥ 100 %	
		Damping factor of inrush current	Circuit-breakers <52 kV	≥ 0,75	
			Circuit-breakers ≥ 52 kV	≥ 0,85	
		Back-to-back current switching: inherent peak value of inrush making current	BC2	$^{+10}_{-0}$ %	
		Back-to-back current switching: frequency of inrush making current	BC2	As close as possible to the required value. Shall not be lower than 77 % of service condition and not be higher than 6 000 Hz.	
	Capacitive current switching tests with specified TRV	Waveshape of the recovery voltage	Theoretical test voltage waveshape of the corresponding single-phase direct test (1-cos curve)	$^{+6}_{-0}$ % of the peak value of the test voltage (i.e. approximately 3 % of the peak recovery voltage u_c shown in Figure 54)	
Annex M	Transient recovery voltage (TRV) for T30, for circuit-breakers of rated voltage less than 100 kV intended to be connected to a transformer with a connection of small capacitance	Peak value of TRV	See Table M.1	$^{+10}_{0}$ %	
		Rate of rise of TRV		$^{+5}_{-10}$ %	

1) If for T10 and T30 the upper limit is exceeded, the smallest value possible shall be used.

NOTE The priority parameter for short-line fault testing is the waveshape of the line side voltage and not the surge impedance of the line.

Annex C
(normative)

Records and reports of type tests

C.1 Information and results to be recorded

All relevant information and results of type tests shall be included in the type test report.

Oscillographic records in accordance with C.2 shall be made of all short-circuit operations, making and breaking operations under out-of-phase conditions, capacitive current switching operations and no-load operations.

The type test report shall include a statement concerning the uncertainty of the measurement systems used for the tests. This statement shall refer to internal procedures of the laboratory through which traceability of the measuring uncertainty is established.

The type test report shall include a statement of the performance of the circuit-breaker during each test-duty and of the condition of the circuit-breaker after each test-duty, in so far as an examination is made, and at the end of the series of test-duties. The statement shall include the following particulars:

a) condition of circuit-breaker, giving details of any replacements or adjustments made and condition of contacts, arc control devices, oil (including any quantity lost), statement of any damage to arc shields, enclosures, insulators and bushings;
b) description of performance during test-duty, including observations regarding emission of oil, gas or flame.

C.2 Information to be included in type test reports

C.2.1 General

a) date of tests;
b) reference of report number;
c) test numbers;
d) oscillogram numbers.

C.2.2 Apparatus tested

Subclause 6.1.3 and Annex A.2 of IEC 62271-1 are applicable with the following additions:

Reference drawing numbers given in the test report shall indicate the manufacturer's reference number, revision number and corresponding contents.

The reference mechanical travel characteristic, if applicable, shall be included or reference shall be made in the test report by the use of a drawing number or in an equivalent way.

C.2.3 Rated characteristics of circuit-breaker, including its operating devices and auxiliary equipment

The values of rated characteristics specified in Clause 4 and the minimum opening time shall be given by the manufacturer.

C.2.4 Test conditions (for each series of tests)

a) number of poles;

b) power factor;

c) frequency, in Hz;

d) generator neutral (earthed or isolated);

e) transformer neutral (earthed or isolated);

f) short-circuit point or load side neutral (earthed or isolated);

g) diagram of test circuit including connection(s) to earth;

h) details of connection of circuit-breaker to the test circuit (e.g. orientation);

i) pressure of fluid for insulation and/or interruption;

j) pressure of fluid for operation.

C.2.5 Short-circuit making and breaking tests

a) operating sequence and time intervals;

b) applied voltage, in kV;

c) making current (peak value), in kA;

d) breaking current:

   1) r.m.s. value of a.c. component in kA for each phase and average;

   2) prospective d.c. component at current zero (calculated from percentage of d.c. component at contact separation and from the d.c. time constant of the test circuit; applicable only to T100a);

   3) peak current in the last current loop (applicable only to T100a for the phase having the highest d.c. component);

   4) loop duration of the last current loop (applicable only to T100a for the phase having the highest d.c. component and first-pole-to-clear; for extended major loop, the prospective loop duration taken from the prospective current calibration test shall be given);

e) power frequency recovery voltage, in kV;

f) prospective transient recovery voltage;

   1) compliance with requirement a) of 6.104.5.1; voltage and time coordinates may be quoted;

   2) compliance with requirement b) of 6.104.5.1;

g) arcing time, in ms;

h) opening time, in ms;

i) break time, in ms;

   Where applicable, break-times up to the instant of extinction of the main arc and up to the instant of the breaking of resistance current shall be given.

j) closing time, in ms;

k) make time, in ms;

l) behaviour of circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDD's shall be noted;

m) condition after tests;

n) parts renewed or reconditioned during the tests.

C.2.6 Short-time withstand current test

a) current
   1) r.m.s. value, in kA,
   2) peak value, in kA;
b) duration, in s;
c) behaviour of circuit-breaker during tests;
d) condition after tests;
e) resistance of the main circuit before and after tests, in μΩ.

C.2.7 No-load operation

a) before making and breaking tests (see 6.102.6);
b) after making and breaking tests (see 6.102.9.2 and 6.102.9.3).

C.2.8 Out-of-phase making and breaking tests

a) breaking current in each phase, in kA;
b) making current in each phase, in kA;
c) voltage across each phase, in kV;
d) prospective transient recovery voltage;
e) arcing time, in ms;
f) opening time, in ms;
g) break-time, in ms;
h) closing time, in ms;
i) make-time, in ms;
j) duration of resistor current (where applicable), in ms;
k) behaviour of circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDD's shall be noted;
l) condition after tests.

C.2.9 Capacitive current switching tests

a) test voltage, in kV;
b) breaking current in each phase, in A;
c) making current in each phase, in kA;
d) peak values of the voltage between phase and earth, in kV:
   1) supply side of circuit-breaker;
   2) load side of circuit-breaker;
e) number of restrikes (if any); the occurrence of NSDD's (if any) shall be noted;
f) details of point-on-wave setting, arcing time in ms;
g) closing time, in ms;
h) make time, in ms;
i) behaviour of circuit-breaker during tests;
j) condition after tests.

C.2.10 Oscillographic and other records

Oscillograms shall record the whole of the operation. The following quantities shall be recorded. Certain of these quantities may be recorded separately from the oscillograms, and several oscillographs with different time scales may be necessary:

a) applied voltage;

b) current in each pole;

c) recovery voltage (voltages on supply and load side of circuit-breaker for charging current tests);

d) current in closing coil;

e) current in opening coil;

f) amplitude and timing scale appropriate for the required accuracy;

g) mechanical travel characteristics (where applicable).

All cases in which the requirements of this standard are not strictly complied with and all deviations shall be explicitly mentioned at the beginning of the test report.

Annex D
(normative)

Determination of short-circuit power factor

There is no method by which the short-circuit power factor can be determined with precision, but, for the purpose of this standard, the determination of the power factor in each phase of the test circuit may be made with sufficient accuracy by whichever of the two following methods is the more appropriate.

D.1 Method I – Calculation from d.c. component

The angle φ (phase angle between voltage vector and current vector) may be determined from the curve of the d.c. component of an asymmetrical current wave between the moment of short-circuit initiation and the moment of contact separation, as shown below:

D.1.1 Equation for the d.c. component

The equation for the d.c. component is as follows:

$$i_{\mathrm{d}} = I_{\mathrm{d0}} \times \mathrm{e}^{-\frac{R}{L}t} = I_{\mathrm{d0}} \times \mathrm{e}^{-\frac{t}{\tau}}$$

where

i_{d} is the value of the d.c. component at any instant;

I_{d0} is the initial value of the d.c. component;

$\tau = L/R$ is the time constant of the circuit, in s;

t is the time interval, in s, from the initiation of the short-circuit;

e is the base of Napierian logarithms.

The time constant L/R can be ascertained from the above equation as follows:

a) measure the value of I_{d0} at the instant of short-circuit and the value of i_{d} at any other time t before contact separation;

b) determine the value of $\mathrm{e}^{-Rt/L}$ by dividing i_{d} by I_{d0};

c) from values of e^{-x} determine the value of $-x$ corresponding to the ratio $i_{\mathrm{d}}/I_{\mathrm{d0}}$;

d) the value x then represents Rt/L, from which L/R can be determined.

D.1.2 Phase angle φ

Determine the phase angle φ from:

$$\varphi = \arctan\left(\omega \frac{L}{R}\right)$$

where ω is 2π times the actual frequency.

D.2 Method II – Determination with pilot generator

When a pilot generator is used on the same shaft as the test generator the voltage of the pilot generator on the oscillogram may be compared in phase, first with the voltage of the test generator and then with the current of the test generator.

The difference between the phase angles between pilot generator voltage and main generator voltage on the one hand, and pilot generator voltage and test generator current on the other hand gives the phase angle between the voltage and current of the test generator, from which the power factor can be determined.

Annex E
(normative)

Method of drawing the envelope of the prospective transient recovery voltage of a circuit and determining the representative parameters

E.1 Introduction

A transient recovery voltage wave may assume different forms, both oscillatory and non-oscillatory.

The wave may be defined by means of an envelope made up of three consecutive line segments; when the wave approaches that of a damped oscillation at one single frequency, the envelope resolves itself into two consecutive line segments. In all cases, the envelope should reflect as closely as possible the actual shape of the transient recovery voltage. The method described here enables this aim to be achieved in the majority of practical cases with sufficient approximation.

NOTE Nevertheless, some cases may arise where the proposed construction would lead to parameters quite obviously more severe than would be justified by the transient recovery voltage curve. Such cases should be dealt with as exceptions and, as a consequence, form the subject of an agreement between the manufacturer and user or the test laboratory.

E.2 Drawing the envelope

The following method is used for constructing the line segments forming the envelope of the prospective transient recovery voltage curve.

a) The first line segment passes through the origin O, is tangential to the curve and does not cut the curve (see Figures E.1 to E.3, segment OB and Figure E.4, segment OA).

   In the case of curves whose initial portion is concave towards the left, the point of contact is often in the vicinity of the first peak (see Figures E.1 and E.2, segment OB).

   If the concavity is towards the right, as in the case of an exponential curve, the point of contact is near the origin (see Figure E.3, segment OB).

b) The second line segment is a horizontal line tangential to the curve at its highest peak (see Figures E.1 to E.4, segment AC).

c) The third line segment is tangential to the curve at one or more points situated between the first two points of contact, and does not cut the curve.

   There are three possible cases for drawing this latter line segment.

   1) One single line segment can be drawn touching the curve at two points (or possibly at more than two points).

      In this case, it forms part of the envelope (see Figure E.1, segment BA).

      The four-parameter envelope O, B, A, C, is then obtained.

   2) Several segments can be drawn which touch the curve at two points (or possibly at more than two points) without cutting it.

      In this case, the segment to be used for the envelope is that which touches the curve at one point only, situated so that the areas on either side of this point between the curve and the envelope are approximately equal (see Figure E.2, segment BA).

      The four-parameter envelope O, B, A, C is then obtained.

   3) No segment can be drawn touching the curve at more than one point without cutting it.

In this case, the following distinction should be made.

i) The point of contact of the first line segment and the highest peak are comparatively far apart from each other. This is typically the case for an exponential curve or a curve approximating to an exponential.

In this case, the line segment shall be tangential to the curve at a point such that the areas on either side of this point between the curve and the envelope are approximately equal, as in case c) 2) of E.2 (see Figure E.3, segment BA).

The four-parameter envelope O, B, A, C is then obtained.

ii) The point of contact of the first line segment and the highest peak are comparatively close to each other.

This is the case for a curve representing a damped oscillation of single frequency or a curve of similar shape.

In this case, a third line segment is not drawn, and representation by two parameters, corresponding to the first two line segments, is adopted (see Figure E.4).

The two-parameter envelope O, A, C is then obtained.

E.3 Determination of parameters

The representative parameters are, by definition, the coordinates of the points of intersection of the line segments constituting the envelope.

When the envelope is composed of three line segments, the four parameters u_1, t_1, u_c and t_2 shown in Figures E.1, E.2 and E.3 can be obtained as coordinates of the points of intersection B and A.

When the envelope is composed of two line segments only, the two parameters u_c and t_3 shown in Figure E.4 can be obtained as coordinates of the point of intersection A.

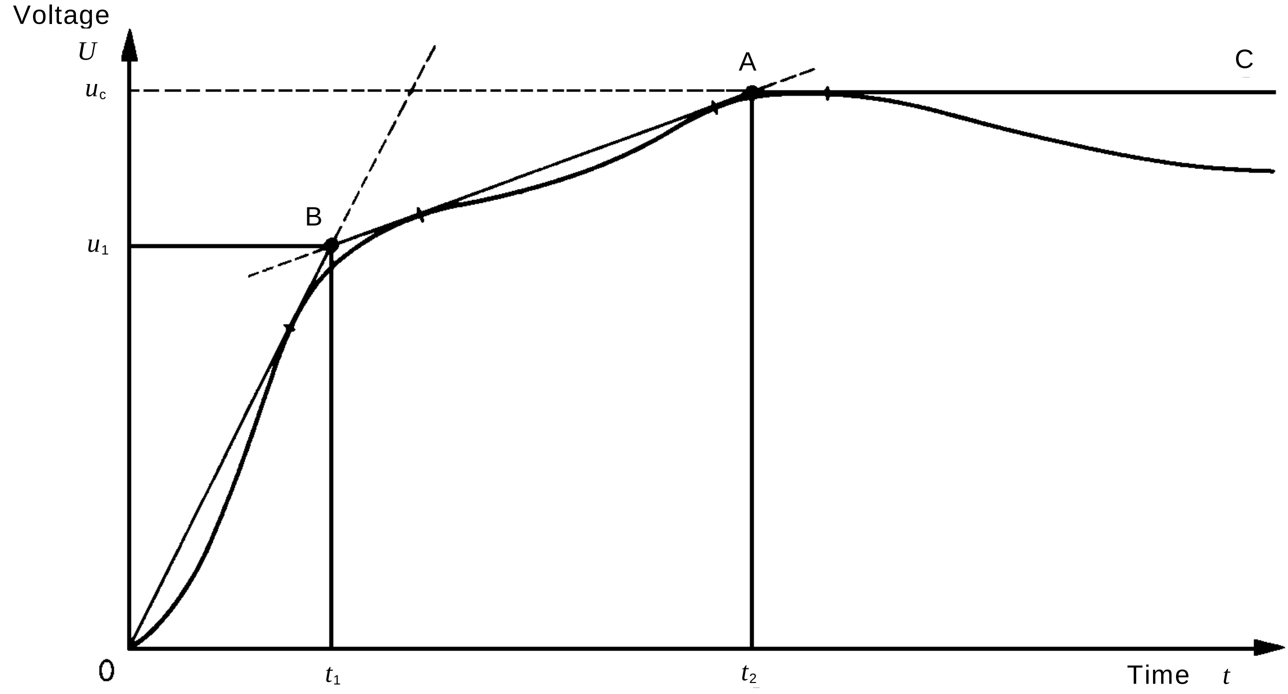


Figure E.1 – Representation by four parameters of a prospective transient recovery voltage of a circuit – Case E.2 c) 1)

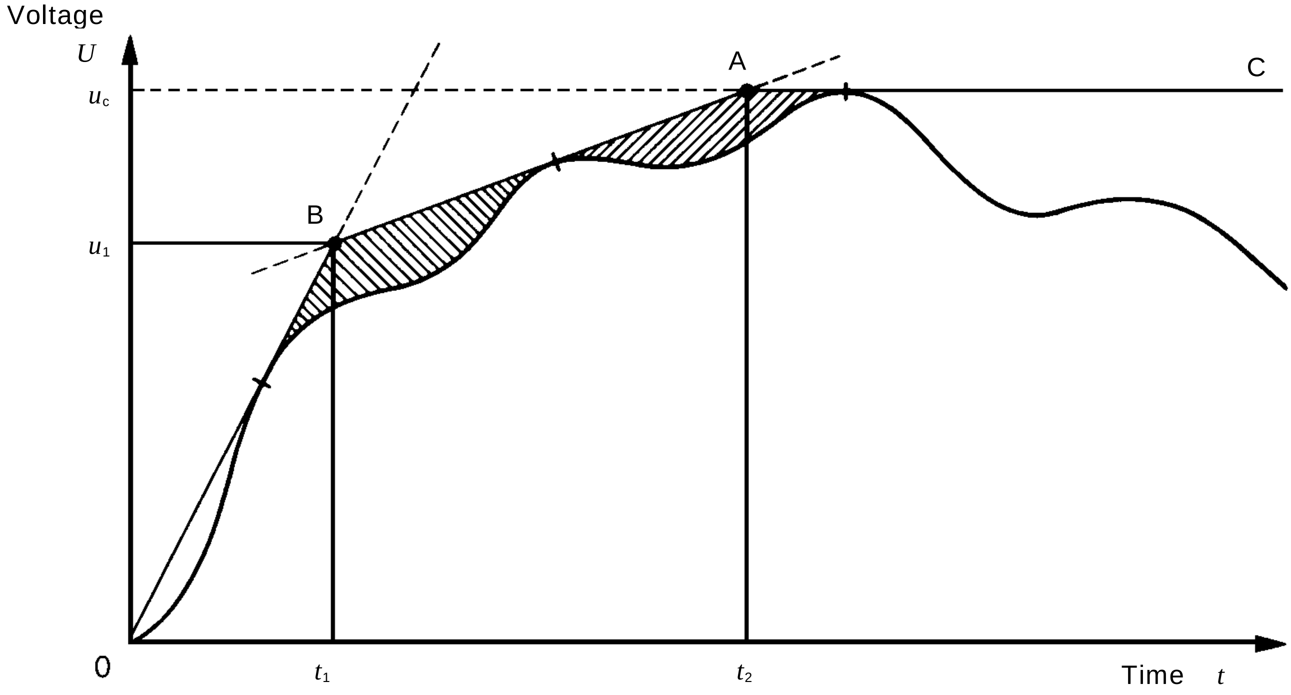


Figure E.2 – Representation by four parameters of a prospective transient recovery voltage of a circuit – Case E.2 c) 2)

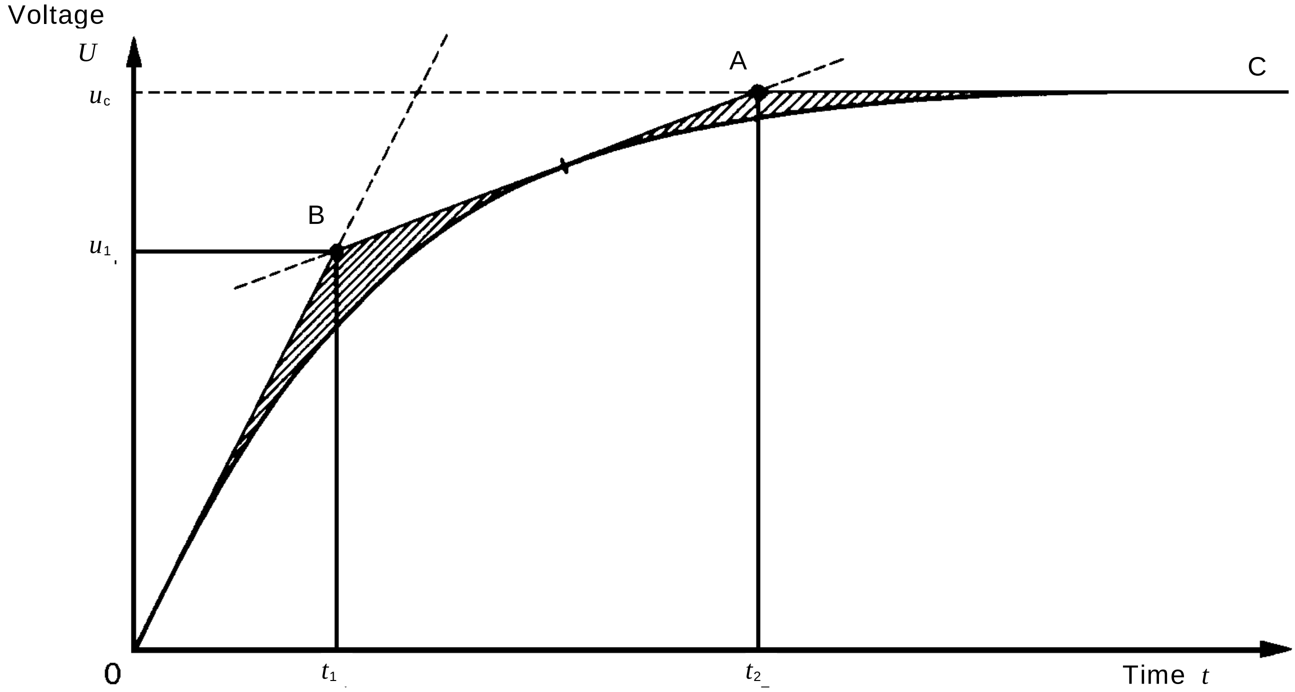


Figure E.3 – Representation by four parameters of a prospective transient recovery voltage of a circuit – Case E.2. c) 3) i)

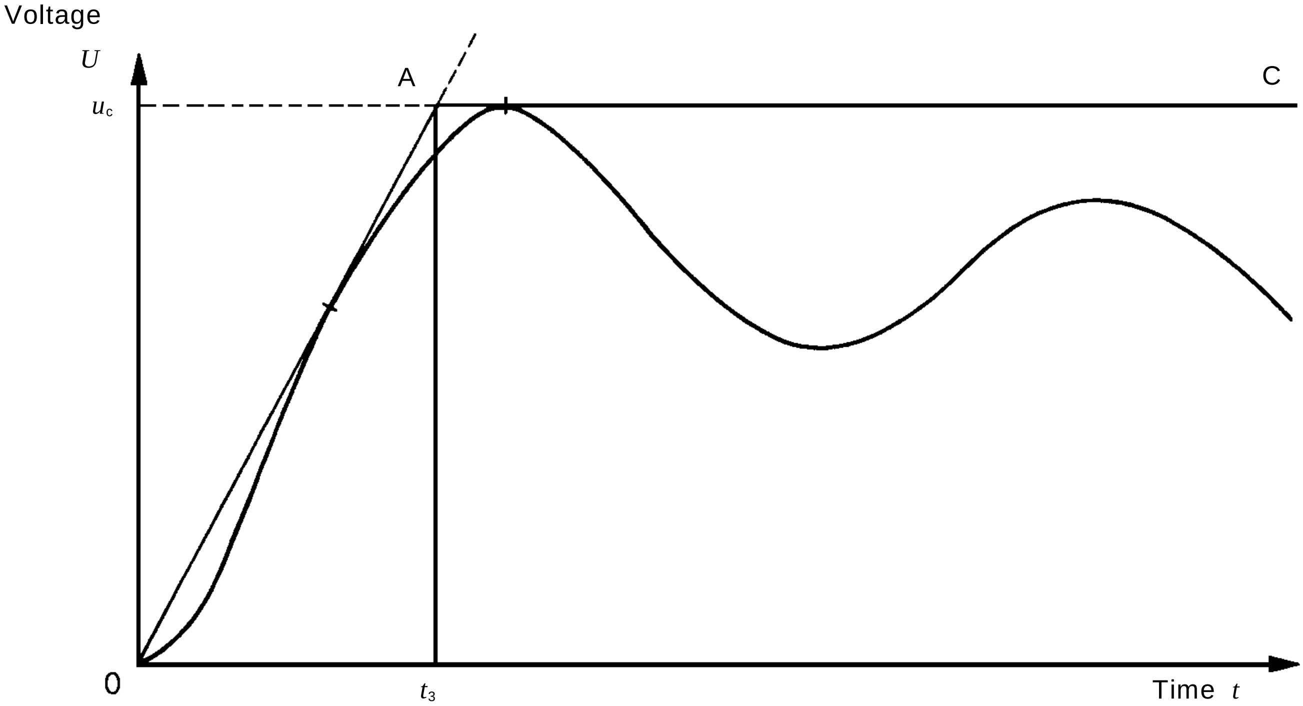


Figure E.4 – Representation by two parameters of a prospective transient recovery voltage of a circuit – Case E.2. c) 3) ii)

Annex F
(normative)

Methods of determining prospective transient recovery voltage waves

F.1 Introduction

The waveforms of the transient recovery voltage (TRV) resulting from the breaking of short-circuit currents depend on two main groups of factors, namely: those dependent on the circuit characteristics (inductance, capacitance, resistance, surge impedance, etc.), and those arising from the circuit-breaker characteristics (arc voltage, post-arc conductivity, capacitors and switching resistors, etc.).

Methods are recommended for determining the waveform of the TRV as produced solely by the circuit characteristics, this being the "prospective TRV".

Since any measuring device will have some effect upon the waveform of the prospective TRV, suitable precautions and, possibly, corrections are necessary.

Methods are available for the evaluation of the prospective TRV of both short-circuit test plant circuits and power systems, and the recommended methods are enumerated and briefly described, taking into account the TRV characteristics which are specified for rating and testing.

Experience on testing plants and also on systems has shown that following the breaking of a short-circuit current, not only is a single or multi-frequency oscillation superimposed on the power-frequency voltage wave, but exponential components of substantial size and duration are also present. The latter have time constants which are dependent upon the characteristics of the components of the circuit, for example generators, transformers, lines, etc. These exponential components have the effect of depressing the peak value of the TRV and the rate-of-rise to below those which would have occurred if the oscillatory components alone had been superimposed on the power-frequency voltage. This is shown in Figure F.1 and any method used for measurement should take this effect into account.

Measurements have shown that the inductance of the various circuit components varies with frequency, owing to the screening effects of eddy currents within the conductors, the earth and the magnetic circuits. Together with other factors tending to reduce instantaneous voltages, this introduces a time constant varying from hundreds of microseconds for some generators down to tens of microseconds for transformers, the exact values depending upon the design of the particular equipment and the frequency of the components of the TRV. In some cases, this can result in a depression of the peak value of the TRV by as much as 25 %.

It is therefore important that these factors are taken into account when assessing the prospective TRV of either a test plant or system, and that guidance is given in connection with the recommended methods.

Irrespective of the method used, the actual values measured in the test plant for the prospective TRV shall be in accordance with the values specified in this standard.

Where the time t_2 of the crest of the TRV exceeds, say, 1 250 µs, then, in addition to the effects described above, the instantaneous power-frequency voltage will, in any case, have decreased by more than 6 % at 50 Hz and more than 10 % at 60 Hz. Consequently, this further effect shall be taken into consideration when using methods for determining the prospective TRV which involve a power-frequency recovery voltage, or where calculations are made using circuit constants.

The instantaneous value of the power-frequency component immediately following current zero is also dependent upon the short-circuit power factor and upon the percentage d.c. component of the last half-cycle of current, and may thus be less than the full crest value. For symmetrical currents and short-circuit power factors of 0,15 or less, the reduction is not more than 1,5 %, and so is of little importance on test plant circuits; it may be of significance, however, at higher power factors which may occur in service.

For the TRV for terminal faults (see 4.102), a time delay has been introduced to allow for the influence of local capacitance on the source side of the circuit-breaker. Corresponding time delays have also been specified for the relevant test circuits (see 6.104.5), and the method used for measuring the TRV should be capable of resolving these time delays.

For some circuit-breakers the characteristics for short-line faults are also specified (see 4.105), and during short-line fault tests the corresponding resulting TRV has been specified. Local capacitance between the circuit-breaker and the line will also produce a time delay in the line side TRV component. During testing, it is desirable to measure and record the line side time delay and the method used should be suitable for evaluating this.

F.2 General summary of the recommended methods

The basic methods for determining prospective TRV waveforms are classified as follows:

- group 1 – Direct short-circuit breaking;
- group 2 – Power-frequency current injection;
- group 3 – Capacitor current injection;
- group 4 – Model networks;
- group 5 – Calculation from circuit parameters;
- group 6 – No-load switching of test circuits including transformers;
- group 7 – Combination of different methods.

Groups 1, 4 and 5 are recommended for power systems.

Groups 2 and 3 can be used for portions of power systems.

Only groups 1 to 3 or a combination of these are suitable for assessing the prospective TRV of circuits used in short-circuit test plants.

When using groups 1, 2, 3, 4, 6 or 7, the voltage recording circuits should be carefully checked to ensure that the overall calibration is constant over the range of TRV frequencies to be recorded, and that time deflections are linear. The oscillograph and any voltage divider should then be calibrated against a known voltage. Where cathode-ray oscillographs with a sweep time base are used, the deflection/time scale should be accurately known, and preferably this should be linear to avoid replotting for comparative purposes, etc.

Where applicable, the injected current and the voltage across the circuit under investigation should be recorded using a time base of suitable velocity and, in addition, high-speed records of current and voltage at the current-zero should be taken. The TRV should be recorded by an oscillograph of suitable sensitivity and with an appropriate time scale.

F.3 Detailed consideration of the recommended methods

F.3.1 Group 1 – Direct short-circuit breaking

This method involves the breaking of an actual short-circuit current, established by means of a solid metallic connection in the system under investigation and recording the resultant TRV by an oscillograph. Ideally, the current broken should be symmetrical, or allowance made for the change in di/dt if there is appreciable asymmetry. With this method, it is essential to allow for the influence of the circuit-breaker. The most important characteristics in this respect are arc voltage and post-arc conductivity.

Due to the voltage of the arc, the voltage across the circuit-breaker contacts may not be zero at the instant of current interruption, and hence the TRV does not rise from zero voltage but from the value of the arc voltage at current zero. The TRV thus begins below the voltage zero axis and then crosses it (see Figure F.3).

As a result, the peak voltage is higher than in the case of an ideal circuit-breaker (zero arc voltage) (see Figure F.2). A similar but more pronounced effect results from interruption at a markedly premature current zero (current chopping) which may occur if the current is small (see Figure F.4). Furthermore, if the prospective TRV comprises several oscillatory components, current chopping may produce a waveform which is markedly different from that which would be obtained with an "ideal" circuit-breaker.

Thus a circuit-breaker with a low arc voltage immediately before current zero and which does not exhibit current chopping is the most suitable for use with direct short-circuit breaking.

The influence of the arc voltage may be compensated for as shown in Figure F.6.

In principle, compensation for the arc voltage is only suitable for TRVs having a single-frequency transient component; nevertheless, it may also be used as a good approximation for multi-frequency transients if the amplitude of the main oscillatory component is predominant.

The post-arc current, i.e. the current flowing through the arc-gap during the rise of the TRV, can influence the waveform of the latter by damping, thus reducing its rate-of-rise and peak value (see Figure F.5). A similar effect results from the use of resistors in parallel with the interrupting chambers of the circuit-breaker.

It follows, therefore, that in addition to the requirements relating to low arc voltage and absence of current chopping, any circuit-breaker used for the direct short-circuit breaking method should not be fitted with shunt resistors and should not exhibit significant post-arc conductivity.

Particularly, where the test plant can be operated at a suitably reduced excitation, vacuum interrupters can often be used as nearly "ideal" circuit-breakers. However, it should be ascertained that any device used does not exhibit significant current chopping in the particular circuit under investigation.

The characteristics of circuit-breakers used for direct short-circuit breaking can sometimes be appropriately improved, for example by delaying the instant of contact separation to produce a short arcing time and low arc voltage.

With this method, an actual short-circuit current is broken in the circuit under investigation and the recorded TRV will take into account, more or less, the effects contributing to depression of the recovery voltage. For this reason, the direct short-circuit breaking method can be, depending upon the characteristics of the circuit-breaker, the most suitable means of obtaining an assessment of the prospective TRV, and is frequently used as the basis for checking other methods. However, the direct short-circuit breaking method is less suited for measuring time delays, particularly the time delay of the line-side TRV, in the case of short-line fault.

F.3.2 Group 2 – Power-frequency current injection

This method is only used with the circuit de-energised and is therefore mainly of use in test plants, or where part of a system can be analysed whilst de-energised. It does not take into account corona or magnetic saturation phenomena.

The basis of this method is the injection of a relatively small current into the circuit and the recording of the response of the circuit when the current is switched off by an ideal switching device, i.e. a device having negligible arc voltage and post-arc current.

A suitable source of injected current is a single-phase transformer operated from the local low-voltage mains, the secondary giving, for example, a range of currents and voltages between 2 A at 200 V and 300 A at 25 V. This range will cover the impedances of the majority of circuits to be assessed. A schematic diagram as an example of the application of this method is shown in Figure F.7 together with details of the components. Figure F.8 shows the sequence of operation of the scheme.

Care should be taken to ensure that the inherent capacitances of the supply and measuring devices do not influence the results.

The voltage response should be measured at the input terminals of the circuit and, when applicable, one terminal of the circuit should be earthed. In those cases where the circuit is not earthed at one of its terminals, it is essential that the measuring and injection equipment are completely isolated from earth. This can be achieved by using an auxiliary generator insulated from earth and having negligible capacitance to earth.

The most convenient switching device for this scheme is a semiconductor diode. In general, semiconductor diodes with reverse recovering times not exceeding 100 ns have been found to be suitable. Longer times are acceptable where the TRV has a low equivalent natural frequency. To obtain the correct current-carrying capacity, several diodes may be operated in parallel.

NOTE The characteristics of diodes are dependent on a number of factors, for example the value of the current in the forward direction, the waveform and value of the reverse voltage, and the manufacturer's data which are dependent on the methods employed to determine the characteristics.

To achieve a symmetrical current wave, it may be necessary for the current to flow for a time of up to 20 cycles. During most of this time, the diodes will be by-passed by a switch which is opened at the end of this time thus allowing the current to pass through the diodes which will interrupt the current at the following current-zero.

To assess the time delay accurately, it is necessary to amplify the voltage and time scales for the initial part of the wave.

The lower speed record of the current shows whether the current was symmetrical when broken, and the high speed record gives the rate-of-change, $\mathrm{d}i/\mathrm{d}t$, immediately before current-zero. It also shows whether or not there was any appreciable post-arc current to cause damping of the TRV, or appreciable suppression of the current, likely to affect the TRV amplitude.

The TRV record represents the natural transient oscillation of the circuit under investigation, and takes into account most of the factors causing voltage depression.

The values can be determined using a voltage calibration in terms of the full power of the circuit. Detailed explanations are given in F.3.4.

F.3.3 Group 3 – Capacitor current injection

This method is similar to group 2 except that the current through the circuit being considered is obtained from the discharge of a capacitor. Thus, the frequency of the injected current will depend upon the values of the capacitor and the inductance of the circuit.

Since the frequency of the injected current is usually much higher than the power frequency, this method does not take into account the factors causing voltage depression.

As the frequency of the discharge current should be one-eighth of the equivalent natural frequency of the circuit, this means that the method is suitable for measuring the TRV of circuits containing components with high natural frequencies. It is particularly useful for measuring the characteristics of the components on the line side of short-line fault test circuits, the natural frequencies of which are very high, with correspondingly small time delays.

Figure F.9 provides a schematic diagram of an example of a capacitor current injection circuit together with details of the components. Figure F.10 shows the sequence of operation of the schema.

The same precautions and method of calibration are used as for group 2, and these are detailed in F.3.4.

F.3.4 Groups 2 and 3 – Methods of calibration

From the measured value of the rate-of-change, di/dt, of the injected current immediately before zero, calculate the equivalent r.m.s. value of the injected current I_i.

$$I_\mathrm{i} = \frac{\dfrac{\mathrm{d}i_\mathrm{i}}{\mathrm{d}t}}{2\pi f_\mathrm{i}\sqrt{2}}$$

where f_i is the frequency of the injected current.

In this calculation, it is assumed that:

$$i_\mathrm{i} = I_\mathrm{i}\sqrt{2}\sin(2\pi f_\mathrm{i} t) \cong I_\mathrm{i}\sqrt{2} \times 2\pi f_\mathrm{i} \mathrm{t}$$

This is approximately valid when t_2 < 1 250 µs (or when t_2 < 1 000 µs on a 60 Hz basis).

On the basis of the above approximations, the following rule may be derived:

The frequency of the injected current should be ≤ 1/8th of the equivalent natural frequency of the circuit being measured. For cases where the coordinate t_2 of the prospective TRV is greater than 1 250 µs (1 000 µs for 60 Hz), the frequency of the injected current should equal the rated power frequency.

NOTE If the factor is 1/8, during the interval (t_2 – t_0) a maximum deviation of the slope of the injection current from a straight line of 15 % would occur. A factor 1/14 would give a maximum deviation of 5 %.

If the r.m.s. value of the maximum short-circuit current of the circuit is I_sc, then the voltage calibration V_sc(in mm) for the TRV corresponding to I_sc will be:

$$V_\mathrm{sc}\text{(in mm)} = V_\mathrm{i}\text{(in mm)} \times (I_\mathrm{sc}/I_\mathrm{i}) \times (f_\mathrm{sc}/f_\mathrm{i})$$

where f_sc is the frequency of the short-circuit current.

Subject to the provisions given above concerning prospective TRV with long times t_2, for those cases where the deviation of the curve of the current from the sinusoidal, symmetrical form is too significant to be neglected, the following basic equation should be used:

$$V_{sc}(\text{in mm}) = V_i(\text{in mm}) \frac{\left(\frac{\mathrm{d}i_{sc}}{\mathrm{d}t}\right)_{i_{sc\to 0}}}{\left(\frac{\mathrm{d}i_i}{\mathrm{d}t}\right)_{i_{i\to 0}}}$$

where $\left(\frac{\mathrm{d}i_{sc}}{\mathrm{d}t}\right)_{i_{sc}\to 0}$ is the rate-of-change of the power frequency short-circuit current at current zero, with the current function:

$$i_{sc} = I_{sc}\sqrt{2}\sin(2\pi f_{sc}t) \cong I_{sc}\sqrt{2}\times(2\pi f_{sc}t)$$

This equation applies particularly to the method of capacitor current injection where the current is of a slightly damped oscillatory form.

To determine the calibration for short-line fault tests, the following method is suitable:

From the high-speed recording measure:

$\frac{\mathrm{d}u_i}{\mathrm{d}t}$ = RRRV of the TRV at zero of the injected current;

u_i = first voltage peak caused by the injected current;

$\left(\frac{\mathrm{d}i_i}{\mathrm{d}t}\right)_{i_i\to 0}$ = rate-of-change of the injected current at its zero.

The value of the surge impedance Z is then obtained by the following calculation:

$$Z = \frac{\frac{\mathrm{d}u_i}{\mathrm{d}t}}{\left(\frac{\mathrm{d}i_i}{\mathrm{d}t}\right)_{i_i\to 0}}$$

F.3.5 Group 4 – Model networks

In this method, a model network is assembled from units which shall be true representations of the components of the full-scale circuit. It is usually necessary to imitate the components of the full-scale circuit which have distributed parameters by model units having lumped parameters. In addition, it is essential that the impedance (especially reactance and resistance) characteristics of the model units shall be, as near as possible, a true imitation of those characteristics of the full-scale components at frequencies up to at least that corresponding to the TRV under consideration.

The accuracy of this method depends upon having exact data for the parameters of the circuit to be imitated, and these are frequently difficult to obtain and to simulate on a small model component.

This applies particularly to parameters which vary with frequency, so that this method in general does not directly take into account the depression of the TRV, and tends to give values which are somewhat higher than those obtained with direct short-circuits on a full-scale system.

The method is mainly useful for investigating power systems since it does not require the system to be taken out of service, and will give useful guidance provided that its limitations are recognised.

F.3.6 Group 5 – Calculation from circuit parameters

When the data concerning the parameters of the components of the circuit are known, as for group 4, it is often convenient to calculate the waveform of the TRV, particularly if the circuit is not too complex.

In general, the method does not take into account depression effects, although some allowance can be made for these if the relevant data for the circuit are available; similarly the decrement of the power-frequency component for those TRV where the time t_2 exceeds 1 250 µs (1 000 µs for 60 Hz), can be taken into account.

The method is subject to the limitations of group 4, plus the errors inherent in calculations unless experience has been gained in checking results with actual TRV obtained from tests using the techniques of groups 1, 2, 3 or 6.

F.3.7 Group 6 – No-load switching of test circuits including transformers

This method consists of connecting the test transformer on the open circuit and recording, by oscillograms, the behaviour of the transient voltage at the open gap of the secondary circuit.

The method is very useful in those test stations where the short-circuit current is obtained by generators. However, the circuit-breaker used for the switching shall have no shunt resistance, be free of any appreciable pre-striking and be located in close proximity to the circuit-breaker under test. Furthermore, this method has a limited application to those circuits producing single frequency TRV and does not reproduce the exponential component which is related to eddy currents.

F.3.8 Group 7 – Combination of different methods

If a synthetic test circuit is applied in which different circuits are combined, it may be necessary to use a combination of the proposed methods. This is always the case, if the TRV is superimposed by the outputs of different sources (up to three different sources are usual). For example, in a voltage injection test circuit, it is possible to check the TRV from the current source separated from the TRV from the voltage injection circuit. This means that each of the separate circuits can be checked by one of the proposed methods. For the different circuits, different methods may be applied. The overall TRV (sum of the TRVs from the different circuits), can be constructed by mathematical methods. If digital recording equipment is used, it is also possible to construct the overall TRV by combining the digital data obtained by the different methods.

In the case of a combined use of the proposed methods, the specific limits of the methods, given in Table F.1, shall be taken into account.

F.4 Comparison of methods

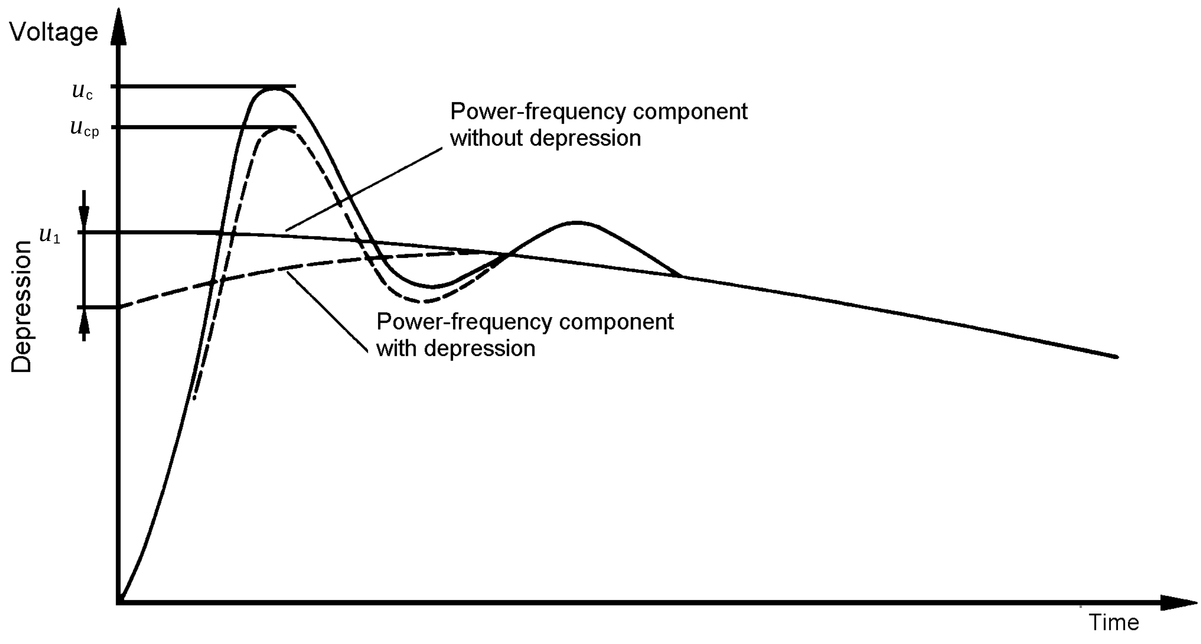
The various methods are listed in Table F.1, with their characteristics, advantages and disadvantages.

Table F.1 – Methods for determination of prospective TRV

Method	Theoretical limitations	Practical limitations
F.1.1 Full scale tests with an ideal circuit-breaker	None. All phenomena are correctly represented	Non-existence of an ideal circuit-breaker to cover the full range of requirements
F.1.2 Power-frequency tests at full voltage with a limited current disturbance. (Either an ideal circuit-breaker test or a "close" test is feasible)	Does not account for non-linearities which may exist in the test circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	Non-existence of an ideal circuit-breaker to cover the full range of requirements. Extraction of the TRV requires sophisticated measurement techniques: otherwise, it is difficult to interpret results in the presence of a large power-frequency voltage component For making tests, the most suitable current limiting device is a perfect inductance; otherwise an element of the test circuit may be used where it is available (e.g. resistor or capacitor) Elements used are likely to be bulky and expensive
F.1.3 Power-frequency tests at reduced voltage with an ideal circuit-breaker on an otherwise unmodified test circuit (i.e. low excitation tests)	Does not account for non-linearities which may exist in the test circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	Whilst ideal circuit-breakers to cover the whole range are not yet available, the selection of the ideal circuit-breaker to be used is limited With circuits employing more than one generator, synchronization can be difficult to achieve Excitation should be sufficiently high to avoid waveform distortion Generally not possible in a network station
F.1.4 Full scale tests with a conventional circuit-breaker	Difficulty of separating the circuit-breaker effects from the TRV characteristics recorded during test	Choice of suitable circuit-breakers having a low arc-voltage producing negligible current distortion at current zero, negligible post-arc current and no shunt impedances. In cases where the above cannot be made, errors are introduced and there is the possibility of lack of uniformity between testing stations due to the use of circuit-breakers having different characteristics

Table F.1 *(continued)*

Method	Theoretical limitations	Practical limitations
F.2 Ideal circuit-breaker tests on a "dead" circuit with power frequency current injection	Does not account for non-linearities which may exist in the circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	In a network-fed testing station, only applicable on "dead" circuit elements, for example short-line fault components, or where the impedance of the network is negligible compared with the remainder of the circuit impedance Generators shall be at rest to avoid remanent voltages Position of rotor may be important if there is a considerable difference between direct and quadrature reactances. The reverse recovery time of switching diodes as used instead of an ideal circuit-breaker, capable of carrying the necessary injected power-frequency current, may affect the TRV where this contains high frequency components, for example in short-line fault test circuits Interference from external sources induced in the "dead" circuit may affect the TRV where the measuring voltage is relatively small due to very low circuit reactance, for example as associated with short-line faults
F.3 Ideal circuit-breaker tests on a "dead" circuit with current injection at a frequency above power frequency	Does not account for non-linearities which may exist in the circuit. Does not give power frequency impedance directly. Gives correct waveform and values for the TRV of single and multi-frequency circuits from zero to the first maximum only, provided that the injection frequency is above power frequency and well below the frequency of the TRV. It is not possible to evaluate amplitude factor correctly	In a network-fed testing station, only applicable on "dead" circuit elements, e.g. short-line fault components, or where the impedance of the network is negligible compared with the remainder of the test circuit impedance. Generators shall be at rest to avoid remanent voltages. Position of rotor may be important if there is a considerable difference between phase and quadrature reactances
F.4 Model network tests (transient net work analysers)	Precise information on non-linear and frequency-dependent characteristics of the network is not always available Exact knowledge of circuit components and their stray parameters is necessary	Adequate representation of circuit components in the transient network analyser elements, including their non-linear and lime-dependent characteristics, is necessary
F.5 Calculation from circuit parameters	Precise information on non-linear and frequency-dependent characteristics of the network is not always available Exact knowledge of circuit components and their stray parameters is necessary	Where the network impedance is not negligible compared with the test station impedance, complete knowledge of the relevant momentary network conditions is necessary Accurate or adequate representation of the circuit components, including their non-linear and time-dependent characteristics and particularly the stray parameters
F.6 No-load switching of testing transformers	Corrections necessary for power frequency voltage wavefront unless the transformers are energized at or near the peak of the voltage wave	Requires actual short-circuit test circuits Applicable only for single-frequency circuits



u_c = peak value of specified TRV

u_{cp} = TRV measured with depression

u_1 = peak value of power frequency voltage without depression

Figure F.1 – Effect of depression on the peak value of the TRV

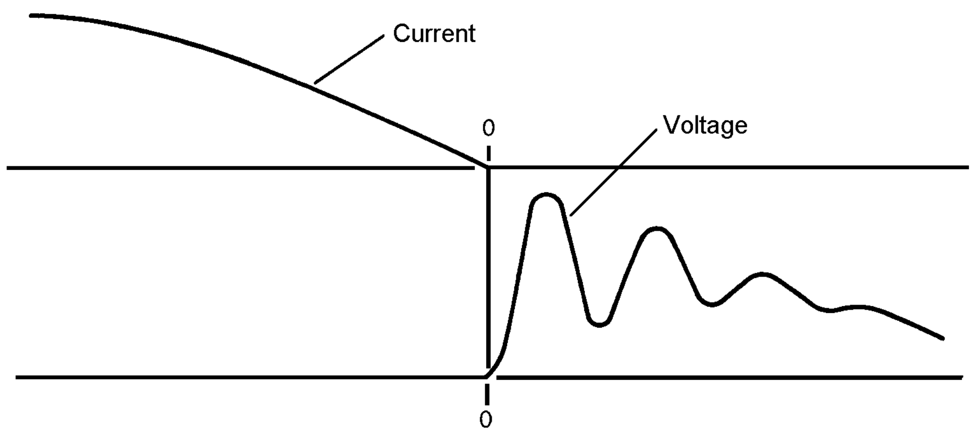


Figure F.2 – TRV in case of ideal breaking

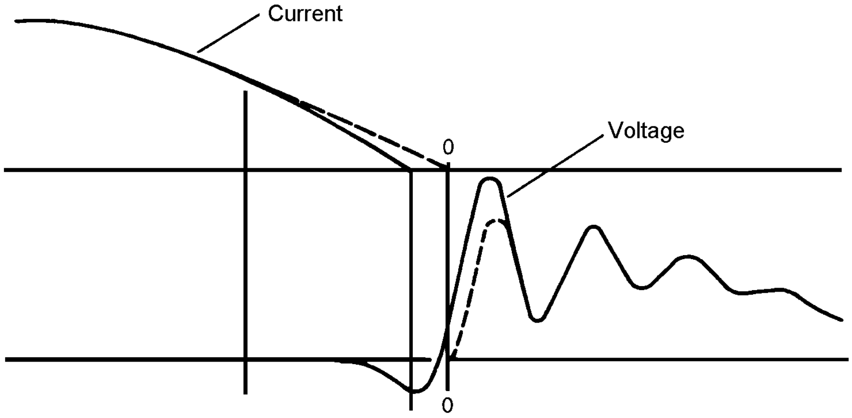


Figure F.3 – Breaking with arc-voltage present

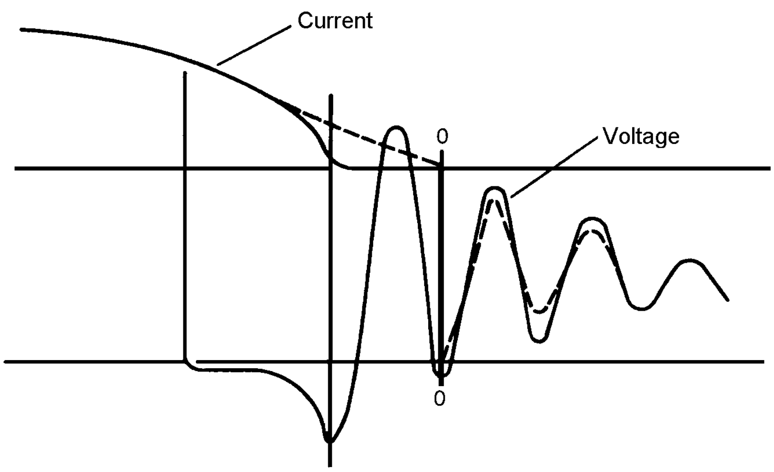


Figure F.4 – Breaking with pronounced premature current-zero

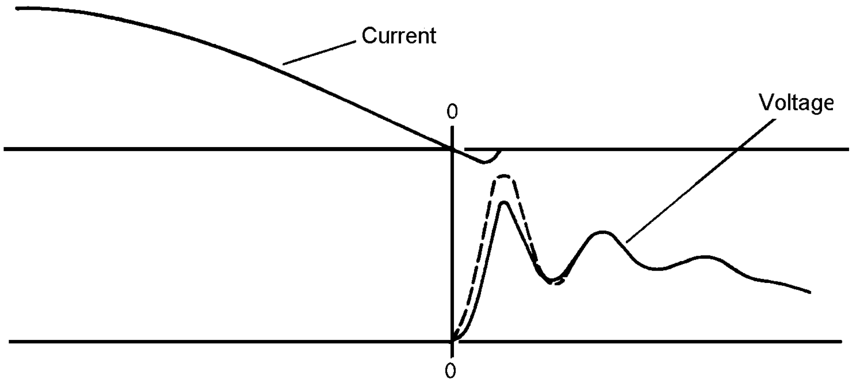
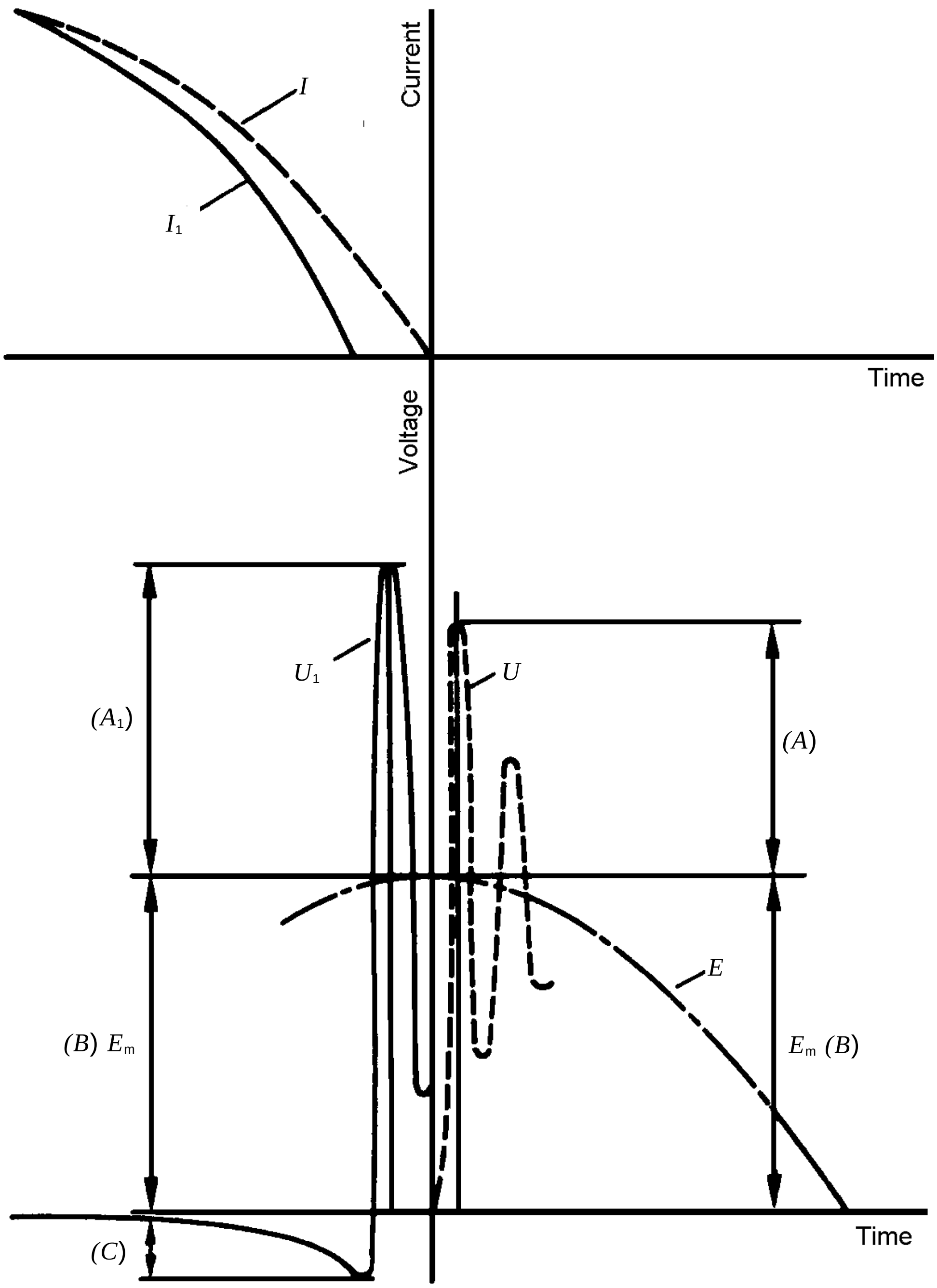


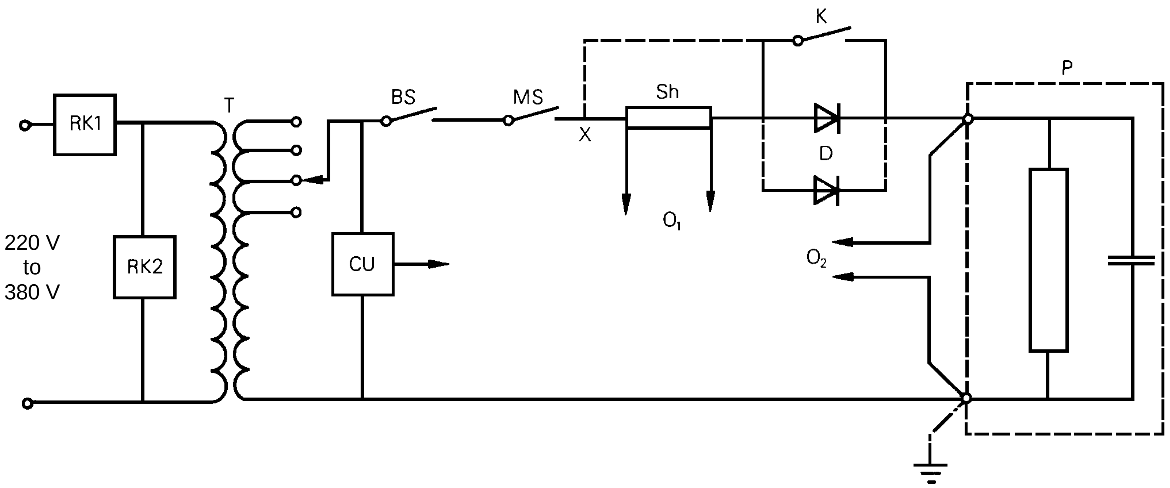
Figure F.5 – Breaking with post-arc current

NOTE Influence of the arc, of premature current-zero and of post-arc conductivity on the transient recovery voltage. The chain-dotted lines in Figures F.3 to F.5 represent the behaviour following ideal breaking.



I_1, U_1	=	current and voltage, respectively, obtained in test
I, U	=	prospective current and voltage, respectively, of system
E	=	power frequency recovery voltage
$A+B=A_1\dfrac{B}{B+C}+B$	=	peak value of transient recovery voltage

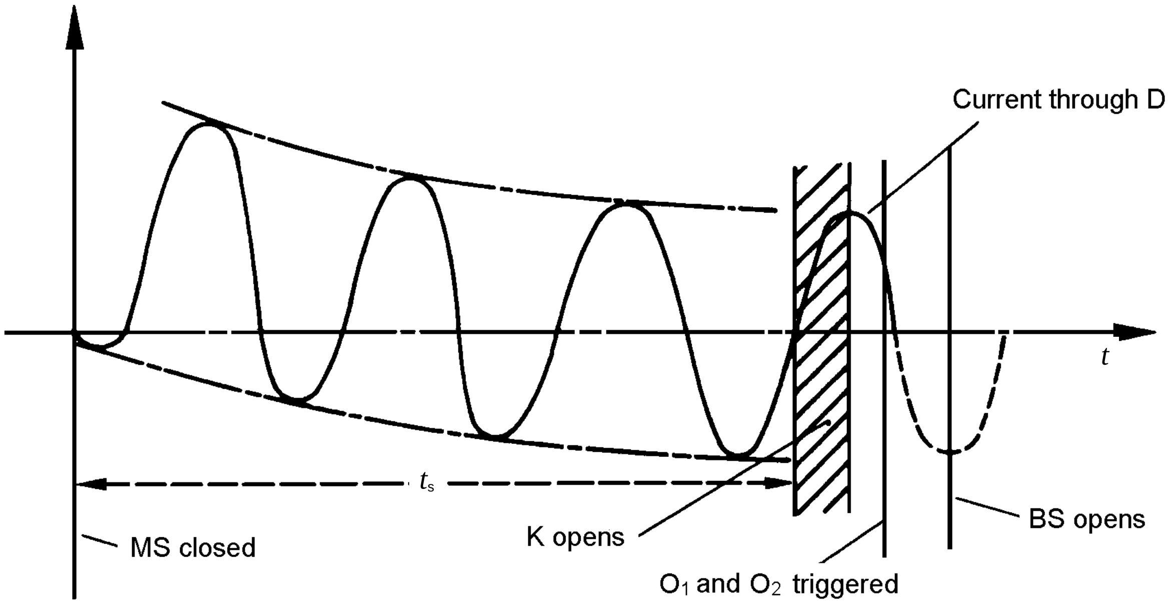
Figure F.6 – Relationship between the values of current and TRV occuring in test and those prospective to the system



RK1, RK2	=	where required, series and parallel resonant circuits for harmonic suppression purposes
T	=	transformer to isolate injection circuit from supply and to provide an adjustable output voltage
BS	=	back-up switch
MS	=	making switch
K	=	diode by-pass switch
X	=	alternative connection for K to permit use of a shunt having relatively low time-current rating
D	=	parallel connection of up to five fast silicon switching diodes
Sh	=	current measuring shunt
O_1	=	cathode-ray oscillograph, trace 1 recording magnitude and linearity of current for checking the diode operation
O_2	=	cathode-ray oscillograph, trace 2 recording the response of the circuit
P	=	circuit the prospective TRV of which is to be measured
CU	=	control unit to provide the sequence of operation given in Figure F.8

NOTE The measurement of the injected current may equally be made at earth potential.

Figure F.7 – Schematic diagram of power-frequency current injection apparatus



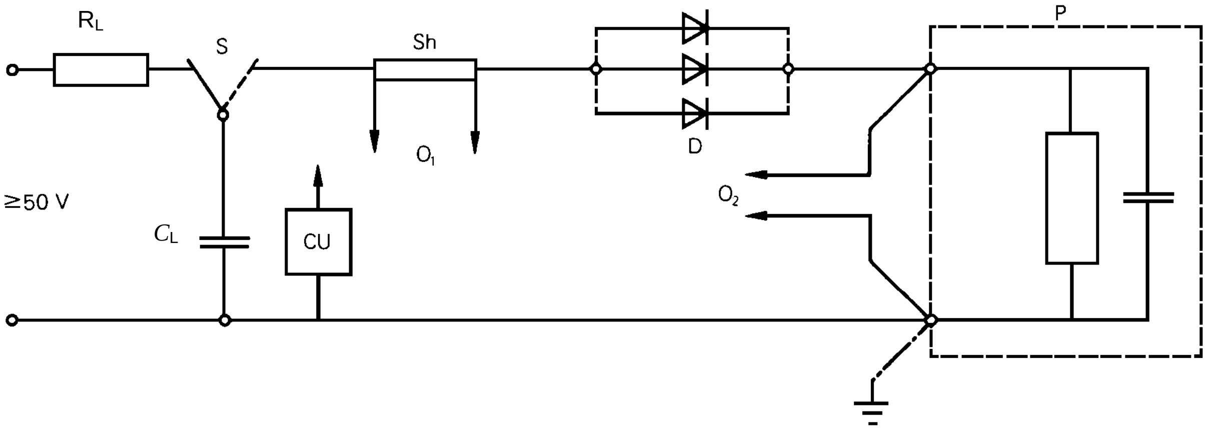
Quiescent state: BS and K closed, MS open.

t_s = duration of current flow prior to operation of switch K

Typical values lie between 10 and 20 cycles of injected current.

The main criterion is that the d.c. component of current, if any, shall have decayed to a value less than 20 % of the a.c. component.

Figure F.8 – Sequence of operation of power-frequency current injection apparatus



R_L = charging resistor

S = switching relais

C_L = source capacitance

NOTE 1 When the charged capacitance C_L is connected to the circuit P via relay S an oscillatory current, of frequency f_i, flows. The value of C_L should be adjusted so that:

$f_i \leq \frac{f_e}{8}$, where f_e is the natural frequency of circuit P, $f_e = \frac{1}{2T_e / 2}$

f_i shall be such that the superimposed current oscillations will have disappeared before the instant of current zero.

Sh = current measuring shunt

O_1 = cathode-ray oscillograph, trace 1 recording magnitude and linearity of the current and checking the diode operation

O_2 = cathode-ray oscillograph, trace 2 recording the response of the circuit

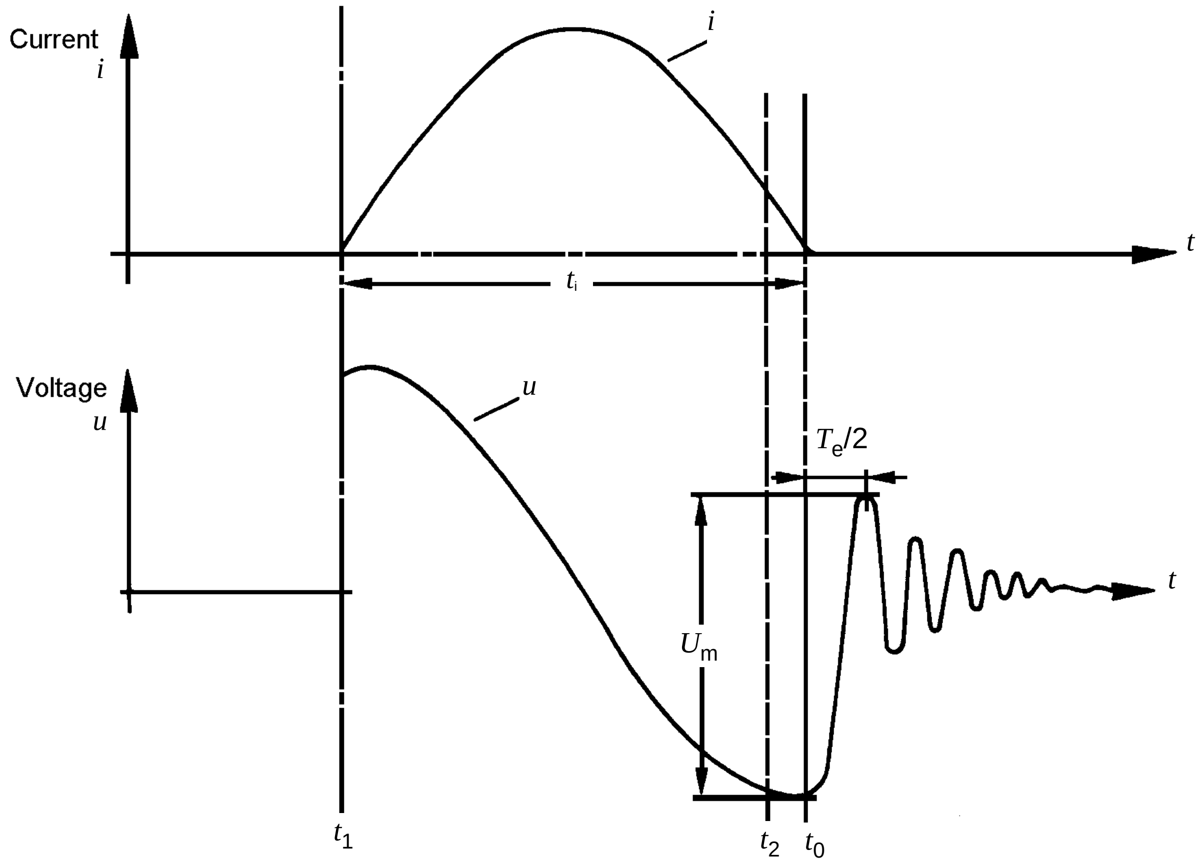
D = parallel connection of up to 100 fast silicon switching diodes

P = circuit the prospective TRV of which is to be measured

CU = control unit to provide the sequence of operation given in Figure F.10

NOTE 2 The measurement of the injected current may equally be made at earth potential.

Figure F.9 – Schematic diagram of capacitance injection apparatus



t_1 = switching of S

t_2 = tripping of the cathode-ray oscillograph

u = voltage curve across the terminals of the circuit P

i = waveform of the injected current

U_m = maximum voltage stressing of the diodes

t_0 = time where current passes through zero (beginning of the TRV oscillation)

t_i = duration of current through diode D, $f_i = \dfrac{1}{2t_i}$

$\dfrac{T_e}{2}$ = duration of half-cycle of TRV

Figure F.10 – Sequence of operation of capacitor-injection apparatus

Annex G
(normative)

Rationale behind introduction of circuit-breakers class E2

It should be noted that the introduction class E2 circuit-breakers is restricted to distribution circuit-breakers. This standard already has cases where some tests are restricted to voltage ranges, so no problems should arise in adding the electrical endurance test only to circuit-breakers of rated voltages up to and including 52 kV.

The majority of circuit-breakers manufactured today are of the sealed type or closed type, only anticipating top-up of gas (where applicable), not internal maintenance. Traditional circuit-breakers do not need to fulfil low-maintenance requirements, but the user may wish (and in very many cases does wish) to specify a circuit-breaker class E2 for sound economic reasons.

There are therefore two choices: either to use a circuit-breaker having maintainable internal parts and maintain as needed during its expected working life, or to use a circuit-breaker class E2 but expect a more onerous testing regime to check its capability.

The proposed electrical endurance test for cable-connected networks is a full series of test-duties T10 to T100a without intermediate maintenance. It is almost certain that all distribution circuit-breakers of the sealed SF_6 or vacuum type have been tested like this for a number of years. No extra tests are therefore required beyond the normal short-circuit type test.

For overhead-line networks, the standard test shall be performed separately. The proposed extra test is a user requirement based on statistical service experience.

Care needs to be taken in comparing different test programmes. The current versus wear relationship is not as simple as it may appear.

Finally, it should be noted that the extra tests are optional, at the user's request, to satisfy these applications.

Annex H
(informative)

Inrush currents of single and back-to-back capacitor banks

H.1 General

Switching on a capacitor bank by closing a circuit-breaker causes transient phenomena resulting from bank charging. The oscillating load provokes an overcurrent (inrush current) with an amplitude and frequency which are functions of the network, the bank characteristics and the instant of switching on. Amplitude and wave shape of the inrush current are functions of the applied voltage, the capacitances of the circuit, the values and location of the inductances in the circuit, the charges on the capacitors at the time the circuit is closed and the damping of the switching transients. Calculations of inrush current are usually made on the assumption that the capacitor bank has no initial charge and that the circuit is closed at a time which produces the maximum inrush current.

When closing onto a pre-charged capacitor bank, the inrush current can be higher than when closing onto an uncharged capacitor bank. An estimate of the factor by which the current may be increased can be obtained from:

$$\frac{\text{voltage change on pre-charged bank while being energised}}{\text{voltage change on uncharged bank while being energised}}$$

It should be noted that restriking circuit-breakers can also impose hazardous stresses on capacitors.

The inrush current can be calculated knowing the network impedances. Figure H.3 shows the three different cases of connection of a capacitor bank when zero, one and n banks, respectively are already connected to the busbar.

Normally the simplified calculations in Figures H.3b) and H.3c) are acceptable.

When two or more capacitor banks are connected close to each other and the inductances between them are small, it may be necessary, both from capacitor and circuit-breaker point of view, to reduce the inrush current by inserting impedances in series with the capacitors. Usually, an inductance is inserted so that the inrush current peak and the inrush current frequency are below acceptable values.

In practice, the inductance is calculated using the principle that the resulting inrush current peak value is less than that given by the preferred values stated in Table 9. The inductance should also be dimensioned for reducing the inrush current frequency below the preferred values stated in Table 9 (4 250 Hz).

In the past first edition of IEC 62271-100, the equivalency rule between the tests performed and the service conditions was based on the product "$i_{\text{max peak}} \times f_{\text{inrush}}$", $i_{\text{max peak}}$ being the making inrush current peak and f_{inrush} being the inrush current frequency. Recent calculations have shown that the arc energy during a making operation is independent of the inrush current frequency for cases where the pre-arcing time is greater than half a period of the inrush frequency which are the usual cases for back-to-back capacitor switching. For back-to-back capacitor bank switching, the arc energy during a making operation is only function on the inrush current peak. On the other hand, it is well known that the shape of the wear on arcing contacts as well as the effect of the pressure shock waves are somewhat frequency dependant and should not disregarded. Because of the later, an upper tolerance of +130 % has been specified on the permissible inrush current frequency that can be used in service. In other words, the inrush current frequency used during tests should not be lower than 77 % of the inrush current frequency foreseen in service. This concept is limited to inrush current frequency up to 6 000 Hz since the information available for higher frequencies is limited.

Two examples of calculation are described in Clauses H.2 and H.3.

H.2 Example 1 – One capacitor to be switched in parallel (see Figure H.1)

H.2.1 Description of the capacitor banks to be switched

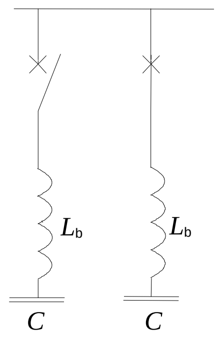


Figure H.1 – Circuit diagram for example 1

- rated voltage U_r = 145 kV
- rated frequency f_r = 50 Hz
- power of a single capacitor bank Q_b = 16 Mvar (three phases at 126 kV r.m.s.)
- total length of conductors between banks l = 40 m
- inductance per length L' = 1 µH/m

From these values the capacitance C and the inductance L_b are calculated.

C = 3,2 µF and L_b = 20 µH

H.2.2 Calculation without any limitation device

Using the equations stated in Figure H.3 the peak inrush current $\hat{\imath}$ and the inrush current frequency f_{ib} are determined:

$$\hat{\imath} = U_r\sqrt{\frac{C}{6L_b}} = 145\times10^3\sqrt{\frac{3{,}2\times10^{-6}}{6\times20\times10^{-6}}} = 23{,}7\times10^3\,\text{A} = 23{,}7\,\text{kA}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{L_bC}} = \frac{1}{2\pi\sqrt{3{,}2\times10^{-}\quad\times20\times10^{-}}} = 19\,900\,\text{Hz}$$

These values are far above the circuit-breaker ratings if tested according to the preferred values given in Table 9. Therefore, some limitation devices must be used. In some cases, the second bank may be already fully charged at the inverse polarity at the instant when the pre-strike in the closing circuit-breaker occurs. Then the value of $\hat{\imath}$ is doubled.

H.2.3 Calculation of limitation devices

The inductance L_a to be added on the busbar in each capacitor feeder should be such that the value of the inrush current peak and of the inrush current frequency are below the preferred values stated in Table 9 (20 kA and 4 250 Hz, within the prescribed tolerances).

The following equations apply when calculating the inrush current and frequency:

$$\hat{i} = U_r \sqrt{\frac{C}{6(L_b + L_a)}} \leq 20 \text{ kA peak} \quad \text{and} \quad f_{ib} = \frac{1}{2\pi\sqrt{(L_b + L_a)C}} \leq 4\,250 \text{ Hz} \times 1{,}3$$

Based on the equations given above, L_a should be ≥ 8,0 µH in order to obtain a peak making inrush current ≤ 20 kA peak and L_a should be ≥ 239 µH in order to obtain an inrush current frequency lower than 5 525 Hz (130 % of 4 250 Hz). Thus, L_a should be ≥ 239 µH in order to meet the criteria on the inrush current frequency. With such inductance value, the resulting peak inrush current will be 6,6 kA and the inrush current frequency will be 5 525 Hz. These values are well within the capabilities of the circuit-breaker if tested according to the preferred values given in Table 9 even if the second bank is fully precharged in inverse polarity at the instant when the pre-strike in the closing circuit-breaker occurs.

H.3 Example 2 – Two capacitors to be switched in parallel (see Figure H.2)

H.3.1 Description of the capacitor banks to be switched

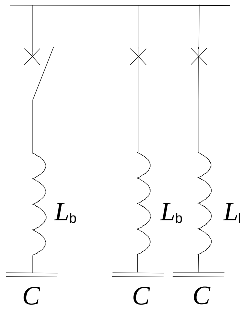


Figure H.2 – Circuit diagram for example 2

- rated voltage U_r = 24 kV
- rated frequency f_r = 50 Hz
- power of a single capacitor bank Q_b = 5 Mvar (three phases at 22 kV r.m.s.)
- length of each conductor between banks l = 5 m
- inductance per length L' = 1 µH/m

From these values the capacitance C and the inductance L_b are calculated:

C = 32,9 µF and L_b = 5 µH

H.3.2 Calculation without any limitation device

Using the equations stated in Figure H.3 the peak inrush current $\hat{i}$ and the inrush current frequency f_{ib} are determined:

$$\hat{i} = U_r \frac{n}{n+1}\sqrt{\frac{2C}{3L_b}} = 24 \times 10^3 \times \frac{2}{3}\sqrt{\frac{2 \times 32{,}9 \times 10^{-6}}{3 \times 5 \times 10^{-6}}} = 33{,}5 \times 10^3 \text{ A} = 33{,}5 \text{ kA}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{L_b C}} = \frac{1}{2\pi\sqrt{32{,}9 \times 10^{-6} \times 5 \times 10^{-6}}} = 12\,400 \text{ Hz}$$

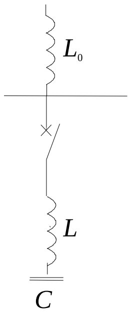
These values are far above the circuit-breaker ratings if tested according to the preferred values given in Table 9. Therefore, some limitation devices must be used. In some cases, the capacitor bank(s) already in service may be fully charged in the inverse polarity at the instant when the pre-strike in the closing circuit-breaker occurs. Then the value of $\hat{i}$ is doubled.

H.3.3 Calculation of limitation devices

The inductance L_a to be added on the busbar in each capacitor feeder should be such that the value of the inrush current peak and of the inrush current frequency are below the preferred values stated in Table 9 (20 kA and 4 250 Hz, within the prescribed tolerances).

$$\hat{i} = U_r \frac{n}{n+1}\sqrt{\frac{2C}{3(L_b + L_a)}} \le 20\,\text{kA peak} \quad \text{and} \quad f_{ib} = \frac{1}{2\pi\sqrt{(L_b + L_a)C}} \le 4\,250\,\text{Hz} \times 1{,}3$$

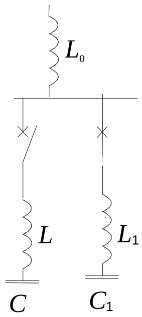
Based on these above equations, L_a should be ≥ 9,0 µH in order to obtain a peak making inrush current ≤ 20 kA peak and L_a should be ≥ 20,2 µH in order to obtain an inrush current frequency lower than 5 525 Hz (130 % of 4 250 Hz). Thus, L_a should be ≥ 20,2 µH in order to meet the criteria on the inrush current frequency. With such inductance value, the resulting peak inrush current will be 14,9 kA and the inrush current frequency will be 5 525 Hz. These values are well within the capabilities of the circuit-breaker if tested according to the preferred values given in Table 9. Attention should be paid for cases where the last bank to be energised is fully precharged in inverse polarity at the instant when the pre-strike in the closing circuit-breaker occurs. If such situation is probable, the value of L_a should be further increased in order to limit the making inrush current peak below the tested value.



a) Connection of a single bank

$$\hat{\imath} = U_{\mathrm{r}}\sqrt{\frac{2}{3}\frac{C}{L_0+L}} \approx U_{\mathrm{r}}\sqrt{\frac{2}{3}\frac{C}{L_0}} \qquad L_0 >> L$$

$$f_{\mathrm{ib}} = \frac{1}{2\pi\sqrt{C(L_0+L)}} \approx \frac{1}{2\pi\sqrt{CL_0}}$$



b) Connection when one bank is already connected

$$\hat{\imath} = U_{\mathrm{r}}\sqrt{\frac{2}{3}\frac{C_1C}{(C_1+C)} \times \frac{1}{(L_1+L)}}$$

$$f_{\mathrm{ib}} = \frac{1}{2\pi\sqrt{\dfrac{C_1C}{(C_1+C)}(L_1+L)}}$$

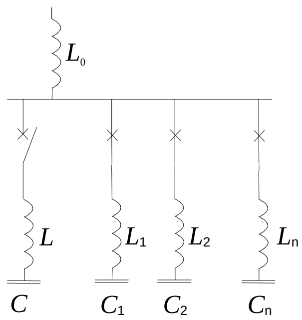
$$S = \frac{U_{\mathrm{r}}}{L_1+L}\sqrt{\frac{2}{3}}$$

When $L_1 = L$ and $C_1 = C$ then:

$$\hat{\imath} = U_{\mathrm{r}}\sqrt{\frac{C}{6L}} \text{ and } f_{\mathrm{ib}} = \frac{1}{2\pi\sqrt{LC}}$$

c) Connection when n banks are already connected

$$L'' = \frac{1}{\dfrac{1}{L_1}+\dfrac{1}{L_2}+\cdots\dfrac{1}{L_n}} \text{ and } C'' = C_1 + C_2 + \cdots C_n$$



If $L_1 = L_2 =\ldots= L_{\mathrm{n}} = L$ and $C_1 = C_2 =\ldots= C_{\mathrm{n}} = C$, then

$$L'' = \frac{L}{\mathrm{n}} \text{ and } C = nC$$

$$\hat{\imath} = U_{\mathrm{r}}\frac{n}{n+1}\sqrt{\frac{2C}{3L}} \text{ and } f_{\mathrm{ib}} = \frac{1}{2\pi\sqrt{LC}}$$

L' and C' substitute L_1 and C_1 in Figure H.3 b).

The calculation is correct if $L_1 \times C_1 = L_2 \times C_2 =\ldots= {}^{L}{}_{\mathrm{n}} \times C_{\mathrm{n}}$; in other cases it is an approximation.

Components

U_{r}	rated voltage	L	inductance in series with switched capacitor bank
$\hat{\imath}$	inrush current peak	C	capacitance of switched capacitor bank (equivalent star value)
f_{ib}	inrush current frequency	L_1, L_2... L_{n}	inductances in series with capacitor banks on source side
S	inrush current rate-of-rise	C_1, C_2... C_{n}	bank capacitances (equivalent star values) on source side
L_0	source inductance		

Figure H.3 – Equations for the calculation of capacitor bank inrush currents

Annex I
(informative)

Explanatory notes

I.1 General

Pending the issue of a guide to the use of this standard all the explanatory notes, existing or future, are collected in this annex.

I.2 Explanatory note regarding the d.c. time constant of the rated short-circuit breaking current (4.101.2) – Advice for the choice of the appropriate time constant

I.2.1 Advice for the choice of the appropriate time constant

A d.c. time constant of 45 ms is adequate for the majority of actual cases except for rated voltages higher than 800 kV for which the standard d.c. time constant is 120 ms. Special case time constants, related to the rated voltage of the circuit-breaker, shall cover such cases where the standard time constant 45 ms is not sufficient. This may apply, for example, to systems with very high rated voltage (for example 800 kV systems with higher X/R ratio for lines), to some medium voltage systems with radial structure or to any systems with particular system structure or line characteristics. Special case time constants have been defined, taking into account the results of the survey by CIGRE WG13.04 (I.2.2).

When specifying a special case time constant, the following considerations should be taken into account:

a) The time constants referred to in this standard are only valid for three-phase fault currents. The single-phase to ground short-circuit time constant is lower than that for three-phase fault currents.

b) For maximum asymmetrical current, the initiation of the short-circuit current has to take place at system voltage zero in at least one phase.

c) The time constant is related to the maximum rated short-circuit current of the circuit-breaker. If, for example, higher time constants than 45 ms are expected but with a short-circuit current lower than rated, such a case may be covered by the asymmetrical rated short-circuit current test using a 45 ms time constant.

d) The time constant of a complete system is a time-dependent parameter considered to be an equivalent constant derived from the decay of the short-circuit currents in the various branches of that system and is not a real, single time constant.

e) Various methods for the calculation of the d.c. time constant are in use, the results of which may differ considerably. Caution should be taken in choosing the right method.

f) When choosing a special case time constant, it has to be kept in mind, that the circuit-breaker is stressed by the asymmetrical current after contact separation. The time instant of contact separation corresponds to the opening time of the circuit-breaker and the reaction time of the protection relay. In this standard this relay time is one half-cycle of power frequency. If the protection time is longer this should be taken into account.

I.2.2 DC component during T100a testing

With the introduction of the special case time constants in edition 1.0 of IEC 62271-100, the decisive parameters with their respective tolerances that should be followed during interruption of asymmetrical faults need to be defined in order to:

– be able to perform asymmetrical tests with a test circuit having a d.c. time constant different from the rated d.c. time constant of the rated short-circuit breaking current, because laboratories are not able to tune the d.c. time constant of the test circuit. For direct tests, when the d.c. time constant of the test circuit is higher than the rated d.c. time constant of the rated short-circuit breaking current, the resulting d*i*/d*t* and TRV peaks are lower than those that can be seen in service conditions. The reverse situation is also true, mainly with the special case d.c. time constants (60 ms, 75 ms and 120 ms) introduced in edition 1.0;

– be able to use the results obtained from one specific test to cover more than one d.c. time constant ratings. This concept of asymmetry equivalence may also help the user in establishing equivalence between system needs and the rating requirements.

A lot of calculations made confirm that the former concept of d.c. component at contact separation (for example IEC 60056 and the first edition of IEC 62271-100) leads to stresses during the tests (including minor and major loop interruptions) being different from those expected under service conditions. That is why IEC 62271-308 was published and has now been incorporated within this new edition of IEC 62271-100.

The only way to obtain that equivalence is to introduce the concept of d.c. component at current zero. This concept is already applied in IEC 62271-101.

The maximum prospective d.c. component at current zero required during tests is determined by using the d.c. component given for the next complete current loop following the minimum interrupting time.

Values given in Tables 15 through 22 are derived from a fully asymmetrical current waveshape corresponding to the rated d.c. time constant of the rated short-circuit breaking current. For the major loop values, the amplitude, duration, percentage of d.c. component at current zero and corresponding d*i*/d*t* are those of the major current loop which appears after the highest value of the minimum clearing time range. For the minor loop values, the amplitude, duration, percentage of the d.c. component at current zero and corresponding d*i*/d*t* are those of the minor current loop preceding the lowest value of the minimum clearing time range.

The parameters concerned by general equivalence criteria are:

a) the amplitude of the last current loop;
b) duration of the last current loop before interruption;
c) arcing time;
d) d*i*/d*t* at current zero;
e) TRV peak voltages, waveshape.

The two first points are linked to the arc energy.

To reach the equivalence according to this concept may lead to modify some tolerances; for example, the actual tolerance (0 %, +10 %) on the symmetrical value of the test current should be relaxed to any value between + 10 % and – 10 % in order to be able to adjust the last current loop amplitude and duration to the required values. For some cases it may be necessary to decrease or increase these values from the rated symmetrical short-circuit current.

With this procedure, depending on the actual test parameters, a specific test may cover several ratings if the applicable asymmetry criteria for each rating with their associated tolerances are met.

Annex Q gives some guidance how to use the asymmetry criteria.

I.3 Explanatory note regarding capacitive current switching tests (6.111)

I.3.1 Restrike performance

As all circuit-breakers have a certain restrike probability in service, it is not possible to define a restrike-free circuit-breaker. Instead, it appears more logical to introduce the notion of a restrike performance in service.

The level of restrike probability also depends on the service conditions (e.g. insulation coordination, number of operations per year, maintenance policy of the user, etc.), so it is impossible to introduce a common probability level related to service condition.

To classify their restrike performance, two classes of circuit-breakers are therefore introduced: class C1 and class C2.

I.3.2 Test programme

In defining the test programme for these two classes, the following elements have been taken into account:

– the average number of operations per year carried out by circuit-breakers switching capacitive loads;
– the ability to reduce the number of tests by performing an increased number of switching operations at the minimum arcing time, usually the most difficult capacitive switching operation for circuit-breakers, thus keeping a high level of reliability.

The expected restrike probability is exclusively related to the type tests. Due to the severity of the type tests, an improved switching performance in service can be expected.

The proposed number of tests may be questioned because of different assumptions for probability calculations. Nevertheless, these values represent a good compromise (which is the role of the standard where conflicting views exist), reflecting the needs of users (in response to market demand) and above all they avoid unrealistic demands. These tests are not reliability tests but type tests to demonstrate the satisfactory capacitive current switching capability of the equipment in service.

I.3.3 Referring to Table 9

Not all actual cases of capacitive current switching are covered by Table 9. The values for lines and cables cover most cases, the values of the current for capacitor banks (single and back-to-back) are typical and representative of actual values in service.

I.3.4 Referring to 6.111.1

Since a lot of circuit-breakers are used on cable circuits from 12 kV and above, it is reasonable to request cable-charging switching tests for circuit-breakers rated 12 kV and above.

I.3.5 Referring to 6.111.3

The paragraph concerning factor k/f_{φ} has been deleted because there is neither use nor need for testing.

The variation of the power frequency voltage has been chosen as 5 % for test-duty 2 (LC2, CC2 and BC2) and 2 % for test-duty 1 (LC1, CC1 and BC1). These values are a compromise, taking limitations of testing laboratories into account. Considering the type test as a whole, because of the different stresses in the individual test-duties, any undue reduction of the electric stress during the tests is avoided. The actual values for the power frequency voltage variation (depending on the short-circuit power of the system and the capacitive load) is in the range of 1 % to 2 %.

I.3.6 Referring to 6.111.5

The interval after final arc extinction, in which the voltage decay shall not exceed 10 %, has been changed from 100 ms to 300 ms based on service conditions.

I.3.7 Referring to 6.111.9.1.1

Performing these capacitive current switching tests for class C2 equipment on a preconditioned circuit-breaker is, on the one hand, a recommendation of the corresponding CIGRE working group; on the other hand, it draws closer to the real conditions of service, without prejudice as to whether this preconditioning improves the capacitive current switching performance of the circuit-breaker or not.

Close-open operating cycles may be performed with no-load closing operations. In any case, the complete cycle shall be tested in order to test the circuit-breaker during opening in a dynamic condition, i.e. during the motion of the fluid caused by the previous closing operation.

I.3.8 Referring to 6.111.9.1.1 and 6.111.9.2.1

The tolerance of the testing current values for test-duty 1 (LC1, CC1 and BC1) were increased from the old range 20 % to 40 % to the new range 10 % to 40 % in order to give more freedom during testing for combined test-duties for different applications.

The test sequences have been tested in a laboratory (particularly the adjustment of the minimum arcing time by steps of 6°) and are well adapted to the philosophy of the tests.

Performing some tests at rated pressure is a more pragmatic approach to the notion of type testing, knowing that the circuit-breaker is usually at its normal operating conditions when in service.

I.3.9 Referring to 6.111.9.1.2 and 6.111.9.1.3

In test-duty 2 of single-phase line-charging and cable-charging tests (LC2 and CC2), the tests are split into open operations and close-open operating cycles (6.111.9.1.3) to follow more or less the actual service conditions. However, for practical reasons, due to the small number of tests, in three-phase tests (6.111.9.1.2) in test-duty 2 (LC2 and CC2), close-open operating cycles are performed exclusively.

I.3.10 Referring to 6.111.9.1.2 to 6.111.9.1.5

Close-open operating cycles are important for capacitor bank switching because of the effect of inrush current. Close-open operating cycles are not significant for line- or cable-switching applications, therefore for line- and cable-switching tests, only a small number of close-open operating cycles are requested.

Where due to limitations of the test plant it is not possible to comply with the specified requirements during the CO operating cycles, a series of separate making tests is necessary in order to produce the wear caused by the inrush making current (capacitor bank switching tests only) and to verify the assigned prestrike behaviour (i.e. commutation from one set of contacts to the other one without producing undue wear, prestrike taking place between the arcing contacts and not between the main contacts, etc.).

A rough parity of the number of three-phase and single-phase tests has been maintained.

The mandatory order for capacitor bank switching tests is due to the necessity to introduce the effect of inrush current at the beginning of the tests.

I.3.11 Referring to 6.111.9.1.4 and 6.111.9.1.5

Because of the large number of operations in actual service compared with the limited number of operations during type testing, a high number (80 or 120 respectively) of close-open operating cycles shall be carried out in capacitor bank tests to simulate the wear in service even if the close-open operating cycle is not the normal switching sequence.

For capacitor bank switching tests test-duty 1 (BC1) also needs to be performed, even if the actual service switching duty is always at 100 % nominal current, for the following reasons:

– the tests at 10-40 % nominal current cover an increased number of actual currents;
– knowledge of the capacitive current switching performance is improved.

I.3.12 Referring to 6.111.9.2

Requirements for class C1 tests are derived from ANSI/IEEE C37.012 [11].

Annex J
(informative)

Test current and line length tolerances for short-line fault testing

The line reactance corresponding to the standardised line length can be calculated as follows:

$$X_{\mathrm{L,stand}} = \frac{1-\dfrac{I_{\mathrm{L,stand}}}{I_{\mathrm{sc}}}}{\dfrac{I_{\mathrm{L,stand}}}{I_{\mathrm{sc}}}} X_{\mathrm{source}}$$

where

$I_{\mathrm{L,stand}}$ is the short-line fault breaking current corresponding to the standardised line length;

$X_{\mathrm{L,stand}}$ is the line reactance corresponding to the standardised line length;

X_{source} is the reactance corresponding to the rated short-circuit breaking current.

If the reactance of the line applied in practice differs from the reactance corresponding to the standardised line length within the tolerances of –20 % for L_{90} and ±20 % for L_{75} and L_{60}, as stated in 6.109.2, the related current values can be calculated as follows:

$$I_{\mathrm{L,act}} = \frac{U_{\mathrm{r}}}{\sqrt{3}(X_{\mathrm{L,act}} + X_{\mathrm{source}})}$$

where

$I_{\mathrm{L,act}}$ is the short-line fault breaking current corresponding to the actual line length;

$X_{\mathrm{L,act}}$ is the line reactance corresponding to the actual line length.

The actual line length is calculated considering the standardised line length and the percentage deviation of the actual line length from the standardised one:

$$l_{\mathrm{act}} = l_{\mathrm{stand}}\left(1+\frac{d}{100}\right)$$

where

l_{stand} is the standardised line length;

l_{act} is the actual line length

d is the deviation of the actual line length from the standardised one in percent.

The actual line reactance is calculated using the following equation:

$$X_{\mathrm{L,act}} = X_{\mathrm{L,stand}} \times \frac{l_{\mathrm{act}}}{l_{\mathrm{stand}}} = X_{\mathrm{L,stand}}\left(1+\frac{d}{100}\right)$$

The actual percentage short-line fault breaking current $I_{\mathrm{perc,act}}$ is determined by the following equation:

$$I_{\mathrm{perc,act}} = \frac{I_{\mathrm{L,act}}}{I_{\mathrm{sc}}} \times 100 = \frac{I_{\mathrm{perc,stand}}}{1+\dfrac{d}{100}\times\left(1-\dfrac{I_{\mathrm{perc,stand}}}{100}\right)}$$

In Table J.1 the actual percentage short-line fault breaking currents are stated for each standardised short-line fault breaking current $I_{\mathrm{perc,stand}}$ taking the maximum tolerances for the line length into account.

Table J.1 – Actual percentage short-line fault breaking currents

Standardised short-line fault breaking current $I_{\mathrm{perc,stand}}$ %	Deviation d %	Actual short-line fault breaking current $I_{\mathrm{perc,act}}$ %
90	–20	91,8
90	0	90
75	–20	78,9
75	+20	71,4
60	–20	65,2
60	+20	55,5

Annex K
(informative)

List of symbols and abbreviations used in this standard

Symbol/ abbreviation	Exemplary reference	Meaning
% dc	4.101.2	Percentage value of the d.c. component
τ	4.101.2	Time constant
ω	Table 11	Angular frequency
τ_1	Figure 9	Standard time constant
τ_2	Figure 9	Special case time constant
τ_3	Figure 9	Special case time constant
τ_4	Figure 9	~~Special case time constant~~ Standard time constant for rated voltages higher than 800 kV and special case time constant for rated voltages equal or less than 800 kV
Δt_1	6.102.10.2.1.2	Duration of the major loop
Δt_2	6.102.10.2.1.2	Duration of the minor loop
A	Table 34	Designation of a terminal of a circuit-breaker
A	6.101.6.2	Direction of horizontal force
A_1	Annex P	Calculation variable
A_2	Annex P	Calculation variable
a	Table 34	Designation of a terminal of a circuit-breaker
B	Table 34	Designation of a terminal of a circuit-breaker
b	Table 34	Designation of a terminal of a circuit-breaker
B_1	6.101.6.2	Direction of horizontal force
B_2	6.101.6.2	Direction of horizontal force
BC1	6.111.9	Capacitor bank current, test-duty 1
BC2	6.111.9	Capacitor bank current, test-duty 2
BS	Figure F.7	Back-up switch
C	Table 34	Designation of a terminal of a circuit-breaker
c	A.2	Speed of the travelling wave propagation
c	Table 34	Designation of a terminal of a circuit-breaker
C	H.2.1	Capacitance of a single capacitor bank
C	Table 13	Closing operation
C.B.	Figure 12 a	Circuit-breaker
C_1	Figure H.3	Capacitance of a first capacitor bank being connected
C_1	6.101.6.2	Direction of vertical force
C1	3.4.114	Class of circuit-breaker with low restrike probability
C_2	Figure H.3	Capacitance of a second capacitor bank being connected
C_2	6.101.6.2	Direction of vertical force
C2	3.4.115	Class of circuit-breaker with very low restrike probability
CC1	6.111.9	Cable-charging current, test-duty 1
CC2	6.111.9	Cable-charging current, test-duty 2
C_d	Figure 12a	Time delaying source side capacitance
C_{dL}	Figure 15	Time delaying line side capacitance

Symbol/ abbreviation	Exemplary reference	Meaning
C_L	Figure F.9	Source capacitance
C_n	Figure H.3	Capacitance of a n-th capacitor bank being connected
CO	4.104	Close-opening operating cycle
CU	Figure F.7	Control unit to provide the sequence of operation
D	Figure F.7	Parallel connection of switching diodes
D	Figure 22	Drive, operating mechanism
d	Annex J	Deviation of actual line length from standardised one
$d\alpha$	6.102.10.2.1.1	Angle difference used for determination of arcing times
du/dt_{SLF}	A.3	Rate of rise of the source side TRV for SLF
du/dt_{TF}	A.3	Rate of rise for terminal fault T100s
du_L/dt	6.109.3	Rate-of-rise of line side TRV
E	Figure F.6	Power frequency recovery voltage
E1	3.4.112	Class of circuit-breaker with basic electrical endurance
E2	3.4.113	Class of circuit-breaker with extended electrical endurance
F	Table 34	Designation of the frame of a circuit-breaker
f_{bi}	Table 9	Frequency of the inrush current (back-to-back)
f_i	Table 11	Multiplying factor to determine ITRV waveshape
f_{inrush}	4.107.5	Frequency of the inrush current (single capacitor bank)
f_r	4.3	Rated frequency
F_{shA}	6.101.6.1	Terminal load, horizontal force
F_{shB}	6.101.6.1	Terminal load, horizontal force
F_{sr1}, F_{sr2}, F_{sr3}, F_{sr4}	6.101.6	Rated static terminal loads (resultant forces)
F_{sv}	6.101.6.1	Terminal load, vertical force
F_{th}	Table 14	Static horizontal force
F_{thA}	Table 14	Static horizontal force, longitudinal
F_{thB}	Table 14	Static horizontal force, transversal
F_{tv}	Table 14	Static vertical force
F_{wh}	6.101.6.2	Horizontal force due to wind pressure on ice coated circuit-breaker
$\hat{I}$	Table 10	Peak current related to the peak value of the short-circuit current
$\hat{\imath}$	H.2.2	Peak inrush current
I_{AC}	Figure 8	Peak value of the a.c. component of the current
I_{bb}	Table 9	Rated back-to-back capacitor bank breaking current
I_{bi}	Table 9	Rated back-to-back capacitor bank inrush making current
I_c	Table 9	Rated cable charging breaking current
i_d	D.1.1	Value of the d.c. current component at any instant
I_d	Table 10	Rated out-of-phase breaking current
I_{d0}	D.1.1	Initial value of the d.c. component
I_{DC}	Figure 8	D.C. component of the current
I_i	F.3.4	Injected current
i_i	F.3.4	Injected current
I_k	4.5	Rated short-time withstand current
I_l	Table 9	Rated line charging breaking current
I_L	6.109.2	Test current for short-line fault

Symbol/ abbreviation	Exemplary reference	Meaning
$I_{L,act}$	Annex J	Short-line fault breaking current corresponding to the actual line length
$I_{L,stand}$	Annex J	Short-line fault breaking current corresponding to the standardised line length
I_m	Figure R.1	Current through main interrupter
$i_{max\ peak}$	4.107.5	Peak inrush making current
I_{MC}	Figure 8	Making current
I_p	4.6	Rated peak withstand current
$I_{perc,act}$	Annex J	Actual percentage short-line fault breaking current
$I_{perc,stand}$	Annex J	Standardised short-line fault breaking current
I_r	4.4	Rated normal current
I_{res}	Figure R.1	Current through resistor interrupter
I_s	Figure R.1	Source current
I_{sb}	Table 9	Rated single capacitor bank breaking current
I_{sc}	4.101	Rated short-circuit breaking current
i_{sc}	F.3.4	Short-circuit current
I_{sh}	4.107.5	Short circuit current at location of capacitor bank
I_{si}	Table 10	Rated capacitor bank inrush making current
ITRV	4.102.1	Initial transient recovery voltage
k	A.2	Peak factor (SLF)
k	4.107.5	Multiplier for calculation of peak inrush making current
k_1	Annex P	Calculation variable
k_2	Annex P	Calculation variable
k_3	Annex P	Calculation variable
K	Figure F.7	Diode by-pass switch
k_{af}	4.102.2	Amplitude factor (TRV)
k_c	6.111.7	Capacitive voltage factor
k_i	A.3	ITRV peak factor
k_p	6.102.10.2.5	Voltage factor for determination of the TRV in the individual pole
k_{pp}	4.102.2	First-pole-to-clear factor
L	Figure 15	Length of line to fault
l	H.2.1	Total length of conductors between capacitor banks
L'	H.2.1	Inductance per length
L_0	Figure H.3	Source side inductance of capacitor bank
L_1	Figure H.3	Inductance of a first capacitor bank being connected
L_2	Figure H.3	Inductance of a second capacitor bank being connected
L_{60}	6.109.2	SLF test-duty at 60 % of the rated short-circuit current
L_{75}	6.109.2	SLF test-duty at 75 % of the rated short-circuit current
L_{90}	6.109.2	SLF test-duty at 90 % of the rated short-circuit current
L_a	H.2.3	Additional busbar inductance
l_{act}	Annex J	Actual line length
L_B	A.1	Inductance of busbar on source side
L_b	H.2.1	Inductance of a capacitor bank
LC1	6.111.9	Line-charging current, test-duty 1

Symbol/ abbreviation	Exemplary reference	Meaning
LC2	6.111.9	Line-charging current, test-duty 2
L_f	6.109.3	Short-line fault current factor
L_L	A.1	Line side inductance
L_n	Figure H.3	Inductance of a n-th capacitor bank being connected
L_S	A.1	Source side inductance
l_{stand}	Annex J	Standardised line length
M	Table 10	Mass of the circuit-breaker
m	Table 10	Mass of fluid for interruption
M1	3.4.116	Class of circuit-breaker with basic mechanical endurance
M2	3.4.117	Class of circuit-breaker with extended mechanical endurance
MS	Figure F.7	Making switch
NSDD	3.1.126	Non-sustained disruptive discharge
O	4.104	Opening operation
O_1	Figure F.8	Cathode ray oscillograph, trace 1
O_2	Figure F.8	Cathode ray oscillograph, trace 2
O-t-CO	4.104	Open-close-opening operating sequence
OP1	6.110.3	Out-of-phase, test-duty 1
OP2	6.110.3	Out-of-phase, test-duty 2
p_{re}	Table 10	Rated pressure for interruption
p_{rm}	Table 10	Rated pressure for operation
Q_b	H.2.1	Power of a single capacitor bank
RV	Table O.3	Recovery voltage
RRRV	Table 24	Rate of rise of recovery voltage
S	Figure H.3	Inrush current rate-of-rise
s	Figure F.9	Switching relay
s	A.2	RRRV factor
S1	3.4.119	Class of circuit-breaker with rated voltage above 1 kV and less than 100 kV, intended for cable systems
S2	3.4.120	Class of circuit-breaker with rated voltage above 1 kV and less than 100 kV, intended for line systems
SLF	6.104.5.2	Short-line fault
~~T~~	~~6.102.10.2.1.1~~	~~Period of the power frequency~~
T	4.109.1	Period of the power frequency
TRV	Table O.3	Transient Recovery Voltage
$t_{arc\ max}$	6.102.10.2.1.1	Maximum arcing time
$t_{arc\ med}$	6.102.10.2.1.1	Medium arcing time
$t_{arc\ min}$	6.102.10.2.1.1	Minimum arcing time
$t_{arc\ new\ min}$	6.102.10.2.3	New minimum arcing time
$t_{arc\ ult\ max}$	6.102.10.2.3	Ultimate maximum arcing time
t'	4.102.2	Time to reach u' (construction of delay line)
t'	4.104	Time interval in the rated operating sequence
t''	4.104	Time interval in the rated operating sequence
t_1	4.109.1	Maximum recorded break time during T30, T60 and T100s
t_1	4.102.2	Time to reach u_1 (TRV)
$t_{1,sp}$	6.108.2	Time to reach u_1 (TRV) in case of single-phase and double earth fault
~~t_2~~	~~4.109.1~~	~~Maximum recorded opening time during no-load~~
t_2	4.102.2	Time to reach u_c (four-parameter TRV)
$t_{2,sp}$	6.108.2	Time to reach u_c (four-parameter TRV) in case of single-phase and

Symbol/ abbreviation	Exemplary reference	Meaning
		double earth fault
t_3	4.109.1	Rated opening time
t_3	4.102.2	Time to reach u_c (two-parameter TRV)
$t_{3,sp}$	6.108.2	Time to reach u_c (two-parameter TRV) in case of single-phase and double earth fault
T_A	6.101.3.3	Ambient air temperature
t_a	6.101.2.3	Time between two operations for mechanical operation test at ambient air temperature
t_a	6.108.3	Arcing time for single-phase breaking operation
$t_{a,100s}$	6.108.3	Minimum of arcing times of first-poles-to-clear in T100s
t_b	4.109.1	Rated break time
t_{bm}	4.109.1	Longest of the minimum recorded break times during T30, T60 and T100s
t_d	4.102.2	Time delay
t_{dL}	6.104.5.2	Line side time delay (short-line fault)
T_H	6.101.3.4	Maximum ambient air temperature
t_i	4.102.2	Time to reach u_i (ITRV)
t_k	4.7	Rated duration of short-circuit
T_L	6.101.3.3	Minimum ambient air temperature
t_L	A.2	Time to reach the first peak of line side TRV
t_m	A.3	Time to reach voltage level U_m
T_{max}	6.101.4.2	High air temperature (humidity test)
T_{min}	6.101.4.2	Low air temperature (humidity test)
t_{om}	4.109.1	Maximum recorded opening time during no-load
T_{op}	4.101.2	Opening time of first opening pole
T_{op}	6.106.5	Minimum opening time
t_{or}	4.109.1	Rated opening time
T_r	4.101.2	Relay time, half cycle of rated frequency
t_T	A.3	Time to the peak of the line side TRV (SLF)
t_x	6.101.3.3	Time interval in low temperature test
u'	4.102.2	Reference voltage (construction of delay line)
u_0	A.1	Voltage drop across the line at the instant of current interruption (SLF)
u_1	4.102.2	First reference voltage (four-parameter reference line)
u_A	O.3.1.2	Resulting voltage between terminals of the auxiliary unit(s) connected to the current circuit and the enclosure
u_B	O.3.1.2	TRV between the terminals of the unit(s) under test
$U_{C/E}$	Table O.1	Voltage between source side terminal and earth
$U_{C'/E}$	Table O.1	Voltage between load side terminal and earth
$U_{C/C'}$	Table O.1	Voltage across the open contacts
u_E	O.3.1.2	Voltage between the enclosure and earth
u_c/t_3	6.104.5.1	Rate of rise of recovery voltage (two-parameter reference line)
u_1/t_1	4.102.2	Rate of rise of recovery voltage (four-parameter reference line)
$u_{1,sp}$	6.108.2	First reference voltage in case of single-phase and double earth fault

Symbol/ abbreviation	Exemplary reference	Meaning
$u_{1,\text{ test}}$	A.3	Actual u_1 value during short-line fault testing
U_a	4.8	Rated supply voltage of auxiliary and control circuits
u_c	4.102.2	Reference voltage (TRV peak value)
$u_{c,sp}$	6.108.2	Reference voltage in case of single-phase and double earth fault
U_{CB}	Figure 12a	Voltage across circuit-breaker
U_{cp}	Figure F.1	TRV measured with depression
U_G	A.1	Supply voltage
u_i	4.102.2	Reference voltage (ITRV peak)
u_{i0}	A.3	Bus-bar voltage drop
U_L	A.1	Voltage drop along the line
u_L	A.2	Transient voltage drop along the line
u_{L*}	6.109.3	Peak voltage across the line (SLF)
$u_{L,mod*}$	6.109.3	Adjusted peak voltage across the line (SLF)
U_m	A.1	Crest value of the total induced voltage
U_m	Figure R.1	Voltage across the main interrupter
U_{op}	Table 10	Rated supply voltage of operating devices
U_p	Table 10	Rated lightning impulse withstand voltage
U_r	4.1	Rated voltage
U_{res}	Figure R.1	Voltage across the resistor interrupter
U_s	Table 10	Rated switching impulse withstand voltage
U_S	Figure 12a	Voltage across source side reactance
U_s	Figure R.1	Source voltage
$u_S{}^*$	A.3	Source side voltage contribution at first peak
u_T	A.3	Total first peak voltage
U_X	A.1	Voltage drop across the source side (SLF)
u_X	A.1	Voltage drop across the source side (SLF) at the instant of current interruption (SLF)
V_{sc}	F.3.4	Voltage calibration for the TRV corresponding to the maximum short circuit current
X_B	Figure 12a	Power frequency busbar reactance
X_L	Figure 15	Power frequency line side reactance
$X_{L,act}$	Annex J	Line reactance corresponding to the actual line length
$X_{L,stand}$	Annex J	Line reactance corresponding to the standardised line length
X_N	Figure 13	Neutral reactance
X_S	Figure 12a	Power frequency source side reactance
X_{source}	Annex J	Reactance corresponding to the rated short-circuit breaking current
Z	Figure 15	Surge impedance of line
Z	6.103.3	Impedance
Z_0	6.103.3	Zero sequence impedance
Z_1	4.102.3	Positive sequence impedance
Z_a	Figure 13	Phase-to-phase impedance
Z_b	Figure 13	Phase-to-ground impedance
Z_i	Table 11	Busbar surge impedance

Symbol/ abbreviation	Exemplary reference	Meaning
Z_i	Figure 12a	ITRV controlling components
Z_S	Figure 12a	Source side TRV control components
Z_{sn}	Figure 13	Source neutral impedance

Annex L
(informative)

Explanatory notes on the revision of TRVs for circuit-breakers of rated voltages higher than 1 kV and less than 100 kV

Following the decision taken at the SC17A meeting in Beijing (CN) in October, 2002, IEC SC 17A/WG35 has prepared a proposal for the revision of TRVs for circuit-breakers rated above 1 kV and less than 100 kV.

This proposal uses the input coming from former Working groups of CIGRE Study Committee A3 (Switching Equipment) that have studied the necessity to adapt the TRV requirements for circuit-breakers rated less than 100 kV. In 1983, a CIGRE SC A3 Task Force reported on Transient Recovery Voltages in Medium Voltage Networks. The results of the study have been published in Electra 88. Another CIGRE working group, WG 13.05, studied the TRVs generated by clearing transformer fed faults and transformer secondary faults. The results have been presented in Electra 102 (1985). In 1992, together with CIRED, CIGRE SC A3 created working group CC-03 to investigate again the definition of TRVs for medium voltage switchgear. The outcome of these investigations has been published in CIGRE Technical Brochure 134 (1998) and is in line with earlier studies.

L.1 General

The main modifications introduced by this amendment can be summarized as follows:

a) In order to cover all types of networks (distribution, industrial and sub-transmission) in the range of rated voltages higher than 1 kV and less than 100 kV, and for standardization purposes, two types of systems are defined:
   - cable systems

     Cable-systems are defined in 3.1.132.
   - line systems

     Line systems are defined in 3.1.133.

b) A particular test duty T30 is specified for the special case of circuit-breakers intended to be connected to a transformer with a connection of small capacitance (cable length less than 20 m), in order to verify their capability to interrupt transformer-limited faults. This is covered in a new Annex M (normative).

   In the general case where the capacitance of the connection is high enough, the normal test duty T30 demonstrates the capability to interrupt transformer-limited faults.

c) Short-line fault is a mandatory duty for circuit-breakers with rated voltages 15 kV and above and directly connected to overhead lines. As specified already in this standard for circuit-breakers rated 48,3 kV and above, the rated short-circuit current must be higher than 12,5 kA (i.e. $I_{sc} \geq 16$ kA).

d) The special case of circuit-breakers installed immediately in series with a reactor is covered in a new subclause 8.103.7.

L.2 Terminal fault

L.2.1 TRV for circuit-breakers in line systems

Line systems are more common to the North American practice than to the European practice. Therefore the TRV ratings as listed in Table 2 of ANSI C37.06-2000 are the basis to define the new Table 25. The values for t_3 are 0,88 times the T_2 values specified in ANSI.

NOTE The factor 0,88 can be derived from a pure “1-cos”-waveshape multiplied with ½ amplitude factor. The standard TRV wave-shape “1-cos” in ANSI C37-06-2000 for rated voltages less than 100 kV does not coincide with the precise mathematical equation for parallel or series damped circuits, for which another ratio t_3/T$_2$ is applicable.

Time t_3 for terminal fault and short-line fault is equal to $4{,}65 \times U_r^{0{,}7}$, with t_3 in microseconds and U_r in kV. The equation is derived from the values given in Table 2 of ANSI/IEEE C37.06-2000 for rated voltages 15,5 kV, 25,8 kV, 48,3 kV and 72,5 kV. The same equation is used for other rated voltages.

The rate of rise of recovery voltage is derived from u_c and t_3.

Time t_3 for out-of-phase is taken as double the time t_3 for terminal fault.

L.2.2 Time delay

Time delay in Table 24 for circuit-breakers in cable systems:

> The time delay t_d is as in the first edition of this standard for rated voltages less than 52 kV. The equation is generalized to all cable systems (rated voltage less than 100 kV).

Time delay in Table 25 for circuit-breakers in line systems:

> The time delay t_d in Table 25 is $0{,}05 \times t_3$, as in the first edition of this standard for rated voltages 48,3 kV – 52 kV and 72,5 kV. The equation has been extended to the lower rated voltages as no change in the initial part of the TRV wave-shape is expected (the initial part is exponential, even with the short line lengths that can be met in distribution and sub-transmission systems). This requirement is not judged excessive as in the worst case (U_r = 15 kV) the time delay value of 2 µs is as specified for circuit-breakers with rated voltages higher than 72,5 kV.
>
> It recognizes the fact that at high short-circuit current the thermal phase of interruption, this time delay can be critical and that has to be taken into account. However, as shown in Tables 13 and 14 of the first edition of this standard, such verification can be made when performing short-line fault tests. Therefore, as it is already the case for rated voltages higher than 38 kV, it is allowed to have a longer time delay during testing of T100, up to $0{,}15 \times t_3$, provided that short-line fault tests are performed. This possibility is indicated in Table 25.

L.2.3 Amplitude factor for T100s and T100a

For circuit-breakers in cable systems, the value of 1,4 in the first edition of this standard is retained, due to the positive experience with past editions of this standard.

For circuit-breakers in line systems, the value of 1,54,defined in ANSI standard C37.06-2000 is taken.

L.2.4 Amplitude factor for T60, T30 and T10

For circuit-breakers in cable systems, the value of 1,5 for T60 in the first edition of this standard is kept, due to the positive experience obtained. For T30 and T10, the amplitude factor has been raised from 1,5 to respectively 1,6 and 1,7, as the contribution to TRV comes mainly from the voltage variation across transformer(s) which has low damping, this combined with source voltage results to a TRV with a relatively high amplitude factor.

For circuit-breakers in line systems, the values are taken from ANSI C37.06-2000: 1,65 for T60, 1,74 for T30 and 1,8 for T10.

L.3 Short-line fault

In the first edition of this standard, short-line fault requirements have been specified for circuit-breakers with a rated voltage of 52 kV and 72,5 kV, in the range of rated voltages considered in this edition, and directly connected to overhead-lines.

In this second edition, short-line fault requirements are specified for class S2 circuit-breakers with a rated voltage of 15 kV and above and directly connected (with busbar) to overhead-lines, irrespective of the type of network on the source side.

As the network and substation topology and layout for 48,3 kV is identical to those of 52 kV and 72,5 kV systems, the short-line test duty for 48,3 kV is specified in a way similar to 52 kV and 72,5 kV.

For the rated voltages 15 kV, 25,8 kV and 38 kV the characteristics and procedure are slightly different. As normally no equipment is connected to the line side of the circuit-breaker the line characteristics are adapted to virtually no delay capacitance: t_{dL} < 0,1 μs. As the line length to the fault location should correspond to realistic distances, the test duty L_{90} has been dropped and the tolerances on the line length for L_{75} have been adapted.

The short-line fault test specified is regarded as covering three-phase short-line faults as well as two-phase and single-phase faults for the following reasons:

– the representative surge impedance, seen from the terminals of the clearing pole, is such that for all cases the RRRV for all three poles to clear is covered by the specified characteristics listed in Table 8;
– the single-phase short-line fault test, with an arcing window of (180°−dα), covers the requirement for the multi-phase fault cases for effectively-earthed and non-effectively earthed systems;
– the withstand of the peak value of TRV during three-phase fault interruption is demonstrated by terminal fault test duty T100.

L.4 Out-of-phase

Not enough system information is available to revise TRV parameters for breaking in out-of-phase condition. CIGRE SC A3 has been asked to investigate the system and service conditions leading to out-of-phase current clearing. Therefore, the TRV for out-of-phase breaking are basically unchanged.

The values of t_3 for out-of-phase are in all cases two times the value for terminal fault T100.

L.5 Series reactor fault

Due to the very small inherent capacitance of a number of current limiting reactors, the natural frequency of transients involving these reactors can be very high. A circuit-breaker installed immediately in series with such type of reactor will face a high frequency TRV when clearing a terminal fault (reactor at supply side of circuit-breaker) or clearing a fault behind the reactor (reactor at load side of circuit-breaker). The resulting TRV frequency generally exceeds by far the standardised TRV values.

In these cases it is necessary to take mitigation measures, such as the application of capacitors in parallel to the reactors or connected to earth. The available mitigation measures are very effective and cost efficient [12]. It is strongly recommended to use them, unless it can be demonstrated by tests that a circuit-breaker can successfully clear faults with the required high frequency TRV.

In the opinion of the members of WG 35 of IEC SC17A, the service experience with TRV mitigation measures is so good and the costs involved are relatively so low, that it makes no sense to specify special requirements for circuit-breakers for this type of application.

L.6 TRV for last clearing poles / Tests circuit topology

In Table 2 of the first edition of this standard, multipliers for transient recovery voltage values for second and third clearing poles are given for circuit-breakers with rated voltages higher than 72,5 kV. Under NOTE 1, it is stated that for voltages equal to or lower than 72,5 kV, the values are under consideration.

For circuit-breakers with rated voltages equal to or lower than 72,5 kV, as not enough information is available to define values other than those specified for higher rated voltages, IEC SC17A has decided during its meeting in Montreal (CA), October 2003, to extend the validity of Table 2 to all rated voltages higher than 1 kV. The values will be revised later on when the results of studies are published.

Annex M
(normative)

Requirements for breaking of transformer-limited faults by circuit-breakers with rated voltage higher than 1 kV ~~and less than 100 kV~~

M.1 General

Figures M.1 and M.2 illustrate the two typical cases of transformer-limited faults. These types of faults can be subdivided into

– transformer-fed faults (Figure M.1);

– transformer-secondary faults (Figure M.2).

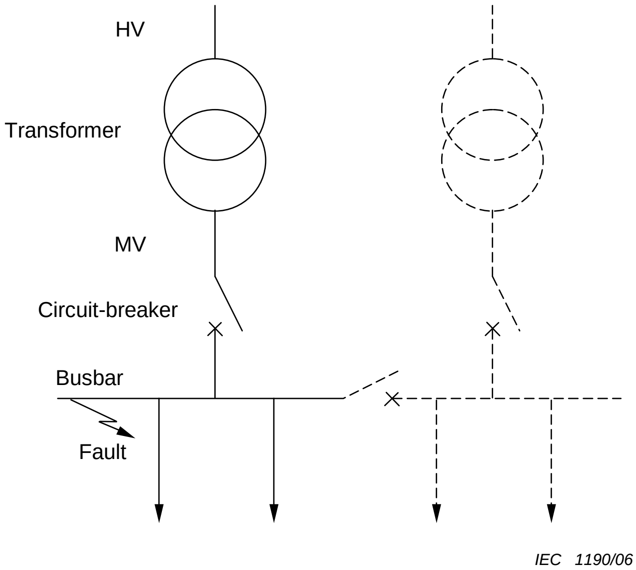
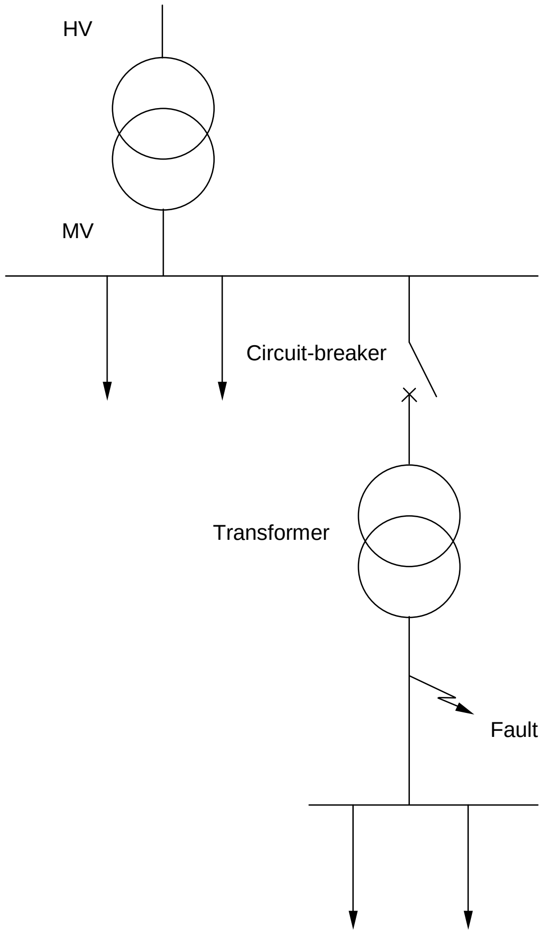


Figure M.1 – First example of transformer-limited fault
(also called transformer-fed fault)



IEC 1191/06

Figure M.2 – Second example of transformer-limited fault
(also called transformer-secondary fault)

M.2 Circuit-breakers with rated voltage less than 100 kV

As most substations have more than one transformer, the breaking current for the transformer breaker is only a fraction of the total short-circuit current of the substation. In general, the same breaking capacity is specified for transformer breakers and outgoing feeders even if the necessary breaking capacity is very different. There are two reasons for this over-dimensioning: the uniformity of all breakers in the station and the fact, that high rated normal currents, as necessary for transformer breakers, the standard coordination of rated values may imply rated short-circuit breaking capability higher than necessary. Therefore, for standardization purposes, test duty T30 is specified to prove the capability of a circuit-breaker to interrupt transformer-limited faults.

Two cases of application need to be considered:

a) in cases where there is sufficient capacitance to earth between transformer and circuit-breaker, transformer-limited faults are covered by performing T30 with TRV parameter values as given in Table 24 for circuit-breakers class S1 or Table 25 for circuit-breakers class S2. Where cables or insulated busbars are used, the capacitance to earth of the connection between transformer and circuit-breaker generally exceed the required value.

~~NOTE 1 Calculations show that the additional capacitance necessary to reduce the transformer's natural frequency to the TRV frequency specified for T30 in Tables 24 and 25 is independent of the rated voltage and proportional to the rated short-circuit current. The additional capacitance to earth has to be at least~~

$$\cancel{C_0 = 0{,}6 \times I_{30}\ (50\ \text{Hz})\ \text{or}\ 0{,}7 \times I_{30}\ (60\ \text{Hz})}$$

~~where~~

~~I_{30} is 30 % of the rated short-circuit current in kA;~~

~~C_0 is in nF.~~

~~Typical cables (0,3 to 0,5 nF/m) easily provide the values of necessary additional capacitance.~~

~~For example, in the case of a circuit-breaker with a rated short-circuit breaking current of 31,5 kA-50 Hz, the minimum length of cable for which type test T30 covers the breaking of transformer-limited faults is~~ $\frac{0,6 \times 0,3 \times 31,5}{0,3} = 19\ \text{m}$~~, assuming that the capacitance is 0,3 nF/m.~~

NOTE 1 Calculations show that the additional capacitance necessary to reduce the transformer's natural frequency to the TRV frequency specified for T30 in Tables 24 and 25 is independent of the rated voltage and proportional to the rated short-circuit current. The additional capacitance to earth should be at least

$$C_0 = 0,6 \times I_{30} \text{ (50 Hz) or } 0,7 \times I_{30} \text{ (60 Hz)}$$

where

I_{30} is 30 % of the rated short-circuit current in kA;

C_0 is in nF.

Typical cables (0,3 nF/m to 0,5 nF/m) easily provide the values of necessary additional capacitance.

For example, in the case of a circuit-breaker with a rated short-circuit breaking current of 31,5 kA - 50 Hz the minimum length of cable for which type test T30 covers the breaking of transformer-limited faults is $\frac{0,6 \times 0,3 \times 31,5}{0,3} = 19\ \text{m}$, assuming that the capacitance is 0,3 nF/m.

b) In the special case where the capacitance of the connection between the transformer and the circuit-breaker is lower than the value Co defined in a) above, a special test duty T30 may be specified to circuit-breakers with a TRV defined in Table M.1.

Alternatively a capacitance should be added to allow the use of a circuit-breaker class S1 or S2.

NOTE 2 Particular cases of application may exist where the substation is fed by only one transformer and with the short-circuit current of the transformer breaker equal to its rated short-circuit current. In such cases, the breaking capability may be demonstrated by performing test duty T100, when the connection has sufficient capacitance as explained in a) above, or alternatively a capacitance may be added in order to obtain TRV parameters covered by the values in Tables 1 or 2.

Table M.1 – Standard values of prospective transient recovery voltage for T30, for circuit-breakers intended to be connected to a transformer with a connection of small capacitance – Rated voltage higher than 1 kV and less than 100 kV – Representation by two parameters

Rated voltage U_r Kv	Test duty	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [a] u_c/t_3 kV/µs
3,6	T30	1,5	1,6	7,1	4,5	1	2,4	2	1,58
4,76 [b]	T30	1,5	1,6	9,3	5,0	1	3,1	2	1,86
7,2	T30	1,5	1,6	14,1	5,5	1	4,7	3	2,56
8,25 [b]	T30	1,5	1,6	16,2	6,0	1	5,4	3	2,70
12	T30	1,5	1,6	23,5	6,5	1	7,8	3	3,62
15 [b]	T30	1,5	1,6	29,4	7,0	1	9,8	3	4,20
17,5	T30	1,5	1,6	34	7,5	1	11,4	4	4,53
24	T30	1,5	1,6	47	9,5	1	15,7	5	4,95
25,8 [b]	T30	1,5	1,6	51	9,5	1	16,9	5	5,37
36	T30	1,5	1,6	71	11,5	2	23,5	6	6,17
38 [b]	T30	1,5	1,6	74	11,5	2	24,8	6	6,43
48,3 [b]	T30	1,5	1,6	95	14	2	31,5	7	6,79
52	T30	1,5	1,6	102	14	2	34	7	7,29
72,5	T30	1,5	1,6	142	18	3	47,4	9	7,89

[a] RRRV = rate of rise of recovery voltage.

[b] Used in North America.

M.3 Circuit-breakers with rated voltage from 100 kV to 800 kV

Standard values of prospective transient recovery voltage are under consideration by CIGRE, therefore no test requirements are specified.

M.4 Circuit-breakers with rated voltage higher than 800 kV

Severe TRV conditions may occur when short-circuit occurs immediately after a transformer without any appreciable capacitance between the transformer and the circuit breaker. In such cases, the rate-of-rise of transient recovery voltage (RRRV) exceeds the values specified for terminal fault test duties. This is due to the fact that the capacitances to earth of transformers are relatively small i.e. 9 000 pF for applications at voltages above 800 kV. The corresponding natural frequency of the transformer leads to a TRV having a rate-of-rise that is approximately two times the value for T10.

The system TRV can be modified by a capacitance and then be within the standard TRV capability envelope. As an alternative, the user can choose to specify a rated transformer limited fault (TLF) current breaking capability.

The rated TLF breaking current is selected from the R10 series in order to limit the number of testing values possible. For applications at voltages above 800 kV, preferred values are 10 kA and 12,5 kA.

TRV parameters are calculated from the TLF current, the rated voltage and a capacitance of the transformer of 9 nF. The first-pole-to clear factor corresponding to this type of fault is 1,2. Pending further studies, conservative values are taken for the amplitude factor and the voltage drop across the transformer. They are respectively equal to 1,7 and 0,9.

Table M.2 – Standard values of prospective transient recovery voltage for circuit-breakers with rated voltages higher than 800 kV intended to be connected to a transformer with a connection of low capacitance

Rated voltage U_r kV	TLF fault current kA r.m.s. sym.	First-pole-to-clear factor k_{pp} p.u.	Ampli-tude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 µs	Time delay t_d µs	Voltage u' kV	Time t' µs	RRRV [a] u_c/t_3 kV/µs
1 100	10	1,2	1,7 × 0,9	1 649	107	16	550	51	15,4
1 100	12,5	1,2	1,7 × 0,9	1 649	96	14	550	46	17,2
1 200	10	1,2	1,7 × 0,9	1 799	112	17	600	54	16,1
1 200	12,5	1,2	1,7 × 0,9	1 799	100	15	600	48	18,0

[a] RRRV = rate of rise of recovery voltage.

Annex N
(normative)

Use of mechanical characteristics and related requirements

At the beginning of the type tests, the mechanical characteristics of the circuit-breaker shall be established, for example, by recording no-load travel curves. This may be done also by the use of characteristic parameters, for example momentary speed at a certain stroke, etc. The mechanical characteristics will serve as the reference for the purpose of characterising the mechanical behaviour of the circuit-breaker.

The mechanical characteristics shall be used to confirm that the different test samples used during the mechanical, making, breaking and switching type tests behave mechanically in a similar way. All test samples used for mechanical, making, breaking and switching type tests shall have a mechanical characteristic within the following described envelopes. Care should be exercised in the interpretation of the curves when, due to variable measuring methods at different laboratories, a direct comparison between the envelopes cannot be made.

The type and location of the sensor used for the record of the mechanical characteristics shall be stated in the test report. The mechanical characteristic curve which can be measured at any part of the power kinematic chain may be recorded continuously or discretely. In case of discrete measurement, at least 20 discrete values should be given for the complete stroke.

The mechanical characteristics shall be used for determining the limits of the allowable deviations over or under this reference curve. From this reference curve, two envelope curves shall be drawn from the instant of contact separation to the end of the contact travel for the opening operation and from the beginning of the contact travel to the instant of contact touch for the closing operation. The distance of the two envelopes from the original course shall be ± 5 % of the total stroke as shown in Figure 23b. In case of circuit-breakers with a total stroke of 40 mm or less the distance of the two envelopes from the original course shall be ±2 mm. It is recognised that for some designs of circuit-breakers, these methods may be unsuitable, as for example for vacuum circuit-breakers or for some circuit-breakers rated less than 52 kV. In such cases the manufacturer shall define an appropriate method to verify the proper operation of the circuit-breaker.

If mechanical characteristics other than curves are used, the manufacturer shall define the alternative method and the tolerances used.

The series of Figures 23a to 23d are for illustrative purposes and only illustrate the opening operation. They are idealised, and do not show the variation in profile caused by the friction effect of the contacts or the end of travel damping. In particular, it is important to note that the effects of damping are not shown in these diagrams. The oscillations produced at the end of travel are dependent upon the efficiency of the damping of the drive system. The shape of these oscillations may be a deliberate function of the design and may slightly vary from one specimen to another. Therefore, it is important that any variations in the curve at the end of the stroke, which are outside the tolerance margin given by the envelope, are fully explained and understood before they are rejected or accepted as showing equivalence with the reference curves. In general, all curves should fall within the envelopes for acceptance.

The envelopes can be moved in the vertical direction until one of the curves covers the reference curve. This gives maximum tolerances over the mechanical characteristics of –0 %, +10 % and –10 %, +0 %, respectively as shown in Figures 23c and 23d. The displacement of the envelope can be used only once for the complete procedure in each test in order to get a maximum total deviation from the reference characteristic of 10 %.

Table N.1 lists type tests and relevant reference mechanical characteristics for no-load, making and breaking tests.

Table N.1 – Summary of type tests related to mechanical characteristics

Applicable subclauses	Tests where the records shall be taken	Evaluation method	Application/Notes
6.101.1.1 Mechanical characteristics	No-load test before the beginning of type tests	Not applicable	General guide for reference mechanical characteristics
6.101.1.3 Characteristics and settings of the circuit-breaker to be recorded before and after the tests	Before and after the mechanical and environmental tests	Not applicable	Items listed in 6.101.1.3 to be recorded
6.101.2.2 Condition of the circuit-breaker before the (mechanical) test	No-load test before the mechanical test	[a]	Mechanical test on a separately operated single-pole of a three-pole circuit-breaker
6.101.2.5 Acceptance criteria for the mechanical operation tests	No-load test after the mechanical test	[b]	
6.101.3.3 Low temperature test	No-load test before and after the low temperature test	[b]	Depending on minimum temperature specification
6.101.3.4 High temperature test	No-load test before and after the high temperature test	[b]	
6.101.4.2 Test procedure (humidity test)	During and after the tests (no-load operations)	[b]	Conditional test when required
6.101.6 Static terminal load test	No-load test before and after the terminal load test	[a]	Refer also to the note in 6.101.6
6.102.2 Number of test specimens	No-load test before making and breaking tests	[a]	For the second test specimen, if more than one specimen is used
6.102.3.3 Multi-enclosure type	No-load test before the test	[a]	For commonly operated multi-enclosure type
	Making and breaking operation based on T100s	[c]	
6.102.4.1 Single-phase testing of a single pole of a three-pole circuit-breaker	No-load test before the test	[a]	For circuit-breakers with common operating mechanism
	Making and breaking operation based on T100s	[c]	
6.102.4.2 Unit testing	No-load test before the test	[a]	For circuit-breakers with two or more units not separately operated within one pole
	Making and breaking operation based on T100s	[c]	
6.102.6 No-load operation before (making and breaking) tests	No-load tests before the test [d]	[a, d]	For all making and breaking tests
6.102.7 Alternative operating mechanism	No-load test before the test	[a]	For equivalent alternative operating mechanisms
	Making and breaking operation based on T100s	[c]	
6.102.9.3 Condition after a short-circuit test-duty	No-load tests after the test-duty	[d]	If components are changed or maintenance is carried out after the test-duty
6.102.9.3 Condition after a short-circuit test series	No-load tests after the test series	[d]	
6.112.2 Class E2 circuit-breakers intended for auto-reclosing duty	No-load tests after the test series	[d]	Conditional test when required

[a] Evaluation to the method given in 6.101.1.1; comparison of the mechanical characteristics.

[b] Evaluation to the method given in 6.101.1.3 and 6.101.1.4.

[c] Evaluation to the method given in 6.102.4.1 for single-pole testing.

[d] Testing method given in 6.102.6.

Annex O
(informative)

Guidance for short-circuit and switching test procedures for metal-enclosed and dead tank circuit-breakers

O.1 Introduction

This annex contains information and recommendations for test circuits and procedures for type testing relevant to short-circuit making and breaking and switching performance of metal-enclosed and dead tank circuit-breakers. Other methods are not excluded, provided that they supply the correct stresses to the circuit-breaker. Other tests, such as dielectric tests, routine tests, commissioning tests and site tests are not within the scope of this annex.

The various test cases are evaluated and special test circuits are given, or special precautions required to use test circuits developed for open-air equipment. The tests described can be made in principle in both direct and synthetic circuits. Synthetic testing is covered in IEC 62271-101.

O.2 General

O.2.1 Special features of metal-enclosed circuit-breakers with respect to making and breaking tests

Circuit-breakers in metal enclosures have to fulfil their duties under conditions which are different from those prevailing in insulating enclosures.

The main features with certain consequences on making and breaking tests are:

a) The switching units are integrated parts of a given substation design. Thus, the surrounding components of a substation have to be considered when defining the test conditions.
b) Several breaking units of one pole, or even all three poles, can be placed within a common enclosure. Various components of switching units of the substation as well as other live and earthed parts, are in close spatial neighbourhood, due to the high dielectric strength of the insulating medium. This may lead to strong interactions of different physical nature between parts of switching units and their surroundings. It also results in a relatively high capacitance and low inductance of tested and surrounding parts.

   The implications of such interactions have to be considered in determining the test requirements.
c) In metal-enclosed equipment, the insulating surfaces are exposed to a relatively high dielectric stress and this may make them sensitive to deposit.

O.2.2 Reduced number of units for testing purposes

Suitable facilities might not be available in high-power test plants for the testing of a complete circuit-breaker or a full pole, even in laboratories which make use of synthetic test circuits.

Hence the necessity exists to perform tests on parts of a complete circuit-breaker.

Depending on the alternatives, the interactions between the tested object and the omitted parts should be analysed:

– between circuit-breaker units and surrounding parts of the substation;
– between poles or between poles and the enclosure;

– between different units or between units and the enclosure.

In this analysis, it is necessary to differentiate between:

– single pole in one enclosure;
– three poles in one enclosure.

It is also necessary to distinguish between two different stresses, which usually can be treated separately:

– stress of the interrupting gap;
– stress of insulation between phases, or between phases and the enclosure.

O.2.3 General description of special features and possible interactions

Interactions, which might influence the test results and cannot be taken into account by unit testing or single-pole testing, will require full-pole or three-pole testing, respectively.

O.2.3.1 Influence of the surrounding parts of a substation

Integrated parts, for example bus-bar sections, feeding cables, bushings, voltage transformers, and surge arresters, may influence the prospective stresses of the test circuit.

The influence of these integrated parts of the system depends on the test sequence. On the one hand, the large capacitance of surrounding elements reduces the stress on the circuit-breaker in the case of SLF and terminal fault ITRV, while, on the other hand, switching of capacitor banks may be more severe when low impedance connections are used.

O.2.3.2 Interaction between poles, interrupting units and enclosures

Various types of interactions of a different physical nature can arise between the elements of the circuit-breaker considered. The most important are:

– mechanical;
– electrostatic;
– electro-magnetic;
– gas dynamical.

The intensity of these interactions will, in most cases, depend on the individual design of the object under test. If a special interaction is eliminated in a given design, it is no longer necessary to adjust the tests to cover this interaction. In that case, it is necessary to demonstrate that the interaction under consideration has negligible influence on the test results, which could be made by model calculation, or experimental demonstration, using special measuring techniques. The same demonstration could be applied for the judgement of the degree of interaction that has to be represented in tests. In addition, consideration must be given to the case of a switching device where the configuration is not symmetrical in respect to the terminals.

O.2.3.2.1 Mechanical interaction

Subclauses 6.102.3 and 6.102.4 apply.

O.2.3.2.2 Electrostatic interaction

Subclause 6.102.4.2.2 applies.

The voltage distribution between units of multi-break circuit-breakers, as well as the electric field in the contact gap, is influenced by the high capacitances and especially by the presence of the earthed enclosure and of other live parts. It may be different in various test sequences and for different earthing conditions.

The voltage distribution between units can be determined as a function of the capacitance across the units and to the enclosure. The maximum gradients on the contact surfaces depend also on the number of interrupters and, for the same circuit-breaker, on the position of the interrupting unit in the circuit-breaker, even when an ideal voltage distribution is assumed.

The electrical field in the contact gap is influenced by the following factors:

– short distances between live parts and the enclosure;
– presence of adjacent live parts.

Here the determination of a representative stress depends on the individual design of the circuit-breaker and on the location of the most critical stress area.

O.2.3.2.3 Electromagnetic interaction

Both single- and three-pole circuit-breakers can experience electromagnetic interaction, which may cause additional forces on the arcs and on moving parts. In the case of three poles in one enclosure, the interaction between phases is pronounced.

Induced currents and return currents in the enclosure may cause additional effects, for instance a voltage drop between earthed parts affecting auxiliary or protective equipment.

O.2.3.2.4 Gas dynamical interaction

Hot, ionised and/or contaminated exhaust gases may influence the dielectric strength between poles in a common enclosure and between the pole(s) and the enclosure. Similar effects may occur between the units of a pole with more than one interrupting unit.

O.3 Tests for single pole in one enclosure

O.3.1 Short-circuit making and breaking tests

The test circuits shall comply with Figures 25a, 26a, 27a and 28a. Test circuits 25b, 26b, 27b and 28b do not stress metal-enclosed and dead tank circuit-breakers in earthed fault conditions correctly.

The conditions of 6.102 shall be fulfilled. The synthetic test circuits shall comply with Clauses 4, 5 and 6 of 62271-101.

For single-phase testing purposes two situations have to be considered:

a) single-pole testing of three-pole circuit-breakers (see O.3.1.1);
b) unit testing (see O.3.1.2).

O.3.1.1 Single-pole testing of a three-pole circuit-breaker

When test circuits shown in Figures 27a and 28a are used, the full voltage has to be applied to one terminal of the circuit-breaker, the other terminal and the enclosure being earthed. The recovery voltage should preferably be a.c. The conventional direct or synthetic circuits shall be used.

O.3.1.2 Unit testing

Particular precautionary measures regarding interaction must be taken (see 6.102.4.2.1 b)).

The required voltage stresses during the unit testing are:

- the full-pole transient recovery voltage and recovery voltage between the relevant live parts and the enclosures. The recovery voltage should preferably be a.c.;
- the portion of these voltages, depending on the number of tested units and on the voltage distribution, across the unit(s) submitted to tests.

All units must break the short-circuit current, which guarantees the correct interaction between units and the correct influence on the insulation between live parts and the enclosure.

This test procedure can only be used if the circuit-breaker is supplied with a third bushing.

This bushing, connected between the unit(s) under test and the voltage circuit, allows the use of the other unit(s) as auxiliary circuit-breakers. This bushing should not produce any mechanical, electrostatic, or magnetic interaction with the unit(s) under test.

The synthetic circuit is shown in IEC 62271-101, both for current and for voltage injection. It consists of:

- a conventional synthetic test circuit that gives the required portion of the total TRV between the terminals of the unit(s) under test u_B;
- an additional test circuit (synthetic, d.c., or a.c. source) that energizes the enclosure, insulated from earth, with a suitable voltage u_E.

In IEC 62271-101 an example relevant to a half-pole test, shows the required voltage u_B, u_E and the resulting voltage u_A between the terminal of the auxiliary unit(s) connected to the current circuit and the enclosure. The full-pole voltage stresses are applied between the earthed terminal of the units under test and the enclosure.

If it is not possible to apply the voltage stresses u_B and u_E at the same time, a multipart testing procedure can be used (see 6.102.4.3). In the first part, only the performance of the unit(s) under test is checked (the enclosure of the circuit-breaker is earthed). In the second part, the insulation between the live parts of the pole and the enclosure is checked. This can be done, for example, with all units breaking the short-circuit current, but at a reduced voltage (dependent on the available current source) and applying voltage between the insulated enclosure and the earth. At the moment when the TRV peak is produced, the instantaneous value of the applied voltage to the enclosure shall be equal to the differences between the "reduced voltage" and the total TRV peak to be applied between the stressed terminal and the enclosure.

Test circuits without the use of a third bushing exist. The required voltage across the unit under test is produced by shunting the other units with large capacitors. The application of such circuits is not valid for the interaction interval, and may only be used subject to agreement between manufacturer and user. These circuits can be used for basic short-circuit test sequences, if the thermal behaviour of the circuit-breaker during interaction interval is verified separately (for example either by two-part testing, or by performing short-line fault tests).

Attention should be paid that during the basic short-circuit test duties, the arcing times are not considerably at variance with those obtained during the thermal verification test.

NOTE 1 In the past, some unit testing has been carried out in a test circuit in which not all units break the short-circuit current. Such a test circuit may only be used for cases with negligible interaction, due to gas circulation. This is, however, mostly not the case and is also very difficult to prove.

In this circuit, a portion of the circuit-breaker has been short-circuited. It is assumed that this does not produce any mechanical, electrostatic, or electromagnetic interaction, and special attention should be paid to the interaction due to gas circulation.

Appropriate synthetic test circuits are shown in IEC 62271-101, both for current and voltage injection.

The value and polarity of the voltage u_E. to be applied to the enclosure are such that the resulting voltage between the energized terminal of the circuit-breaker and the enclosure is equal to the required value of the full-pole test voltage.

NOTE 2 Insulation between live parts and enclosures during making and breaking short-circuit currents for most circuit-breakers can be proved by short-circuit test duties T100s and T100a. Short-circuit test duties T10, T30 and T60 may be performed by conventional unit test procedures.

NOTE 3 To uncouple the control circuit of the circuit-breaker from the energized enclosure, the fibre-optics transmission technique can be applied successfully; the power required to operate the closing and trip coils can be provided by a turbine generator group driven by compressed air.

O.3.2 Short-line fault tests

Subclause 6.109 of IEC 62271-100 and 4.2.1, 4.2.2 and 6.109 of IEC 62271-101 apply when the synthetic testing method is used.

Provided that the basic short-circuit test duties have been carried out, no further attention need be paid to the insulation between the live parts and the enclosure during short-line fault tests.

O.3.3 Capacitive current switching tests

The testing procedure shall be in agreement with 6.111.

Table O.1 gives the source-side and load-side voltages as well as the recovery voltages during three-phase capacitive current switching in actual service conditions.

Table O.2 gives the corresponding values of the source-side, load-side, and recovery voltages during single-phase capacitive current switching.

If during the tests to check the recovery voltage withstand capability between the contacts (see 6.111.5) the applied voltages on source-side and load-side are at least equal to the required values between live parts and the enclosure given in Tables O.1 and O.2, additional tests are not necessary.

For single-phase tests, according to 6.111.7, the dielectric stress between the live part and the enclosure is not always correctly reproduced. Verification of the dielectric withstand between the live part and the enclosure should be carried out and is achieved by any test method that demonstrates the withstand between live parts and the enclosure of the values given in Table O.2.

For single-phase tests performed to prove three-phase switching of capacitor banks with unearthed neutral and switching in non-effectively earthed neutral systems, the dielectric withstand can be demonstrated, but is not limited to, by one of the following test methods:

a) Switching tests with an intermediate earth point in the source-side or in the load-side resulting in a voltage between the live parts on the source side and the enclosure of $1{,}5 \times U_r \sqrt{2} / \sqrt{3}$ and a recovery voltage of $2{,}8 \times U_r \sqrt{2} / \sqrt{3}$.

b) Dielectric tests additional to the switching tests according to 6.111.7 with the aim of applying proper d.c. and/or power frequency dielectric stresses between the terminals and the enclosure. The power frequency voltage should be applied on the source-side terminal of the circuit-breaker, and should be maintained for 1 min. The d.c. voltage should be applied, with both polarities, on the load-side terminal of the circuit-breaker and maintained for 0,3 s. The voltages can be applied on the terminals in separate steps.

c) Subject to agreement of the manufacturer, tests can be performed with a supply circuit having an earthed neutral and a supply voltage of $1{,}5 \times U_r \sqrt{2} / \sqrt{3}$.

Table O.1 – Three-phase capacitive current switching in actual service conditions: typical values of voltages on the source-side, load-side, and recovery voltages

Voltage at circuit-breaker terminal	Values of the voltages for effectively earthed neutral systems			Values of the voltages for non-effectively earthed neutral systems
	Unearthed capacitors	Earthed capacitor banks and screened cables	Lines	In all cases
$U_{C/E}$	$U_r\sqrt{2}/\sqrt{3}$	$U_r\sqrt{2}/\sqrt{3}$	$U_r\sqrt{2}/\sqrt{3}$	$1{,}5\times U_r\sqrt{2}/\sqrt{3}$
$U_{C'/E}$	$1{,}5\times U_r\sqrt{2}/\sqrt{3}$	$U_r\sqrt{2}/\sqrt{3}$	$1{,}2\times U_r\sqrt{2}/\sqrt{3}$	$U_r\sqrt{2}/\sqrt{3}$
$U_{C/C'}$	$2{,}5\times U_r\sqrt{2}/\sqrt{3}$	$2\times U_r\sqrt{2}/\sqrt{3}$	$2{,}2\times U_r\sqrt{2}/\sqrt{3}$	$2{,}5\times U_r\sqrt{2}/\sqrt{3}$

Pole C is assumed to be the first pole to clear.

C: source side C': load side C/C': across the open contacts

U_r = rated voltage

$U_{C/E}$ = voltage between source-side terminal and earth

$U_{C'/E}$ = voltage between load-side terminal and earth

$U_{C/C'}$ = voltage across the open contacts

NOTE 1 The indicated values for non-effectively earthed neutral systems apply if the source-side zero sequence capacitance is negligible compared to that of the load side.

NOTE 2 The designation of the poles is illustrated in Figure O.1.

Table O.2 – Corresponding capacitive current-switching tests in accordance with 6.111.7 for single-phase laboratory tests. Values of voltages on the source-side, load-side, and recovery voltages

Voltage at circuit-breaker terminal	Values of the voltages for effectively earthed neutral systems			Values of the voltages for non-effectively earthed neutral systems
	Unearthed capacitors	Earthed capacitor banks and screened cables	Lines	In all cases
$U_{C/E}$	$1{,}3\times U_r\sqrt{2}/\sqrt{3}$	$U_r\sqrt{2}/\sqrt{3}$	$1{,}2\times U_r\sqrt{2}/\sqrt{3}$	$1{,}5\times U_r\sqrt{2}/\sqrt{3}$
$U_{C'/E}$	$1{,}5\times U_r\sqrt{2}/\sqrt{3}$	$U_r\sqrt{2}/\sqrt{3}$	$1{,}2\times U_r\sqrt{2}/\sqrt{3}$	$1{,}3\times U_r\sqrt{2}/\sqrt{3}$
$U_{C/C'}$	$2{,}8\times U_r\sqrt{2}/\sqrt{3}$	$2\times U_r\sqrt{2}/\sqrt{3}$	$2{,}4\times U_r\sqrt{2}/\sqrt{3}$	$2{,}8\times U_r\sqrt{2}/\sqrt{3}$

Pole C is assumed to be the first pole to clear.

C: source side C': load side C/C': across the open contacts

U_r = rated voltage

$U_{C/E}$ = voltage between source-side terminal and earth

$U_{C'/E}$ = voltage between load-side terminal and earth

$U_{C/C'}$ = voltage across the open contacts

NOTE The designation of the poles is illustrated in Figure O.1.

In addition to the conditions of Tables O.1 and O.2, the following paragraphs give information concerning items d) and e) of 6.111.7.

With the neutral of the supply effectively earthed and in presence of single- or two-phase earth faults, the voltages in the healthy phases can reach up to $1{,}4\times U_r\sqrt{2}/\sqrt{3}$. The precise value depends on the zero sequence impedances. In that case, the values of the voltages on source-side and load-side terminals to earth which should be considered are:

– $U_{C/E} = U_{C'/E} = 1{,}4 \times U_r \sqrt{2} / \sqrt{3}$

– $U_{C/C'} = 2{,}8 \times U_r \sqrt{2} / \sqrt{3}$ (recovery voltage)

With the neutral of the supply not effectively earthed and in presence of single- or two-phase earth faults, the voltages in the healthy phases can reach up to approximately $1{,}7 \times U_r \sqrt{2} / \sqrt{3}$.

In that case, the values of the voltages on source-side and load-side terminals to earth which should be considered are:

– $U_{C/E} = U_{C'/E} = 1{,}7 \times U_r \sqrt{2} / \sqrt{3}$

– $U_{C/C'} = 3{,}4 \times U_r \sqrt{2} / \sqrt{3}$ (recovery voltage)

O.3.3.1 Single-pole testing of three-pole circuit-breakers

Direct circuits or synthetic circuits shall be used.

In some synthetic test circuits, both voltages are combined at one terminal of the circuit-breaker, the other terminal being earthed.

This condition is more severe for the insulation to earth and may affect the severity of the test across the circuit-breaker.

To compensate for this effect, a bias voltage stress to the enclosure may be applied.

Possible solutions relevant to the current injection circuit and to the circuit using two power frequency sources are illustrated in IEC 62271-101.

O.3.3.2 Unit testing

It is necessary to take into account local field distortion within the gap between neighbouring elements, such as enclosures. In some cases, depending on the number of the units of the pole, the test circuits do not reproduce the requested d.c. and a.c. recovery voltages between the live parts of the unit(s) under test and the enclosure.

Unit testing is only acceptable if the field strength to earth at one terminal is equal to the field strength to earth at full-pole testing. This condition can be met by:

– energizing the enclosure of the circuit-breaker, insulated from earth, with a proper voltage;
– performing half-pole testing with both voltages (a.c. and d.c.) superimposed at one terminal and the other terminal earthed.

O.3.4 Out-of-phase switching

Subclause 6.110 applies.

The following considerations apply:

– during these tests the mechanical, magnetic and gas dynamical interactions are low and smaller than during short-circuit and short-line fault test conditions;
– the voltage stress between the phases and the enclosure, as well as between phases, might be equal to, or smaller than, those in short-circuit test conditions.

NOTE To simulate the network conditions, it is recommended to earth the enclosure and to apply the voltage stresses to both sides of the circuit-breaker.

Earthing of the enclosure and one terminal yields a more severe stress between the phases and enclosure; consequently, this test configuration is subject to the agreement of the manufacturer.

For testing purposes two situations have to be considered:

a) single-pole testing of three-pole circuit-breakers (see O.3.4.1);

b) unit testing (see O.3.4.2).

O.3.4.1 Single-pole testing of three-pole circuit-breakers

A direct or synthetic test method in a symmetrical circuit as indicated in Figure 51, with voltages applied on both sides and the enclosure earthed, can be used. The recovery voltage preferably should be a.c.

Synthetic test circuits are described in IEC 62271-101.

Alternatively, a conventional direct or synthetic circuit can be used with one of the terminals of the circuit-breaker earthed and the enclosure energized and insulated from earth.

O.3.4.2 Unit testing

To reproduce the correct voltage stress between the terminals and the enclosure, the enclosure has to be insulated and energized using a voltage source as described in O.3.1 2.

Unit testing with the enclosure and one terminal of the circuit-breaker earthed is permissible, provided that the required voltage stress between the terminals and the enclosure has already been checked during the short-circuit tests.

O.4 Tests for three poles in one enclosure

O.4.1 Terminal fault tests

When a direct circuit is available to test the three-phase circuit-breaker, direct testing will cover all the stresses.

When a synthetic method is used, to ensure that the suitable stresses in the interrupting element and those between poles and to the enclosure are applied, the following general requirements shall be fulfilled.

a) Full three-phase current shall be supplied to the three-pole circuit-breaker under test.

NOTE Short-circuit test duties T10, T30 and T60 may be performed in single-phase test circuits.

b) Information about the required test circuits for test duties T100s and T100a is given in 62271-101.

c) Between the different poles and between poles and the enclosure, the maximum stresses for TRV and RV are given in Tables O.3 and O.4 (see also Figures O.2 and O.3).

These stresses may be tested by using the synthetic circuits described in IEC 62271-101.

For test duty T100a, reference should be made to IEC 62271-101. The recovery voltage should be a.c.

**Table O.3 – Test duties T10, T30, T60 and T100s –
First-pole-to-clear factor: 1,5.
Voltage values during 3-phase interruption**

TRV peak / TRV peak first pole %				RV peak p.u.	d*u*/d*t* %
		At the instant of first-pole clearance	**At the instant of second-pole clearance**		
Phases	a	0	58	1	70
	b	0	58	1	70
	c	100	-	1	100
Between phases	a-b	0	115	1,732	
	b-c	100	58	1,732	
	c-a	100	58	1,732	
u_c = TRV peak first pole = $1{,}5 \times 1{,}4 \times U_r \sqrt{2} / \sqrt{3}$ 1 p.u. = $U_r \sqrt{2} / \sqrt{3}$ The first-pole-to-clear is located on phase c.					

**Table O.4 – Test duties T10, T30, T60 and T100s –
First-pole-to-clear factor: 1,3.
Voltage values during 3-phase interruption**

TRV peak / TRV peak first pole %					RV peak p.u.	d*u*/d*t* %
		At the instant of first-pole clearance	**At the instant of second-pole clearance**	**At the instant of third-pole clearance**		
Phases	a	0	0	77	1	70
	b	0	98	-	1	95
	c	100	-	-	1	100
Between phases	a-b	0	98	98	1,732	
	b-c	100	89	-	1,732	
	c-a	100	-	91	1,732	
u_c = TRV peak first pole = $1{,}3 \times 1{,}4 \times U_r \sqrt{2} / \sqrt{3}$ 1 p.u. = $U_r \sqrt{2} / \sqrt{3}$ The first-pole-to-clear is located on phase c.						

a) In accordance with the requirements of 6.105.1, and with the aim to reduce the time interval to the minimum, and also to avoid changing the connection of the high-voltage circuit to the circuit-breaker between the tests of each test duty, all the required arcing times shall be applied on the same phase.

b) All the above stresses preferably should be applied in the same test. If this is impossible, a multi-part testing procedure may be allowed.

O.4.2 Short-line fault tests

The test is based on the single-phase-to-earth fault interruption, as for the single-pole enclosure type (see O.3.2).

Therefore, only one pole shall be stressed by the short-circuit current and full voltage. Subclauses 6.102.3 and 6.102.4 apply.

O.4.3 Capacitive current switching tests

Three-phase testing is preferred.

In the case of single-phase testing, some extra dielectric tests are necessary (see O.3.3). In the three-phase situation, both the insulation to earth and between poles has to be considered. These dielectric tests, as far as required, may be carried out separately.

Table O.5 – Capacitive current switching in actual service conditions: maximum typical voltage values

Voltage between terminal	Effectively earthed neutral systems			Non-effectively earthed neutral systems
	Unearthed capacitor banks p.u.	Earthed capacitor banks p.u.	Lines p.u.	p.u.
A-earth	1,0	1,0	1,0	1,5
A'-earth	1,5	1,0	1,2	1,0
A-A'	2,5	2,0	2,2	2,5
A'-B'	≤1,73	≤1,73	≤1,73	≤1,73
A'-C'	2,37	2,0	2,1	2,37
B'-C'	≤1,73	2,0	1,9	≤1,73
A-B'	1,87	2,0	2,0	1,87
A-C'	1,87	2,0	1,9	1,87
B-A'	2,5	2,0	2,2	2,5
B-C'	1,87	2,0	1,9	1,87
C-A'	2,5	2,0	2,2	2,5
C-B'	1,87	2,0	2,0	1,87
A-A' First-pole-to-clear	A = Source side		A' = Load side	

NOTE 1 The indicated values for non-effectively earthed neutral systems apply if the source-side zero sequence capacitance is negligible compared to that of the load side.

NOTE 2 1 p.u. = $U_r \sqrt{2} / \sqrt{3}$

NOTE 3 Poles B and C clear at the first current zeros after the clearance of pole A.

NOTE 4 The voltage value for A-B, A-C and B-C are in all cases equal to $U_r \sqrt{2}$.

NOTE 5 The voltages B-earth, B'-earth, B-B' and C-earth, C'-earth and C-C' are not incorporated in the table, because their values are lower than those for pole A.

O.4.4 Out-of-phase switching test

Single-phase testing may be used. Three-phase testing is considered not to be necessary because of relatively small currents and relatively low voltage to the enclosure, due to the sharing between both sides of the breaks.

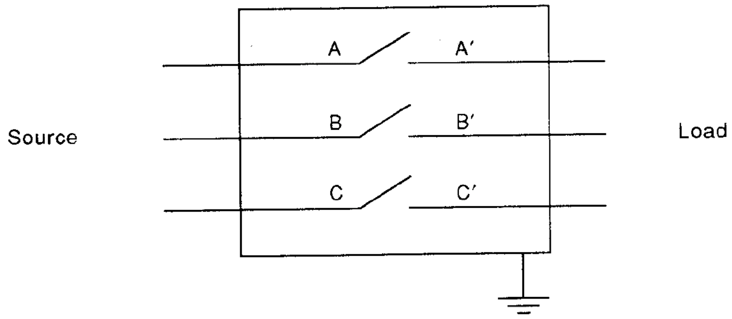


Figure O.1 – Test configuration considered in Tables O.1 and O.2

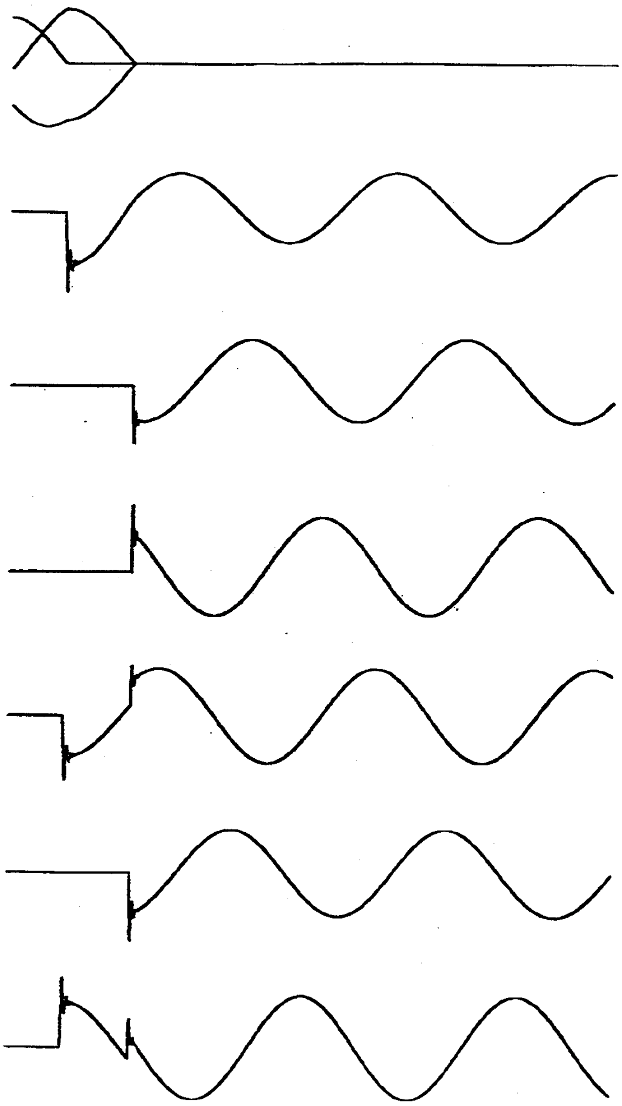


Figure O.2 – Example showing the waveshapes of symmetrical currents, phase-to-ground and phase-to-phase voltages during three-phase interruption, as for Figure 25a

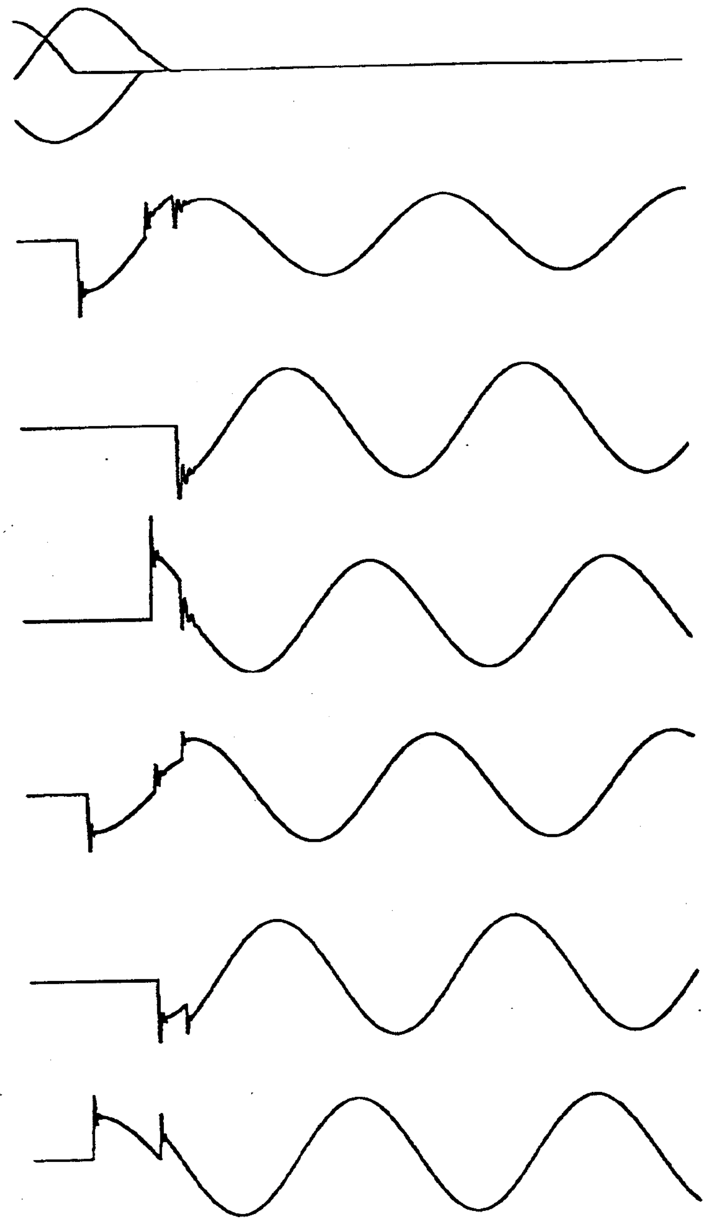


Figure O.3 – Example showing the waveshapes of symmetrical currents, phase-to-ground and phase-to-phase voltages during three-phase interruption, as for Figure 26a

Annex P
(normative)

Calculation of the TRV parameters during asymmetrical fault condition (T100a)

This annex is applicable for the calculation of prospective TRV parameters during asymmetrical fault conditions.

NOTE 1 The calculation shown in this annex applies only to the first pole-to-clear. For the second and third pole-to-clear, see Table 10 for guidance.

NOTE 2 Further details of the calculation for the TRV for asymmetrical current interruption are given in IEC 62271-101.

During asymmetrical fault condition, the resultant d*i*/d*t* and TRV are modified by the d.c. component of the fault current.

For the d*i*/d*t*, the maximum value is reached for symmetrical fault condition. During asymmetrical fault condition, the d*i*/d*t* is reduced and it is function of the d.c. component at current zero. The required d*i*/d*t* at current zero is calculated by the following equations:

a) For the minor loop:

$$\frac{\mathrm{d}i}{\mathrm{d}t}(\mathrm{p.u.})_{-} = \sqrt{(1-p^2)} - \frac{p}{2\pi f\tau} \qquad \text{(P.1)}$$

b) For the major loop:

$$\frac{\mathrm{d}i}{\mathrm{d}t}(\mathrm{p.u.})_{+} = \sqrt{(1-p^2)} + \frac{p}{2\pi f\tau} \qquad \text{(P.2)}$$

where

d*i*/d*t* (p.u.) d*i*/d*t* in p.u. of the symmetrical fault condition;

– = index used to designate the minor loop;

+ = index used to designate the major loop;

p = d.c. component at current zero in p.u.;

f = frequency (Hz);

τ = d.c. time constant of the short-circuit current (s).

When the interruption occurs, the moment of current zero does not correspond with the peak of the applied voltage as it is the case during symmetrical fault condition. The d.c. component modifies the phase angle between current zeros and the applied power frequency voltage. The TRV amplitude co-ordinates (u_1, u_c) are then modified according to the phase shift between the moment of current zero and the peak of the applied power frequency voltage.

The corresponding TRV amplitude co-ordinates (u_1, u_c) shall be calculated with the following equations:

c) Two parameter TRV:

$$u_c(\mathrm{p.u.}) = \frac{k_1 A_1}{2\pi f} \qquad \text{(P.3)}$$

and

$$k_{1-} = \sin(2\pi f t_3 - a\sin(p)) + p \times e^{-\frac{t_3}{\tau}} \text{ (for the minor loop)} \tag{P.4}$$

$$k_{1+} = \sin(2\pi f t_3 + a\sin(p)) - p \times e^{-\frac{t_3}{\tau}} \text{ (for the major loop)} \tag{P.5}$$

$$A_1 = \frac{2\pi f}{\sin(2\pi f t_3)} \tag{P.6}$$

where

- u_c = TRV peak in p.u. of the symmetrical case;
- k_1 = calculation constant;
- – = index used to designate the minor loop;
- + = index used to designate the major loop;
- A_1 = calculation variable;
- p = d.c. component at current zero in p.u.;
- f = frequency (Hz);
- τ = d.c. time constant of the short-circuit current (s);
- t_3 = specified t_3 time co-ordinate (s).

d) Four parameter TRV:

$$u_1(\text{p.u.}) = \frac{k_1 A_1}{2\pi f} \tag{P.7}$$

and

$$k_{1-} = \sin(2\pi f t_1 - a\sin(p)) + p \times e^{-\frac{t_1}{\tau}} \text{ (for the minor loop)} \tag{P.8}$$

$$k_{1+} = \sin(2\pi f t_1 + a\sin(p)) - p \times e^{-\frac{t_1}{\tau}} \text{ (for the major loop)} \tag{P.9}$$

$$A_1 = \frac{2\pi f}{\sin(2\pi f t_1)} \tag{P.10}$$

where

- u_1 = TRV peak in p.u. of the symmetrical case;
- k_1 = calculation constant;
- – = index used to designate the minor loop;
- + = index used to designate the major loop;
- A_1 = calculation variable;
- p = d.c. component at current zero in p.u.;
- f = frequency (Hz);
- τ = d.c. time constant of the short-circuit current (s);
- t_1 = specified t_1 time co-ordinate (s).

and

$$u_c(\text{p.u.}) = \frac{k_2 A_1}{1{,}4 \times 2\pi f} - \frac{k_3 A_2}{2\pi f} \tag{P.11}$$

and

$$k_{2-} = \sin(2\pi f t_2 - a\sin(p)) + p \times e^{-\frac{t_2}{\tau}} \text{ (for the minor loop)} \tag{P.12}$$

$$k_{2+} = \sin(2\pi f t_2 + a\sin(p)) - p \times e^{-\frac{t_2}{\tau}} \text{ (for the major loop)} \tag{P.13}$$

$$k_{3-} = \sin(2\pi f (t_2 - t_1) - a\sin(p)) + p \times e^{-(\frac{t_2 - t_1}{\tau})} \text{ (for the minor loop)} \tag{P.14}$$

$$k_{3+} = \sin(2\pi f (t_2 - t_1) + a\sin(p)) - p \times e^{-(\frac{t_2 - t_1}{\tau})} \text{ (for the major loop)} \tag{P.15}$$

$$A_1 = \frac{2\pi f}{\sin(2\pi f t_1)} \tag{P.16}$$

$$A_2 = \frac{A_1 \sin(2\pi f t_2)/1{,}4 - 2\pi f}{\sin(2\pi f (t_2 - t_1))} \tag{P.17}$$

where

u_c = TRV peak in p.u. of the symmetrical case;
k_2 = calculation variable;
k_3 = calculation variable;
– = indices used to designate the minor loop;
+ = indices used to designate the major loop;
A_1 = calculation variable;
A_2 = calculation variable;
p = d.c. component at current zero in p.u.;
f = frequency (Hz);
τ = d.c. time constant of the short-circuit current (s);
t_1 = specified t_1 time co-ordinate (s);
t_2 = specified t_2 time co-ordinate (s).

As an example the following parameters are considered:

– circuit-breaker rated voltage:		145 kV
– rated frequency:		50 Hz
– rated short-circuit current:		40 kA
– d.c. time constant of the short-circuit current:		45 ms
– first-pole-to-clear factor:		1,3
– minimum clearing time:		43 ms
– rated TRV (symmetrical case):	u_1	154 kV
	t_1	77 µs
	u_c	215 kV
	t_2	231 µs.

According to Table 15, the following parameters are given:

a) For the minor loop:
   - percentage of the d.c. component at current zero: 37,9 % (0,379 p.u.);
   - percentage of di/dt at current zero: 89,9 % (0,899 p.u.).

b) For the major loop:

– percentage of the d.c. component at current zero: 28,9 % (0,289 p.u.);

– percentage of di/dt at current zero: 97,8 % (0,978 p.u.).

The following values are calculated from the previous equations:

k_{1-} = 0,02185;

k_{1+} = 0,02357;

A_1 = 12988,28;

u_{1-} = 0,90319 p.u.;

u_{1+} = 0,97426 p.u.;

k_{2-} = 0,06616;

k_{2+} = 0,07013;

k_{3-} = 0,04390;

k_{3+} = 0,04695;

A_2 = 7413,155;

u_{c-} = 0,91764 p.u.;

u_{c+} = 0,96325 p.u.

With these results, the resultant modified di/dt and TRV to be applied to the circuit-breaker are:

a) For the minor loop:

di/dt = 0,899 p.u. × 40 kA × √2 × 2πf = 15,98 A/µs;

u_1 = 0,90319 p.u. × 154 kV = 139,1 kV;

t_1 = 77 µs;

u_1/t_1 = 1,81 kV/µs

u_c = 0,91764 p.u. × 215 kV = 197,3 kV;

t_2 = 231 µs.

b) For the major loop:

di/dt = 0,978 p.u. × 40 kA × √2 × 2πf = 17,38 A/µs;

u_1 = 0,97426 p.u. × 154 kV = 150,0 kV;

t_1 = 77 µs;

u_1/t_1 = 1,95 kV/µs

u_c = 0,96325 p.u. × 215 kV = 207,1 kV;

t_2 = 231 µs.

Normally, for direct tests, when the circuit elements are adjusted to get the rated TRV envelope, and that the required d.c. component at current zero is obtained, the reduction of the di/dt and the TRV amplitude co-ordinates (u_1 and/or u_c) are automatically met without the need to perform the calculation described above.

The calculation described above, shall be used in the following cases:

– for synthetic testing in order to set the circuit components as well as the charging voltage of the capacitor bank;

– for direct testing in order to obtain a tighter tolerance on the TRV applied during tests;

– for direct testing, when the d.c. component at current zero is outside the allowable tolerances in order to obtain a prospective TRV which is within the tolerances given in Annex B and in 6.104.5.

For synthetic testing, two options may be used:

1 Test circuit set to obtain the rated TRV associated with T100s

In that case, it is impossible to meet simultaneously all parameters (di/dt, u_1 and u_c) since these parameters are not varying linearly with the d.c. component at current zero. The charging voltage of the synthetic circuit shall be set to obtain the most onerous test parameter. For tests on the minor loop, the most onerous test parameter is always u_c while the most onerous parameter for tests on the major loop is the di/dt. In case of voltage injection test method, the most onerous test parameter for tests on major loop becomes u_1.

2 Use two different test circuits; one circuit set to obtain the modified TRV associated with tests on the minor loop and a second circuit set to obtain the modified TRV associated with tests on the on the major loop.

In that case all required parameters (di/dt, u_1 and u_c), as calculated above, can be met simultaneously.

The choice of the option is let to the manufacturer since option "1" may overstress the circuit-breaker (for example for tests on major loop, the required correction on di/dt will produce a higher u_c than required).

Annex Q
(informative)

Examples for the application of the asymmetry criteria during asymmetrical test-duty T100a

The examples given in this annex are based on standardised cases and give guidelines how to use the asymmetry criteria in an actual test. Three different cases are given covering the major cases that may occur in test laboratories.

Q.1 Three-phase testing of a circuit-breaker with a rated d.c. time constant of the rated short-circuit breaking current constant longer than the test circuit time constant

Rated voltage of the circuit-breaker:	24	kV
First-pole-to-clear factor:	1,5	
Rated d.c. time constant of the rated short-circuit breaking current:	120	ms
Test circuit time constant:	60	ms
Minimum arcing time:	7,5	ms
Minimum opening time:	32,5	ms
DC component at contact separation:	70,2	%
Minimum clearing time:	40	ms
Frequency:	50	Hz

The time constant of the test circuit differs from the rated d.c. time constant of the rated short-circuit breaking current. The adjustment method chosen in order to reach the required data is the pre-tripping method together with controlled closing.

NOTE Controlled closing means the initiation of the test current at a chosen instant on the applied voltage in order to vary the initial d.c. component of the test current.

Table Q.1 – Example showing the test parameters obtained during a three-phase test when the d.c. time constant of the test circuit is shorter than the rated d.c. time constant of the rated short-circuit current

Parameters	**Requirements** (calculated values, rounded values are given in Tables 17 and 18)		**Test data when using pre-tripping and controlled closing methods**		**Deviation between required values and test values** %
	Major loop with first clearing pole	**Second-pole-to-clear major/minor loop** [a]	**Major loop with first clearing pole**	**Second-pole-to-clear major/minor loop** [a]	
D.C. component at current interruption (%)	62,1		54,2		-13
di/dt at current interruption (%)	80,1		86,9		+8
Peak of the last current loop (p.u.)	1,66	1,34/0,72	1,61	1,32/0,76	-3 –1,5/+5,6 [b]
Duration of the last current loop (ms)	14,5	13,2/7,65	14,4	13,05/7,8	-2 –1/+2 [b]
Δt (ms) [c]		3		3,3	+10
$I \times t$ (p.u. ms)	24,07		23,18		-3,7

[a] Values calculated for a non-effectively earthed neutral system using a network calculation program (see Note).

[b] Second-pole-to-clear.

[c] Δt is the time interval between the first pole-to-clear and the last pole-to clear.

Result: It is possible to fulfil the requirements by using the pre-tripping and controlled closing options. The TRV and di/dt values will be higher than required, but still within the given tolerances. The arcing time for the second clearing pole will be slightly longer than the required one. The test data cover the required values. Tighter tolerances may be achieved by changing test current and/or the TRV amplitude factor. The results are illustrated in Figure Q.1.

As seen in Table Q.1, the ratings of the circuit-breaker given in Q.1 are fully covered by the test data. Attention should be paid to the fact that the percentage of asymmetry at current zero is lower than the rating given by the manufacturer at contact separation. This difference is normal because the value assigned by the manufacturer is based on the specified d.c. time constant of the rated short-circuit breaking current of 120 ms, it does not take into account the arcing time and the dc time constant of the test circuit. The test parameters to be fulfilled are those described for the last current loop as defined in 6.106.6.

NOTE The recommended way (easiest way) to calculate the required three-phase or single-phase waveshape characteristics is by a network calculation program such as EMTP, MATHLAB, etc. The required waveshape characteristics can also be calculated by hand from the fundamental three-phase or single-phase short-circuit current equations.

Q.2 Single phase testing of a circuit-breaker with a rated d.c. time constant of the rated short-circuit breaking current shorter than the test circuit time constant

Rated voltage of the circuit-breaker:	550	kV
First-pole-to-clear factor:	1,3	
Rated d.c. time constant of the rated short-circuit breaking current:	45	ms
Test circuit time constant:	60	ms
Minimum arcing time:	7,5	ms
Minimum opening time:	32,5	ms
DC component at contact separation:	38,9	%
Minimum clearing time:	40	ms
Frequency:	50	Hz

The time constant of the test circuit differs from the rated d.c. time constant of the rated short-circuit breaking current. The adjustment method chosen to reach the required data is the controlled closing method.

Table Q.2 – Example showing the test parameters obtained during a single-phase test when the d.c. time constant of the test circuit is longer than the rated d.c. time constant of the rated short-circuit current

Parameters	Requirements (calculated values, rounded values are given in Tables 15 and 16)		Test data when using controlled closing method		Deviation between required values and test values %
	Major loop with longest possible arcing time	Minor loop with shortest possible arcing time	Major loop	Minor loop	
D.C. component at current interruption (%)	28,9	37,9	28,6	40,2	-1,0 +6,1 [b]
di/dt at current interruption [a] (%)	97,8	89,9	97,3	89,6	+0,5 –0,6 [b]
Peak of the last current loop (p.u.)	1,33	0,59	1,32	0,57	-0,8 –3,4 [b]
Duration of the last current loop (ms)	12,3	7,35	12,15	7,35	-1,2 0 [b]
u_1 [a]	96,5 %	91,9 %	96,0 %	91,3 %	-0,5 –0,7 [b]
u_c [a]	92,3 %	97,9 %	91,9 %	97,1 %	-0,4 –0,9 [b]
$I \times t$ (p.u. ms)	16,36	4,34	16,04	4,19	-2,0 –3,5 [b]

[a] In case of synthetic testing it is possible to control these values independent from the time constant.

[b] Minor loop

Result: All test requirements can be fulfilled by using the controlled closing method. All values obtained are very close to the required values. Tighter tolerances may be achieved by changing the test current amplitude and/or the TRV amplitude factor of the TRV shaping circuit. The values for u_1 and u_c have been derived from the equations of Annex P. The results are illustrated in Figure Q.2.

As seen in Table Q.2, the ratings of the circuit-breaker given in Q.2 are fully covered by the test data. Attention should be paid to the fact that the percentage of asymmetry at current zero is lower than the rating given by the manufacturer at contact separation. This difference is normal because the value assigned by the manufacturer is based on the specified dc time constant of the rated short-circuit breaking current of 45 ms, it does not take into account the arcing time and the d.c. time constant of the test circuit. The test parameters to be fulfilled are those described for the last current loop as defined in 6.106.6.

Q.3 Single-phase testing of a circuit-breaker with a rated d.c. time constant of the rated short-circuit breaking current longer than the test circuit time constant

Rated voltage of the circuit-breaker:	550	kV
First-pole-to-clear factor:	1,3	
Rated d.c. time constant of the rated short-circuit breaking current:	75	ms
Test circuit time constant:	60	ms
Minimum arcing time:	7,5	ms
Minimum opening time:	32,5	ms
DC component at contact separation:	56,7	%
Minimum clearing time:	40	ms
Frequency:	50	Hz

The time constant of the test circuit differs from the rated d.c. time constant of the rated short-circuit breaking current. The adjustment method chosen in order to reach the required data was the controlled closing method.

Table Q.3 – Example showing the test parameters obtained during a single-phase test when the d.c. time constant of the test circuit is shorter than the rated d.c. time constant of the rated short-circuit current

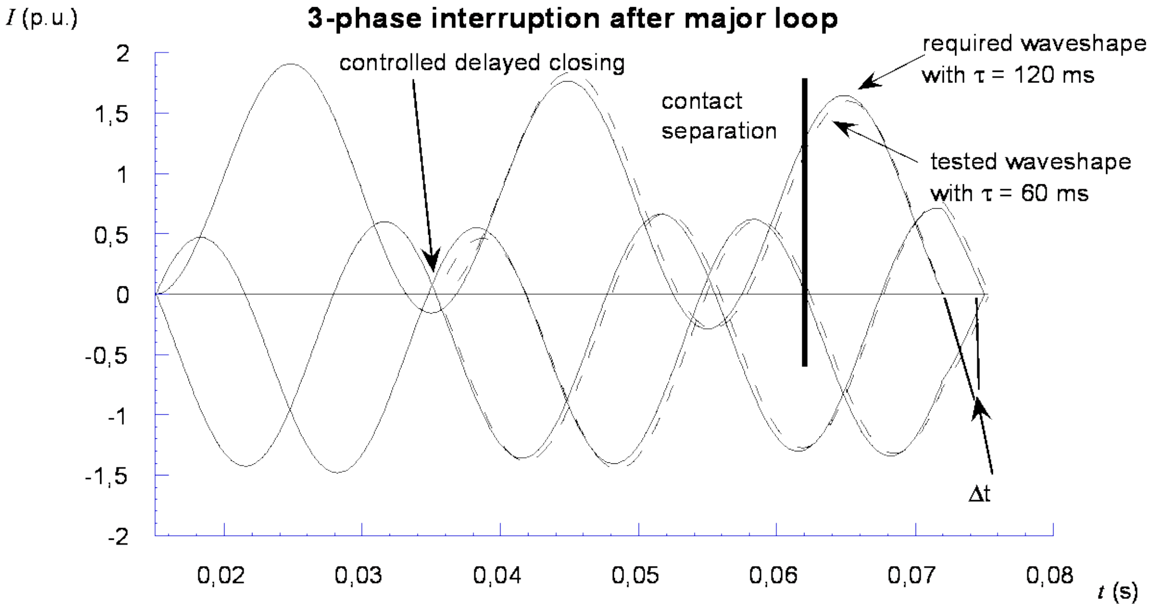
Parameters	Requirements (calculated values, rounded values are given in Tables 17 and 18)		Test data when using controlled closing method		Deviation between required values and test values %
	Major loop with longest possible arcing time	Minor loop with shortest possible arcing time	Major loop	minor loop	
D.C. component at current interruption (%)	47,2	56,4	39,2	48,6	-20 –16,6 [b]
di/dt at current interruption* (%)	90,2	80,2	94,1	84,9	+4,3 +5,8 [b]
Peak of the last current loop (p.u.)	1,51	0,41	1,44	0,44	-4,6 +7,3 [b]
Duration of the last current loop (ms)	13,65	6,15	13,5	6,75	1,1 +9,8 [b]
u_1 [a]	88,1 %	82,8 %	92,3 %	82,1 %	+4,8 +5,2 [b]
u_c [a]	81,3 %	90,9 %	86,6 %	94 %	+6,5 +3,4 [b]
$I \times t$ (p.u. ms)	20,61	2,52	19,44	2,97	-5,7 +17,9 [b]

[a] In case of synthetic testing it is possible to control these values independent from the time constant.

[b] Minor loop

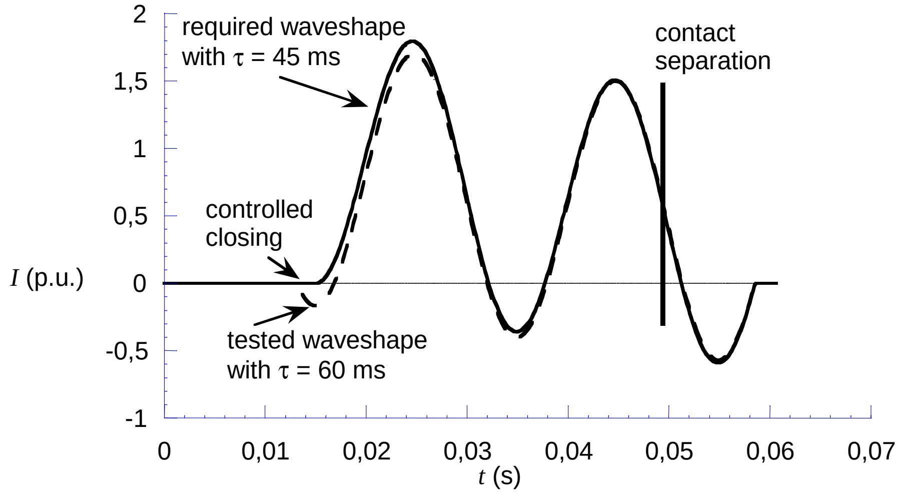
Result: All test requirements can be fulfilled by using the controlled closing method. All values, except the d.c. component, are very close to the required values. In this case additional pre-tripping is necessary to achieve the allowed tolerances ($^{-5}_{+10}$ %). Tighter tolerances may be achieved by changing the test current amplitude and/or the TRV amplitude factor of the TRV shaping circuit. The values for u_1 and u_c have been derived from the equations of Annex P. The results are illustrated in Figure Q.3.

As seen in Table Q.3, the ratings of the circuit-breaker given in Q.3 are fully covered by the test data. Attention should be paid to the fact that the percentage of asymmetry at current zero is lower than the rating given by the manufacturer at contact separation. This difference is normal because the value assigned by the manufacturer is based on the specified d.c. time constant of the rated short-circuit breaking current of 75 ms, it does not take into account the arcing time and the d.c. time constant of the test circuit. The test parameters to be fulfilled are those described for the last current loop as defined in 6.106.6.

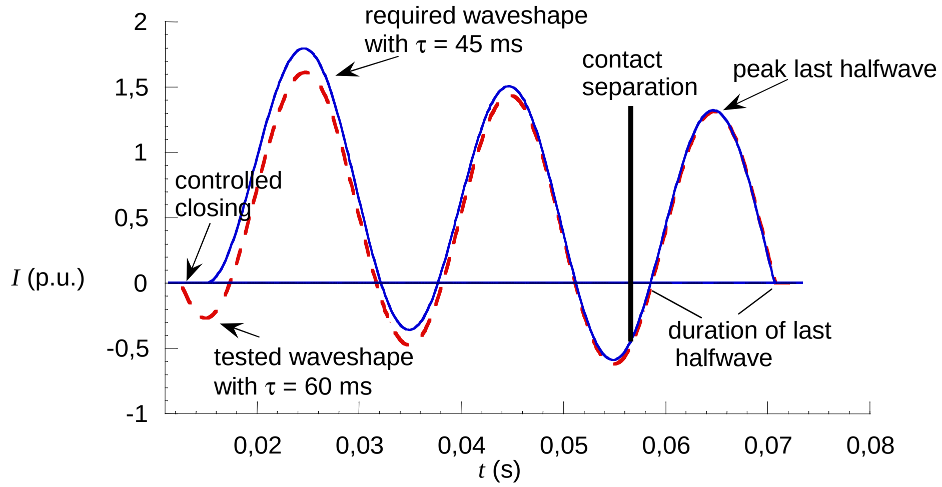


Due to the shorter time constant of the test circuit it is necessary to initiate the short-circuit current later (pre-tripping method, see NOTE 1 of 6.106.6.3) and to choose the closing angle in a way to achieve the required d.c. component at current zero (controlled closing).

Figure Q.1 – Three-phase testing of a circuit-breaker with a rated d.c. time constant of the rated short-circuit breaking current longer than the test circuit time constant

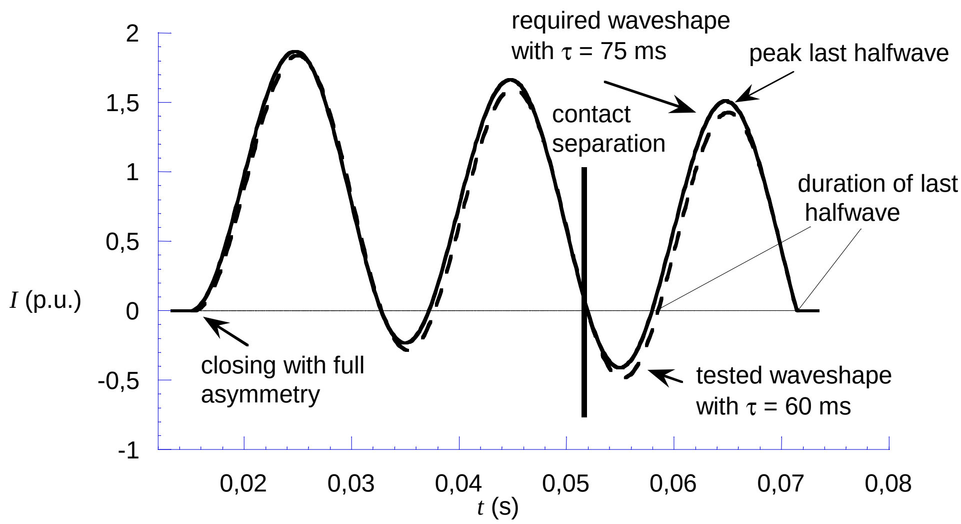


Interruption in a current zero following a minor loop

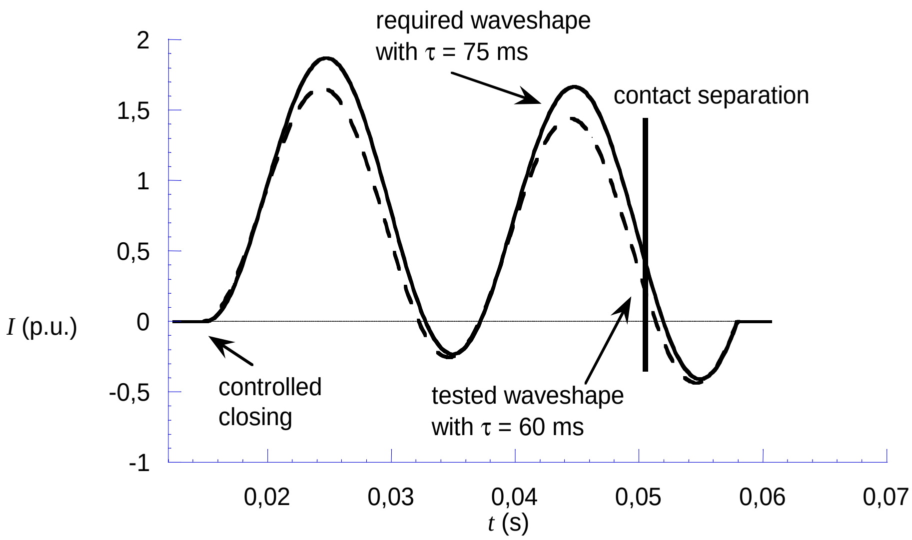


Interruption in a current zero following a major loop

Figure Q.2 – Single phase testing of a circuit-breaker with a rated d.c. time constant of the rated short-circuit breaking current shorter than the test circuit time constant



Interruption in a current zero following a major loop



Interruption in a current zero following a minor loop

Figure Q.3 – Single-phase testing of a circuit-breaker with a rated d.c. time constant of the rated short-circuit breaking current longer than the test circuit time constant

Annex R
(normative)

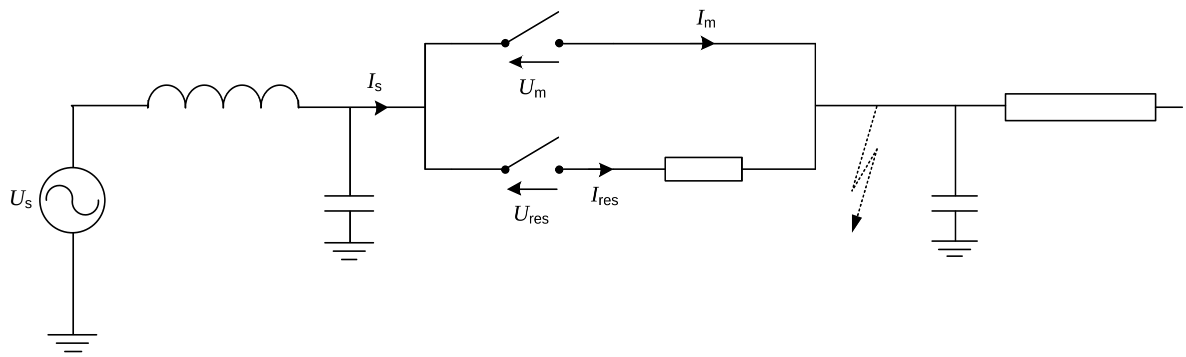
Requirements for circuit-breakers with opening resistors

R.1 General

This annex is applicable to circuit-breakers in which a resistor is inserted in series with the circuit to be interrupted. This resistor is connected in parallel to the main interrupter at least for breaking operations. During the interruption process, the main interrupter transfers the current to the resistor and then the resistor interrupter connected in series to the resistor break the remaining current.

Circuit-breakers with opening resistors shall meet all requirements of the main text of this standard. This annex supplements the main text and defines specific design and testing requirements which take into account the presence of the opening resistors.

A typical system configuration is given in Figure R.1.



Key

I_m	Current through the main interrupter	U_m	Voltage across the main interrupter
I_{res}	Current through the resistor interrupter	U_{res}	Voltage across the resistor interrupter
I_s	Source side current	U_s	Source side voltage

Figure R.1 – Typical system configuration for interruption by a circuit-breaker with opening resistors

R.2 Switching performance to be verified

R.2.1 General

The switching performance of the circuit-breaker with opening resistors is adequately verified if a direct test method is used. In case of limitations in testing facilities, synthetic test methods shall be used, refer to Annex F of IEC 62271-101:2006.

Appropriate timing of mechanical and electrical operation including pre-arcing time and arcing times for both main interrupter and resistor interrupter shall be achieved.

NOTE 1 The number of consecutive operations during tests and in service will be limited by the thermal capacity of the resistor and by its cooling time constant.

Tests should be performed preferably with opening resistor. Alternatively, the tests may also be performed without opening resistor provided that interruption by the main interrupter is not affected by or affecting the resistor interrupter. The resistor is taken into account by applying modified current and voltage parameters as calculated under breaking conditions.

If the tests are performed without the opening resistor, modified TRV values should be calculated on a case-by-case basis, depending on the operating conditions such as short-circuit current and ohmic resistance value of the opening resistor. TRV calculations may be performed using transient calculation programs. Modified TRV values should be specified by the system designer in this case.

Modified TRV parameters may also be obtained by calculating the influence of the resistor on the circuits with lumped elements that generates the uninfluenced TRV.

NOTE 2 It is common that making, breaking and switching tests are performed without the opening resistor and the test parameters are adjusted considering the effects of the resistor on the current to be interrupted and on the following recovery voltage for both main and resistor interrupters.

NOTE 3 When tests are performed without the opening resistor, it is essential that the operation and performances of the main and of the resistor interrupter are not mutually affected during operations e.g. influence of hot gases.

Because of limited available energy using synthetic circuits, synthetic tests shall be done in three parts:

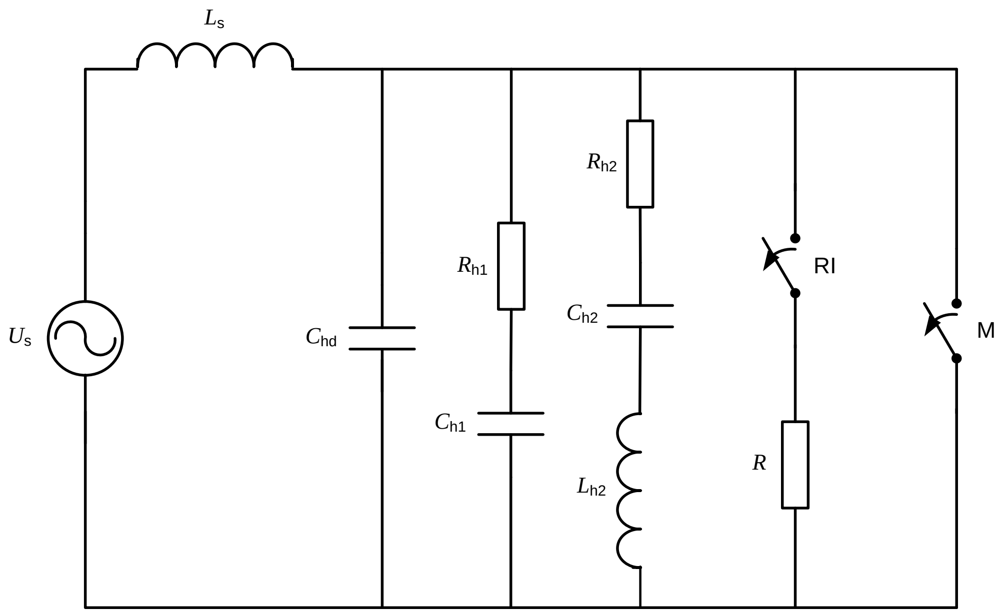
– tests on the main interrupter;
– tests on the resistor interrupter;
– tests on the resistor stack.

R.2.2 Tests of the main interrupter

R.2.2.1 Terminal fault tests and out-of-phase switching tests

These tests are normally performed using synthetic test methods.

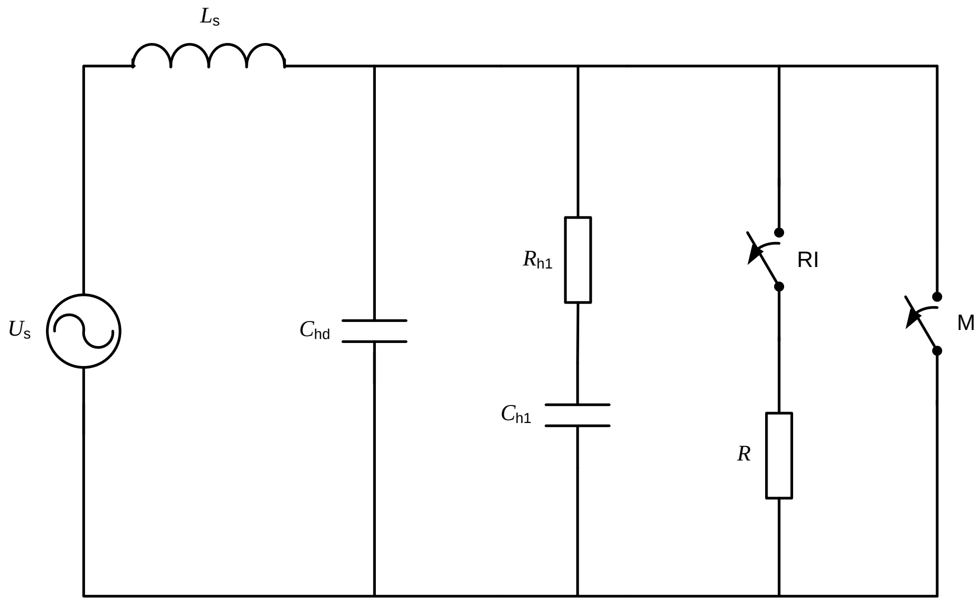
An example of a test circuit for test duties T60 and T100 is given in Figure R.2. An example of a test circuit for test duties T10, T30 and OP2 is given in Figure R.3.



Key

U_s	Source voltage	C_{h2}	TRV capacitance part 2
L_s	Source inductance	L_{h2}	TRV inductance
C_{hd}	Capacitance for time delay	RI	Resistor interrupter
R_{h1}	TRV resistance part 1	R	Resistance
C_{h1}	TRV capacitance part 1	M	Main contacts
R_{h2}	TRV resistance part 2		

Figure R.2 – Test circuit for test duties T60 and T100



Key

U_s	Source voltage	C_{h1}	TRV capacitance
L_s	Source inductance	RI	Resistor interrupter
C_{hd}	Capacitance for time delay	R	Resistance
R_{h1}	TRV resistance	M	Main contacts

Figure R.3 – Test circuit for test duties T10, T30 and OP2

Calculation of parameters:

$U_s = k_{pp} \times U_r/\sqrt{3}$

$L_s = (U_s/I_s)/\omega$

Calculation of the TRV components for T100:

$R_{h1} \approx (\mathrm{d}u/\mathrm{d}t)/(\mathrm{d}i/\mathrm{d}t)$

$C_{h1} \approx 0{,}31 \times L_s/R_{h1}^2$

$R_{h2} \approx 0{,}32 \times R_{h1}$

$C_{h2} \approx 0{,}7 \times C_{h1}$

$L_{h2} \approx 1{,}15 \times L_v$

$C_{hd} \approx t_d/R_{h1}$

Calculation of the TRV components for T60:

$R_{h1} \approx 0{,}9 \times (\mathrm{d}u/\mathrm{d}t)/(\mathrm{d}i/\mathrm{d}t)$

$C_{h1} \approx 0{,}3 \times L_s/R_{h1}^2$

$R_{h2} \approx 0{,}1 \times R_{h1}$

$C_{h2} \approx 1{,}16 \times C_{h1}$

$L_{h2} \approx 1{,}38 \times L_v$

$C_{hd} \approx t_d/R_{h1}$

Calculation of the TRV components for T30:

$R_{h1} \approx (\mathrm{d}u/\mathrm{d}t)/(\mathrm{d}i/\mathrm{d}t)$

$C_{h1} \approx 0{,}42 \times L_s/R_{h1}^2$

$C_{hd} \approx t_d/R_{h1}$

Calculation of the TRV components for T10:

$R_{h1} \approx 1{,}3 \times (\mathrm{d}u/\mathrm{d}t)/ (\mathrm{d}i/\mathrm{d}t)$

$C_{h1} \approx 0{,}42 \times L_s/R_{h1}^2$

$C_{hd} \approx t_d/R_{h1}$

Calculation of the TRV components for OP2:

$R_{h1} \approx 1{,}85 \times (\mathrm{d}u/\mathrm{d}t)/(\mathrm{d}i/\mathrm{d}t)$

$C_{h1} \approx 2{,}55 \times L_s/R_{h1}^2$

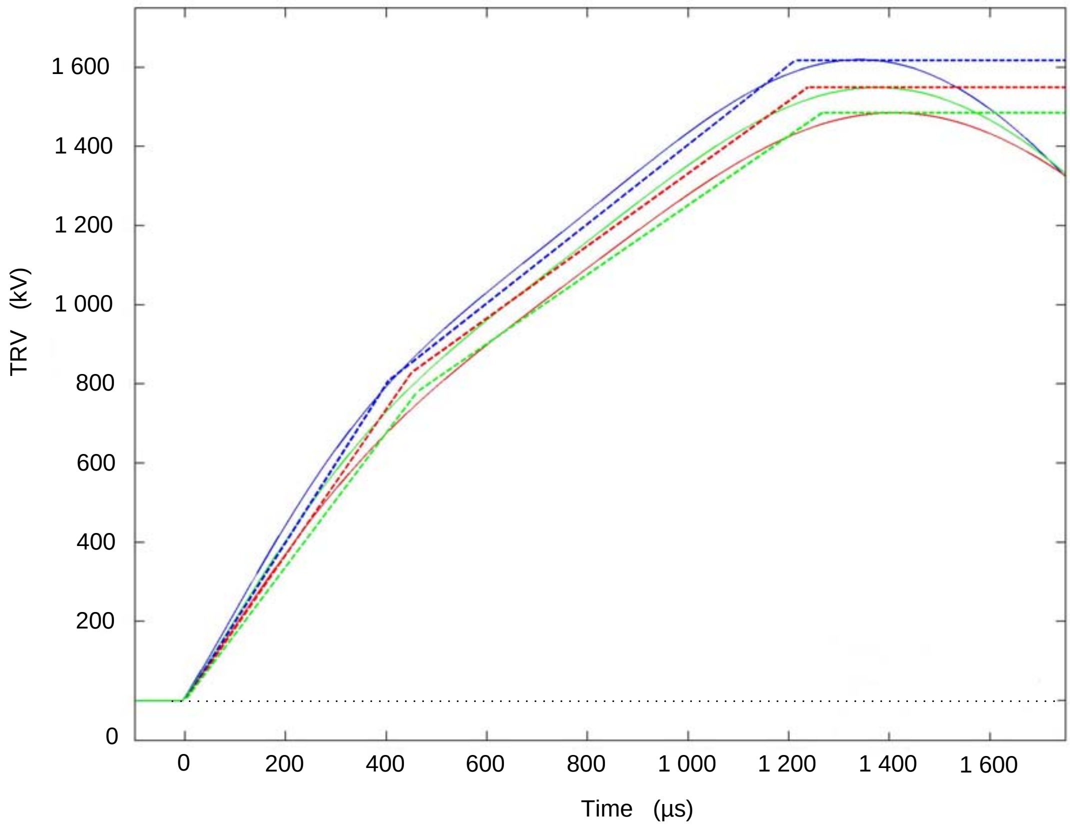
$C_{hd} \approx t_d/R_{h1}$

Table R.1 lists the results of calculations done using the two circuits. The reduction of the TRV_{peak} is listed under u_{cred}.

Table R.1 – Results of the TRV calculation for terminal faults and out-of-phase

U_r (kV)	I_{sc} (kA)	f (Hz)	Duty	R (Ω)	u_1 (kV)	t_1 (µs)	u_c (kV)	t_2 or t_3 (µs)	u_{cred} (%)	Result
1 100	50	50	T100s(b)	∞	808	404	1 617	1 212	0	-
1 100	50	50	T100s(b)	1 000	830	451	1 549	1 238	-4	Underdamped
1 100	50	50	T100s(b)	500	780	461	1 485	1 267	-8	Underdamped
1 100	50	50	T60	∞	808	269	1 617	1 212	0	-
1 100	50	50	T60	1 000	740	320	1 508	1 210	-7	Underdamped
1 100	50	50	T60	500	660	340	1 410	1 237	-13	Underdamped
1 100	50	50	T30	∞	-	-	1 660	332	0	-
1 100	50	50	T30	1 000	-	-	1 163	407	-30	Underdamped
1 100	50	50	T30	500	-	-	1 036	531	-38	Overdamped
1 100	50	50	T10	∞	-	-	1 897	271	0	-
1 100	50	50	T10	1 000	-	-	971	624	-49	Overdamped
1 100	50	50	T10	500	-	-	853	935	-55	Overdamped
1 100	50	50	OP2	∞	-	-	2 245	1 344	0	-
1 100	50	50	OP2	1 000	-	-	1 877	1 435	-16	Underdamped
1 100	50	50	OP2	500	-	-	1 639	1 502	-27	Overdamped

Figures R.4 and R.5 show examples of underdamped TRV and overdamped TRV, respectively.



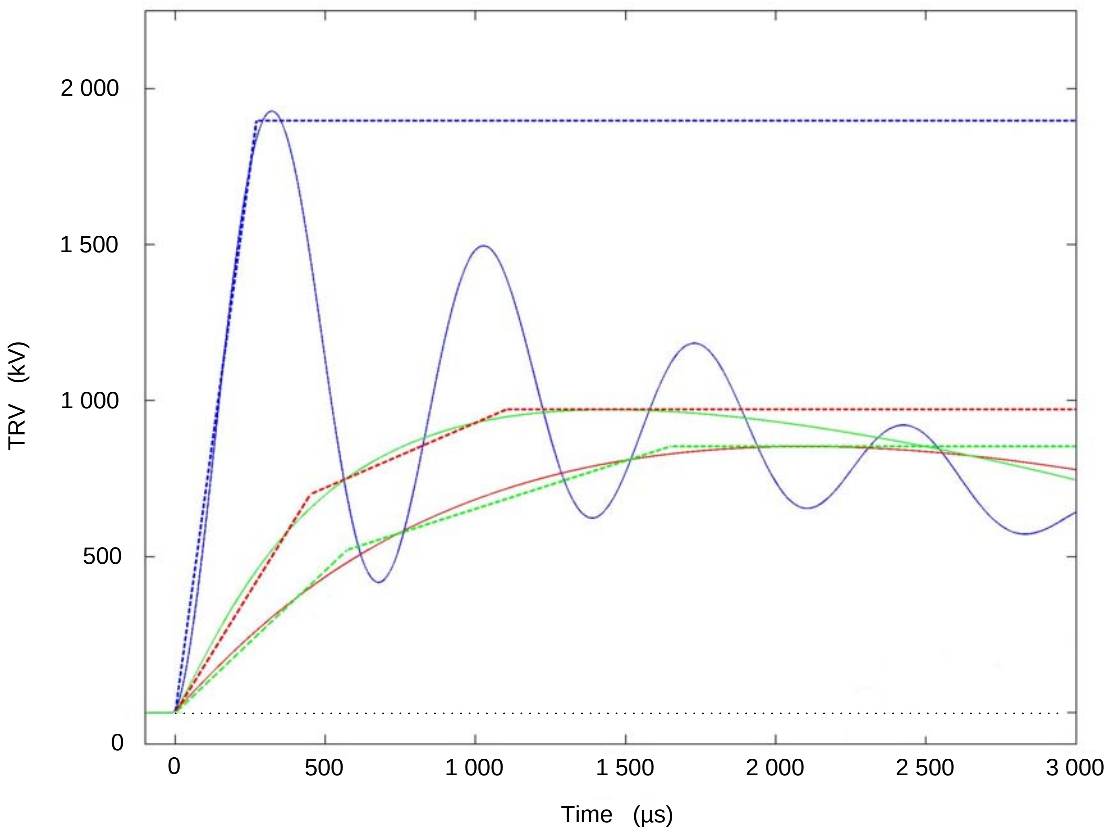
Key

Blue line $R = \infty$

Red line $R = 1\,000\ \Omega$

Green line $R = 500\ \Omega$

Figure R.4 – Example of an underdamped TRV for T100s(b), U_r = 1 100 kV I_{sc} = 50 kA, f_r = 50 Hz



Key

Blue line $R = \infty$

Red line $R = 1\ 000\ \Omega$

Green line $R = 500\ \Omega$

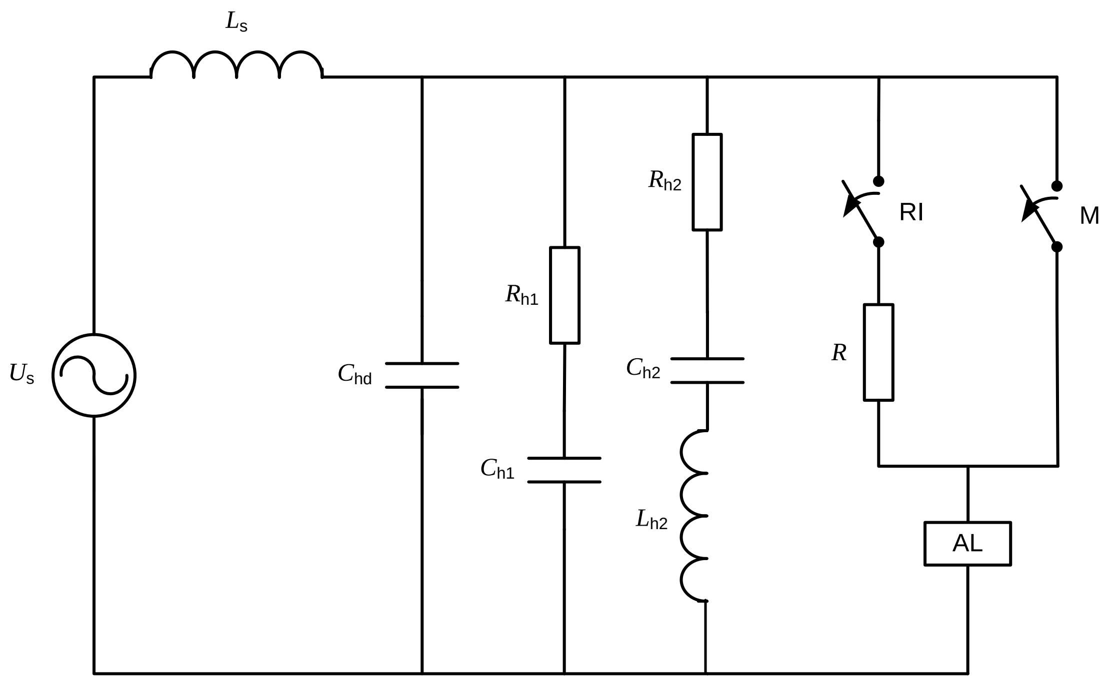
Figure R.5 – Example of an overdamped TRV for T10, U_r = 1 100 kV I_{sc} = 50 kA, f_r = 50 Hz

R.2.2.2 Short-line fault tests

These tests are normally performed using synthetic test methods.

An example of a test circuit for test duty L_{90} is given in Figure R.6.

The equivalent line side TRV shall be calculated by simulation of a line having at least 10 π sections with the specified surge impedance. An example of such a calculation is given in Figure R.7.



Key

U_s	Source voltage	C_{h2}	TRV capacitance part 2
L_s	Source inductance	L_{h2}	TRV inductance
C_{hd}	Capacitance for time delay	RI	Resistor interrupter
R_{h1}	TRV resistance part 1	R	Resistance
C_{h1}	TRV capacitance part 1	M	Main contacts
R_{h2}	TRV resistance part 2	AL	Artificial line

Figure R.6 – Example of a test circuit for short-line fault test duty L_{90}

Table R.2 lists the results of calculations done using the test circuit shown in Figure R.6. The reduction of the TRV$_{peak}$ is listed under u_{cred} column.

Calculation of the TRV components for L_{90}:

– Source side

$R_{h1} \approx (du/dt)/(di/dt)$

$C_{h1} \approx 0{,}31 \times L_s/R_{h1}^2$

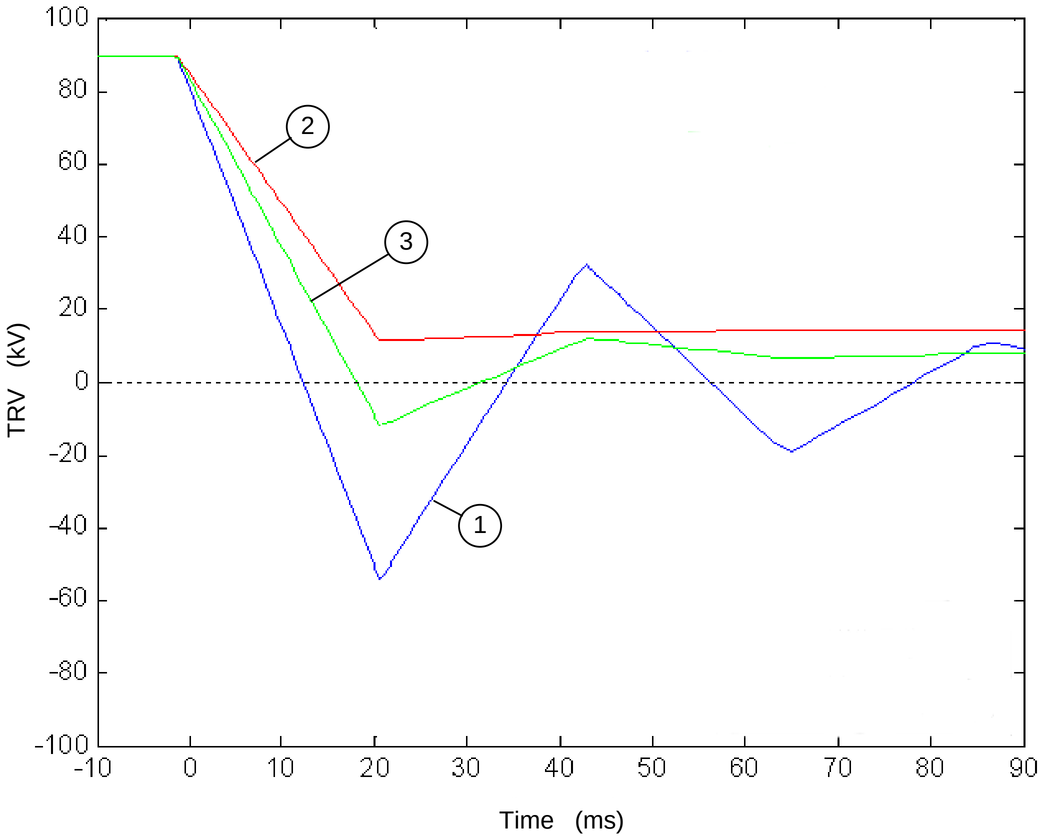
$R_{h2} \approx 0{,}32 \times R_{h1}$

$C_{h2} \approx 0{,}7 \times C_{h1}$

$L_{h2} \approx 1{,}15 \times L_v$

$C_{hd} \approx t_d/R_{h1}$

– Line side by real line simulation as indicated in Figure R.7



Key

1	Blue line:	IEC 62271-100 (R = ∞): k = 1,6 and Z = 330 Ω
2	Red line:	R = 500 Ω: k = 0,87 and Z = 173 Ω
3	Green line:	R = 1 000 Ω: k = 1,13 and Z = 224 Ω

Figure R.7 – Example of real line simulation for short-line fault test-duty L_{90} based on U_r = 1 100 kV, I_{sc} = 50 kA and f_r = 50 Hz

Table R.2 – Results of the TRV calculation for test-duty L_{90}

U_r (kV)	I_{sc} (kA)	f (Hz)	Duty	R (Ω)	u_1 (kV)	t_1 (us)	u_c (kV)	t_2 (us)	u_{cred} (%)	k	Z (Ω)
					Source					**Line**	
1 100	50	50	L90	∞	674	337	1 347	1 011	0	1,6	330
1 100	50	50	L90	1 000	635	350	1 302	1 050	-3	1,13	224
1 100	50	50	L90	500	605	360	1 251	1 076	-7	0,87	173

R.2.2.3 Capacitive current switching tests

Application of circuit-breakers with opening resistors is limited to overhead line switching only.

The recovery voltage waveshape during the insertion period is expressed as follows:

$$U(t) = \frac{\sqrt{2}\ U_s R}{Z}\left[\cos\varphi \times e^{-(1/RC)t} - \cos(\omega t + \varphi)\right] \tag{R.1}$$

where U_s is the source voltage including the capacitive voltage factor k_c expressed in r.m.s. value (kV);

C is the line side capacitance (F);

R is the value of the opening resistor (Ω);

$Z = \sqrt{R^2 + (1/\omega C)^2}$;

$\varphi = \tan^{-1}(1/\omega RC)$.

Line-charging current switching tests on the main interrupter are performed in two parts:

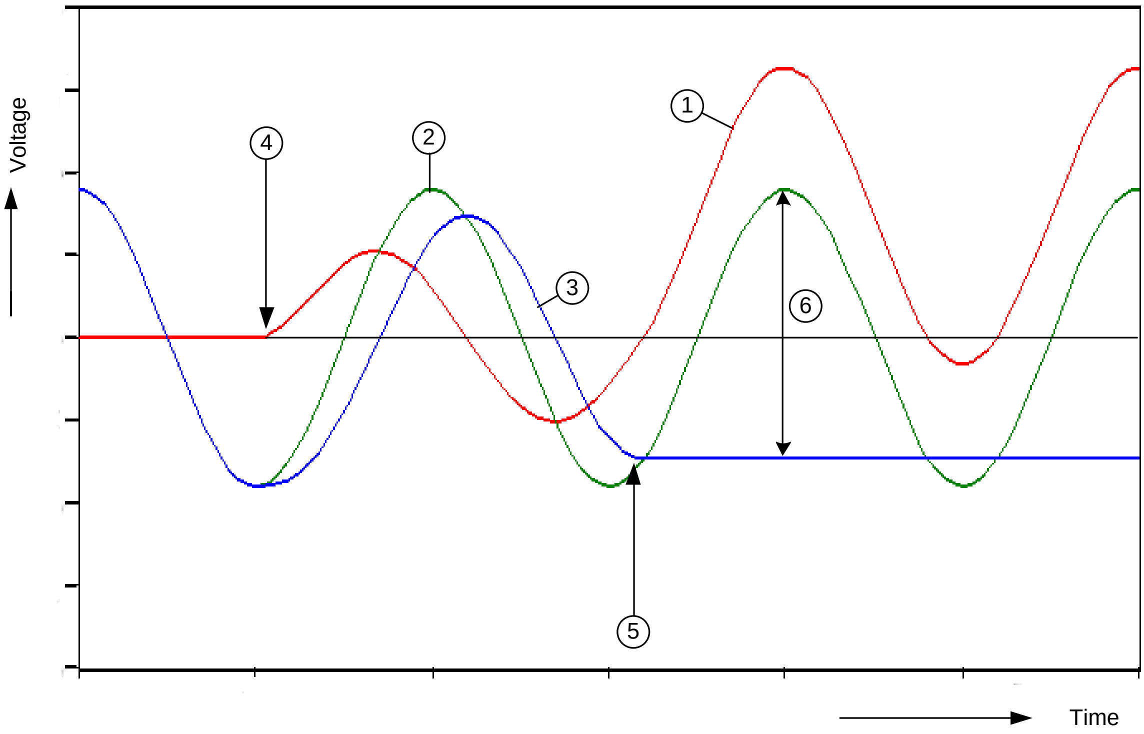
a) Test duty LC2 with a sinusoidal recovery voltage to verify that there is no restrike or reignition during the resistor insertion period. If a reignition(s) occurs the tests are considered to be invalid and direct tests shall be performed to confirm the adequate behaviour of the main interrupter.

b) Test duty LC1 with a modified "1 – cos" waveshape to verify the voltage withstand for the highest recovery voltage peak. The modified "1 - cos" waveshape shall be applied at a time after current zero equal to or less than the rated opening resistor insertion time.

NOTE The recovery voltage waveshape after insertion period is considered to be without reduction. An alternative way is to conduct the tests with a single test to cover both conditions with same number of tests as described in 6.111.9.

The restrike performance of the main interrupter shall be in accordance with 6.111.11.

A typical recovery voltage waveshape for capacitive current switching is shown in Figure R.8.



Key

1	red line	Voltage across the terminals of the main interrupter U_m
2	green line	Source side voltage U_s
3	blue line	Load side voltage U_l
4		Interruption of main interrupter
5		Interruption of resistor interrupter
6		Voltage across the terminals of the resistor interrupter U_{res}

Figure R.8 – Typical recovery voltage waveshape of capacitive current switching on a circuit-breaker equipped with opening resistors

R.2.3 Tests on the resistor interrupter

R.2.3.1 Terminal fault and out-of-phase switching tests

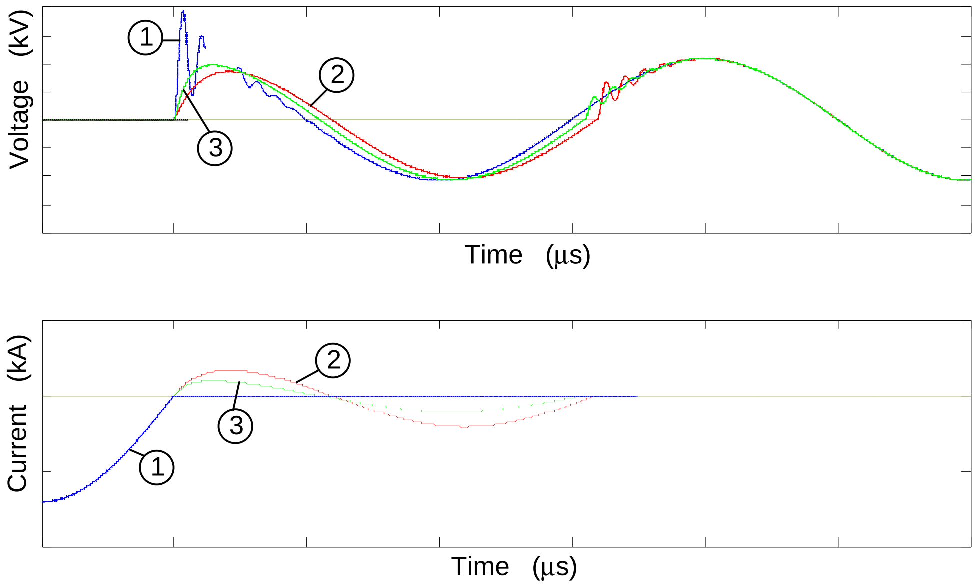
The breaking current value of the resistor interrupter is generally of the order of 1,5 kA or less even in the case of rated voltages above 800 kV, since the ohmic value of the opening resistor is in the range of 500 Ω to 2 000 Ω. The short-circuit current is assumed to be in the range of 40 kA to 63 kA. Then the current flowing in the resistor interrupter is in the order of 1 % to 4 % of the rated short-circuit current. Only in the case of out-of-phase switching the current could be of the order of 3 kA.

As done for the main interrupter, modified TRV values shall be calculated for each specific case.

TRV calculations may be conducted using a suitable electromagnetic transient calculation program.

Modified TRV parameters may also be obtained by calculating the influence of the resistor on the circuits with lumped elements. An example of a test circuit is given in Figure R.3.

A typical recovery voltage waveshape and the current through the resistor interrupter are shown in Figure R.9.



Key

1 Blue line: Main interrupter, $R = \infty$

2 Red line: R = 500 Ω

3 Green line: R = 1 000 Ω

Figure R.9 – Typical recovery voltage waveshape of T10 (based on U_r = 1 100 kV, I_{sc} = 50 kA and f_r = 50 Hz) on the resistor interrupter of a circuit-breaker equipped with opening resistors

Table R.3 lists the results of calculations done using the circuit as given in Figure R.3.

Table R.3 – Results of the TRV calculations for test-duty T10

U_r (kV)	I_{sc} (kA)	f (Hz)	Duty	R (Ω)	U_c (kV)	t_3 (µs)	I_r (kA)
1 100	50	50	T10	∞			
1 100	50	50	T10	1 000	408	295	0,75
1 100	50	50	T10	500	673	287	1,46

When terminal fault test duty T10 is performed, it is not necessary to repeat the other terminal fault test duties on the resistor interrupter (T30, T60, T100a and T100s).

R.2.3.2 Short-line fault (SLF) tests

For the breaking current value of the resistor interrupter refer to R.2.3.1.

As done for the main interrupter, modified TRV values shall be calculated for each specific case.

TRV calculations may be conducted using a suitable electromagnetic transient calculation program.

When terminal fault test duty T10 is performed, no SLF tests are required on the resistor interrupter.

R.2.3.3 Capacitive current switching tests

Two series of line-charging current switching tests are required:

a) LC1: using a "1 – cos" waveshape as defined for circuit-breakers not equipped with opening resistors;

b) LC2: with a modified “1 – cos” waveshape on a circuit-breaker equipped with opening resistors. The following equation gives the modified momentary and peak recovery voltage of the resistor interrupter in a circuit with a resistor R in series:

$$U(t) = \sqrt{2}\, U_S \left[\cos(\theta) - \cos(\omega t + \theta)\right] \qquad \text{(R.2)}$$

where

$$\theta = \tan^{-1}(\omega CR)$$

The restrike performance of the resistor interrupter shall be in accordance with 6.111.11.

R.2.4 Tests of the resistor stack

The resistor stack shall withstand the thermal stresses caused by current flow through the resistor during the insertion time. This is tested by performing one T100s breaking operation, followed by one out-of-phase make-break duty (CO operation). Both energy and current levels shall be obtained in the resistor elements during test. Upon agreement with the manufacturer, it is permissible to shorten the current duration during the test if the current used in an actual test is higher than the current flowing in the resistor during an out-of-phase condition. These tests may be conducted with the actual circuit-breaker contacts or with an auxiliary interrupter.

Tests on thermally pro-rated sections containing at least 20 series connected resistor elements may be performed. The pro-rated sections shall simulate thermal and dielectric conditions that are equal to or more severe than those of the complete module.

Prospective insertion times are considered to be 10 ms for a making operation and 30 ms for a breaking operation.

NOTE Different insertion time(s) may be used if the assigned insertion time(s) are different than mentioned above.

The duration between two rated energy injections shall be stated by the manufacturer.

To verify the thermal capacity of resistor stacks, a second test duty after the prescribed duration of cooling shall be performed. The cooling of the resistor assembly in between the two test-duties shall not be more favourable than service conditions. No significant deterioration shall be observed on the resistor elements after the second test duty.

Measurement of the ohmic values of the resistor assembly and each individual resistor element shall be such that the ohmic values after test, and after a sufficient cooling time, does not vary by more than 2,5 % from the values measured before test.

R.3 Insertion time of the resistor

The resistor shall be inserted in the circuit during breaking operations for a certain period of time. The mechanical insertion time of the resistor shall be longer than the maximum arcing time of the main interrupter and a value around 30 ms is generally sufficient (the arcing time of the resistor interrupter shall also be considered).

Depending on the design, the same resistor and resistor interrupter assembly may be used for closing and opening. The resistor shall be inserted in the circuit during the preinsertion time defined in 3.7.145, taking the pre-arcing of resistor and main interrupters into consideration.

R.4 Current carrying performance

The resistor shall be capable of carrying its current for a specified period without any abnormalities such as arcing, flashover to the adjacent parts, cracks, or any mechanical damages. Their electrical contact surfaces shall not show any signs of arcing such as burning marks.

Insulating material supporting resistor elements, if any, shall withstand the thermal and electrical stresses caused by current through the resistors during breaking and making operations.

R.5 Dielectric performance

See 6.2 of this standard.

R.6 Mechanical performance

The mechanical operation test (see 6.101.2) shall be conducted on a pole or poles of circuit-breaker fully equipped with main and resistor interrupters and resistor assembly.

The resistor elements shall fulfil the conditions stated in 6.101.1.4 during and after a mechanical test. In addition, the resistor elements shall not show any damages such as chips, cracks, etc. The ohmic resistance of resistor assembly measured after tests shall not differ by more than 2,5 % from the value measured before tests.

R.7 Requirements for the specification of opening resistors

For circuit-breakers equipped with opening resistors, the following items shall be specified:

– resistor value;

– insertion time for resistors;

– duty cycle.

  The time between two consecutive duty cycles identified in R.2.3 (one duty cycle being one O under terminal fault and one CO under out-of-phase) shall be stated by the manufacturer.

R.8 Examples of recovery voltage waveshapes

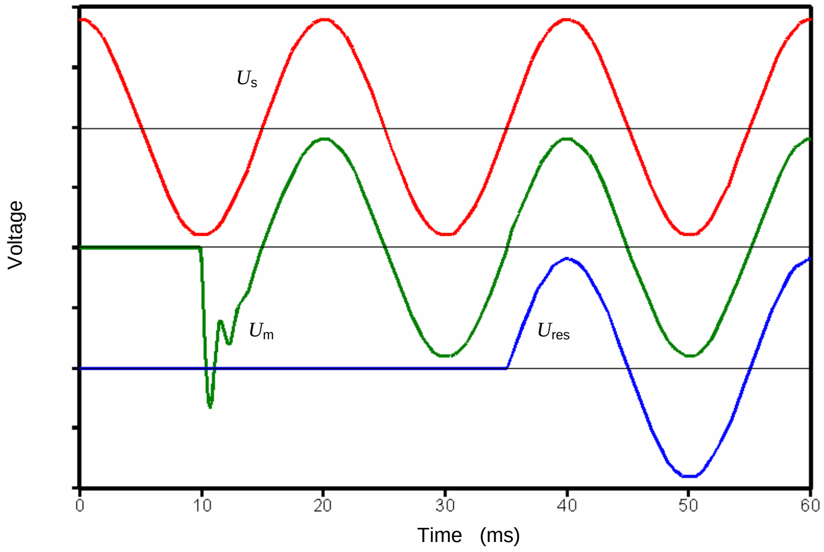
R.8.1 General

Figures R.10 to R.15 give the waveshapes for various breaking and switching conditions. The aim is to show a graphical representation and to illustrate the effects of an opening resistor.

R.8.2 Terminal faults

Typical examples of waveshapes for main and resistor interrupters in case of breaking high short-circuit currents such as T100s are given in Figure R.10 and corresponding currents are shown in Figure R.11.

In case of rather low short-circuit currents such as T30 and T10, the TRV waveshapes are shown in Figure R.12 and current shapes are illustrated in Figure R.13.



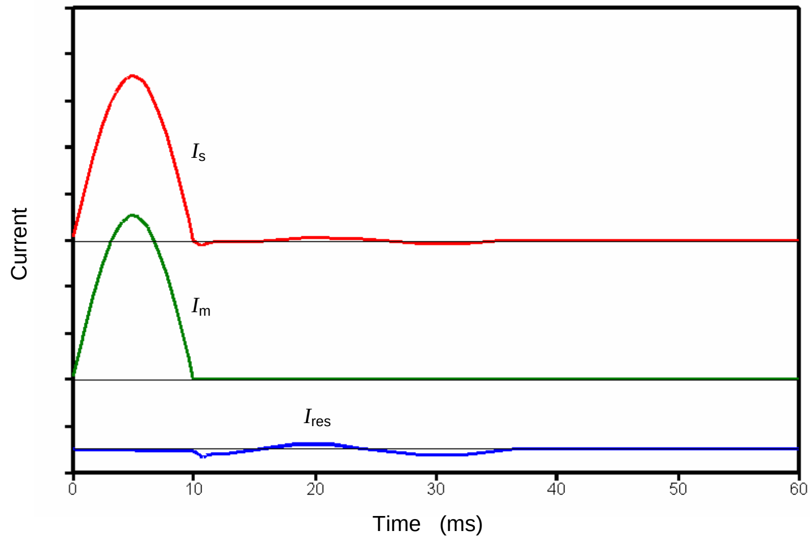
Key

U_m Voltage across main interrupter

U_{res} Voltage across resistor interrupter

U_s Source voltage

Figure R.10 – TRV waveshapes for high short-circuit current breaking operation



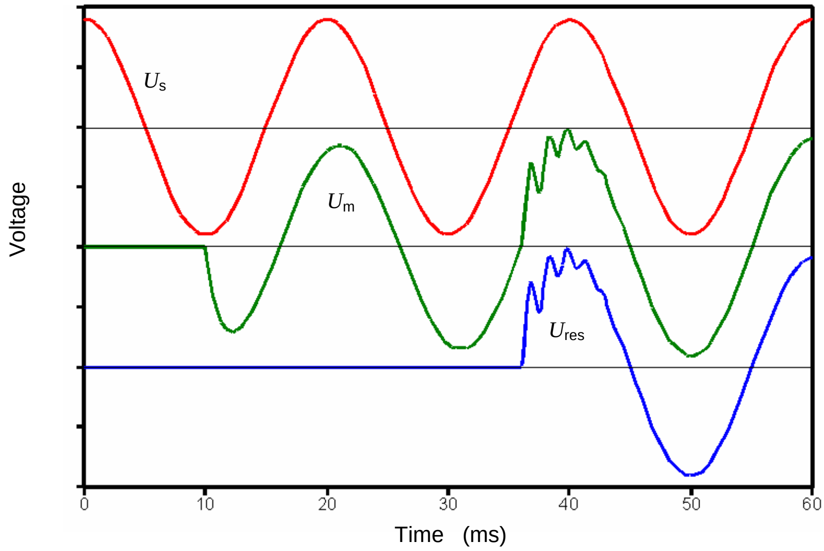
Key

I_m Current through main interrupter

I_{res} Current through resistor interrupter

I_s Source current

Figure R.11 – Currents in case of high short-circuit current breaking operation



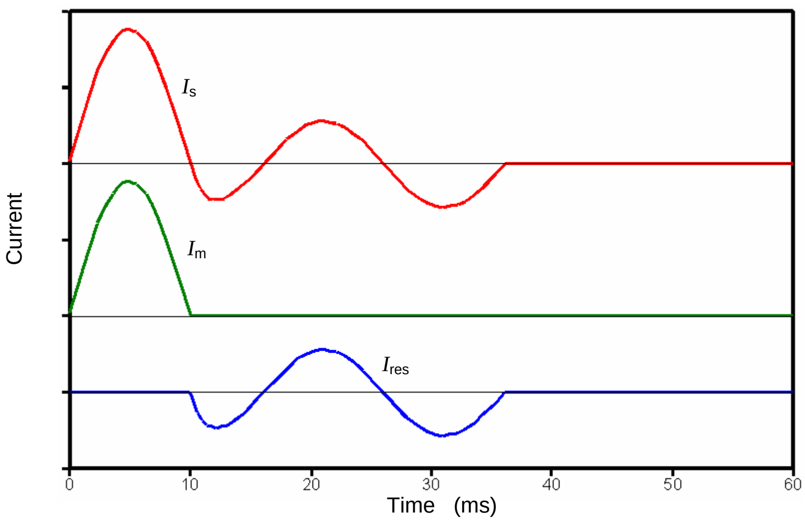
Key

U_m Voltage across main interrupter

U_{res} Voltage across resistor interrupter

U_s Source voltage

Figure R.12 – TRV shapes for low short-circuit current breaking operation



Key

I_m Current through main interrupter

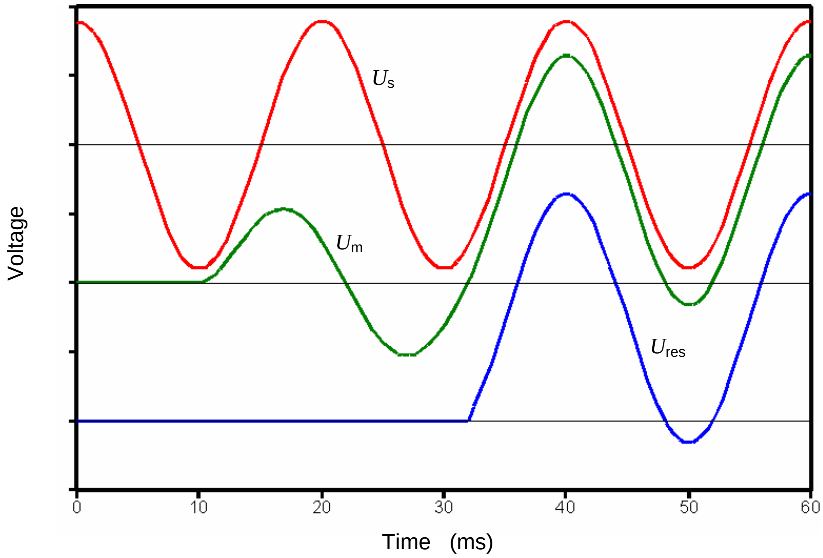
I_{res} Current through resistor interrupter

I_s Source current

Figure R.13 – Currents in case of low short-circuit current breaking operation

R.8.3 Line-charging current breaking

Typical recovery voltage waveshapes for line-charging current breaking operations are given in Figure R.14, current waveshapes are shown in Figure R.15.



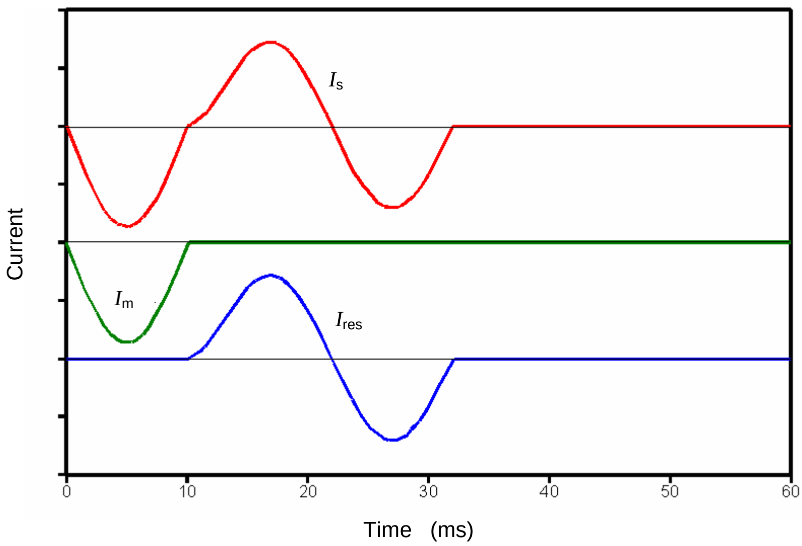
Key

U_m Voltage across main interrupter

U_{res} Voltage across resistor interrupter

U_s Source voltage

Figure R.14 – Voltage waveshapes for line-charging current breaking operation



Key

I_m Current through main interrupter

I_{res} Current through resistor interrupter

I_s Source current

Figure R.15 – Current waveshapes for line-charging current breaking operation

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[8] ~~ANSI C37.06.1:2000, *Guide for high-voltage circuit breakers rated on a symmetrical current basis – designated "definite purpose for fast transient recovery voltage rise times"*~~

(Void)

[9] IEC 62271-200, *High-voltage switchgear and controlgear – Part 200: AC metal enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

[10] IEC 62271-203:2011, *High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages ~~of 72,5 kV and~~ above 52kV*

[11] ANSI/EEE C37.012-1979, *IEEE Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*

[12] IEEE *Transactions on Power Delivery*, Vol. 11, N°2, April 1996, pp 865-870

Other documents providing additional information:

IEC 60044-1, *Instrument transformers – Part 1: Current transformers*

IEC 60044-2, *Instrument transformers – Part 2: Inductive voltage transformers*

IEC 60071-1:2008, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60099-4, *Surge arresters – Part 4: Metal oxide surge arresters without gaps for a.c. systems*

IEC 60186, *Voltage transformers*[3]

IEC/TR 62271-300, *High-voltage switchgear and controlgear – Part 300: Seismic qualification of alternating current circuit-breakers*

ANSI/IEEE C37.013-1997, *Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis*

ANSI/IEEE, C37.09-1999, *Test procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*

IEEE 100, *The authoritative dictionary of IEEE standards terms*, 7th edition, 2000.

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[3] IEC 60186 and its amendments remain in force for capacitor voltage transformers. As far as inductive voltage transformers are concerned, it is replaced by IEC 60044-2.

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

APPAREILLAGE À HAUTE TENSION –

Partie 100: Disjoncteurs à courant alternatif

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Cette version consolidée de la CEI 62271-100 comprend la deuxième édition (2008) [documents 17A/815/FDIS et 17A/822/RVD] et son amendement 1 (2012) [documents 17A/1009/FDIS et 17A/1019/RVD]. Elle porte le numéro d'édition 2.1.

Le contenu technique de cette version consolidée est donc identique à celui de l'édition de base et à son amendement; cette version a été préparée par commodité pour l'utilisateur. Une ligne verticale dans la marge indique où la publication de base a été modifiée par l'amendement 1. Les ajouts et les suppressions apparaissent en rouge, les suppressions sont barrées.

La Norme internationale CEI 62271-100 a été établie par le sous-comité 17A: Appareillage à haute tension, du comité d'études 17 de la CEI: Appareillage.

Les modifications principales par rapport à l'édition précédente sont les suivantes:

– introduction des formes d'onde de TTR harmonisées (CEI et IEEE) pour les tensions assignées supérieures ou égales à 100 kV (amendement 1 de la première édition);
– introduction des réseaux par câbles et réseaux aériens et de leurs TTR associées pour les tensions assignées inférieures à 100 kV (amendement 2 de la première édition)
– inclusion des CEI 61633 et CEI 62271-308.

Cette publication a été rédigée selon les Directives ISO/CEI, Partie 2.

Cette norme doit être lue conjointement avec la CEI 62271-1, première édition, publiée en 2007, à laquelle elle fait référence et qui est applicable sauf spécification particulière dans la présente norme. Pour faciliter le repérage des exigences correspondantes, cette norme utilise une numérotation identique des articles et des paragraphes à celui de la CEI 62271-1. Les modifications de ces articles et de ces paragraphes ont des références identiques ; les paragraphes supplémentaires, qui n'ont pas d'équivalent dans la CEI 62271-1, sont numérotés à partir de 101.

Une liste de toutes les parties de la série CEI 62271, présentées sous le titre général *Appareillage à haute tension* peut être consultée sur le site web de la CEI.

Le comité a décidé que le contenu de la publication de base et de ses amendements ne sera pas modifié avant la date de stabilité indiquée sur le site web de la CEI sous "http://webstore.iec.ch" dans les données relatives à la publication recherchée. A cette date, la publication sera

- reconduite,
- supprimée,
- remplacée par une édition révisée, ou
- amendée.

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APPAREILLAGE À HAUTE TENSION –

Partie 100: Disjoncteurs à courant alternatif

1 Généralités

1.1 Domaine d'application

La présente partie de la CEI 62271 est applicable aux disjoncteurs à courant alternatif conçus pour l'installation à l'intérieur ou à l'extérieur, et pour fonctionner à des fréquences de 50 Hz à 60 Hz, sur des réseaux de tensions supérieures à 1 000 V.

Elle est applicable uniquement aux disjoncteurs tripolaires pour réseaux triphasés et aux disjoncteurs unipolaires pour réseaux monophasés. Les disjoncteurs bipolaires pour réseaux monophasés et les applications à des fréquences inférieures à 50 Hz font l'objet d'un accord entre le constructeur et l'utilisateur.

Cette norme est également applicable aux dispositifs de commande des disjoncteurs et à leurs équipements auxiliaires. Toutefois, cette norme ne couvre pas les disjoncteurs comportant un mécanisme de fermeture à manœuvre dépendante manuelle, car pour ces appareils on ne peut spécifier un pouvoir de fermeture assigné en court-circuit, et une telle manœuvre dépendante manuelle peut être inacceptable pour des raisons de sécurité.

Les règles relatives aux disjoncteurs ayant une non-simultanéité intentionnelle entre les pôles sont à l'étude; les disjoncteurs pourvus d'un dispositif de refermeture automatique unipolaire sont compris dans le domaine d'application de la présente norme.

NOTE 1 Les disjoncteurs ayant une non-simultanéité intentionnelle entre les pôles peuvent, dans certains cas, être soumis aux essais conformément à la présente norme. Par exemple, ceux de type à pôles décalés mécaniquement peuvent être soumis aux essais conformément à cette norme, à l'aide d'essais directs triphasés. Pour les essais synthétiques, la détermination des essais les plus appropriés, en particulier en ce qui concerne le courant d'essai, la tension de rétablissement et la tension transitoire de rétablissement, est soumise à un accord entre le constructeur et l'utilisateur.

Cette norme ne couvre pas les disjoncteurs destinés aux unités motrices des équipements de traction électrique; ceux-ci sont couverts par la CEI 60077 [1][1].

Les disjoncteurs d'alternateur installés entre l'alternateur et le transformateur élévateur ne sont pas du domaine d'application de cette norme.

L'établissement et la coupure de charge inductive sont couverts par la CEI 62271-110.

La présente norme ne traite pas des disjoncteurs à déclenchement autonome ~~avec~~ ayant des dispositifs de déclenchement ~~mécaniques ou des dispositifs~~ qui ne peuvent pas être rendus inopérants pendant l'essai.

Les disjoncteurs installés comme des interrupteurs de contournement en parallèle avec des condensateurs série de ligne et leurs dispositifs de protection n'entrent pas dans le domaine d'application de la présente norme. Ils sont couverts par la CEI 62271-109 [2] et la CEI 60143-2 [3].

[1] Les chiffres entre crochets se réfèrent à la bibliographie.

NOTE 2 Il convient que les essais en vue de vérifier le fonctionnement des disjoncteurs dans des conditions anormales fassent l'objet d'un accord entre le constructeur et l'utilisateur. De telles conditions anormales sont, par exemple, celles qui se produisent lorsque la tension est supérieure à la tension assignée du disjoncteur, ce qui peut arriver lors de la perte soudaine de la charge sur des lignes longues ou sur des câbles.

1.2 Références normatives

Les documents de référence suivants sont indispensables pour l'application du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

CEI 60050(151):2001, *Vocabulaire Electrotechnique International – Chapitre 151: Dispositifs électriques et magnétiques*

CEI 60050(441):1984, *Vocabulaire Electrotechnique International – Chapitre 441: Appareillage et fusibles*

CEI 60050(601):1985, *Vocabulaire Electrotechnique International – Chapitre 601: Production, transport et distribution d'énergie électrique – Généralités*

CEI 60050(604):1987, *Vocabulaire Electrotechnique international – Chapitre 604: Production, transport et distribution d'énergie électrique – Exploitation*

CEI 60059, *Caractéristiques des courants normaux de la CEI*

CEI 60060-1:1989, *Technique des essais à haute tension – Partie 1:Définitions et prescriptions générales relative aux essais*

CEI 60071-2, *Coordination de l'isolement – Partie 2: Guide d'application*

CEI 60137: *Traversées isolées pour tensions alternatives supérieures à 1000 V*

CEI 60255-3:1989, *Relais électriques – Troisième partie: Relais de mesure et dispositifs de protection à une seule grandeur d'alimentation d'entrée à temps dépendant ou indépendant*

CEI 60296, *Spécification des huiles minérales isolantes neuves pour transformateurs et appareillage de connexion*

CEI 60376: *Spécifications et réception de l'hexafluorure de soufre neuf*

CEI 60480, *Guide relatif au contrôle de l'hexafluorure de soufre (SF_6) prélevé sur le matériel électrique*

CEI 60529, *Degrés de protection procurés par les enveloppes (code IP)*

CEI/TS 61634, *Appareillage à haute tension – Utilisation et manipulation du gaz hexafluorure de soufre (SF_6) dans l'appareillage à haute tension*

CEI 62271-1:2007, *Appareillage à haute tension – Partie 1: Spécifications communes*

CEI 62271-101:2006, *Appareillage à haute tension – Partie 101: Essais synthétiques*

CEI 62271-102:2001, *Appareillage à haute tension – Partie 102: Sectionneurs à courant alternatif et sectionneurs de terre*

CEI 62271-110, *Appareillage à haute tension – Partie 110: Courants inductifs*

2 Conditions normales et spéciales de service

L'Article 2 de la CEI 62271-1 est applicable.

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions de la CEI 60050-441 et de la CEI 62271-1 s'appliquent. Pour faciliter l'utilisation de cette norme, certains d'entre eux ont été rappelés ci-après.

Des termes et définitions supplémentaires sont classés conformément à ceux de la CEI 60050-441.

3.1 Termes généraux

3.1.101
appareillage
[VEI 441-11-01]

3.1.102
appareillage pour l'intérieur
[VEI 441-11-04]

3.1.103
appareillage pour l'extérieur
[VEI 441-11-05]

3.1.104
courant de court-circuit
[VEI 441-11-07]

3.1.105
réseau à neutre isolé
[VEI 601-02-24]

3.1.106
réseau à neutre directement à la terre
[VEI 601-02-25]

3.1.107
réseau à neutre non directement à la terre
[VEI 601-02-26]

3.1.108
réseau compensé par bobine d'extinction
[VEI 601-02-27]

3.1.109
facteur de défaut à la terre
rapport, en un emplacement défini d'un réseau triphasé (qui sera généralement le point d'installation d'un matériel) et pour un schéma d'exploitation donné de ce réseau, entre la tension efficace la plus élevée à la fréquence du réseau entre une phase saine et la terre pendant un défaut à la terre (affectant une phase quelconque ou plusieurs en un point quelconque du réseau) et la tension efficace entre phase et terre à la fréquence du réseau qui serait obtenue à l'emplacement considéré en l'absence du défaut

NOTE 1 Ce facteur est un simple rapport numérique (en général supérieur à l'unité) qui caractérise, d'une façon générale, les conditions de mise à la terre d'un réseau, vues de l'emplacement considéré, indépendamment de la valeur particulière réelle de la tension de fonctionnement à cet emplacement. Le «facteur de défaut à la terre» est le produit par $\sqrt{3}$ du «facteur de mise à terre» utilisé antérieurement.

NOTE 2 Les facteurs de défaut à la terre sont calculables à partir des impédances de phase du réseau dans les systèmes de composantes symétriques, telles qu'elles sont vues de l'emplacement considéré, en adoptant pour toute machine tournante les réactances subtransitoires.

NOTE 3 Si pour tous les schémas d'exploitation possibles, la réactance homopolaire est inférieure au triple de la réactance directe et que la résistance homopolaire ne dépasse pas la réactance directe, le facteur de défaut à la terre ne dépassera pas 1,4.

3.1.110
température de l'air ambiant
[VEI 441-11-13]

3.1.111
échauffement (d'une partie d'un disjoncteur)
écart entre la température de la partie et la température de l'air ambiant

3.1.112
batterie unique de condensateurs
batterie de condensateurs dans laquelle le courant d'appel est limité par l'inductance du réseau d'alimentation et la capacité de la batterie de condensateurs mise sous tension, en l'absence d'autres condensateurs connectés en parallèle au réseau suffisamment près pour accroître de manière appréciable le courant d'appel

3.1.113
batterie de condensateurs à gradins
batterie de condensateurs comportant plusieurs condensateurs ou ensembles de condensateurs reliés chacun au réseau d'alimentation par un appareil de connexion, le courant d'appel d'un élément étant augmenté de façon appréciable par les condensateurs déjà reliés à la source d'alimentation

3.1.114
surtension (dans un réseau)
toute tension entre un conducteur de phase et la terre ou entre deux conducteurs de phase dont la ou les valeurs de crête dépassent la valeur de crête correspondant à la tension la plus élevée pour le matériel

[VEI 604-03-09, modifié]

3.1.115
conditions de la discordance de phases
conditions de circuit anormales de perte ou de manque de synchronisme entre deux éléments d'un réseau électrique situés de chaque côté d'un disjoncteur aux bornes duquel, à l'instant de son fonctionnement, l'angle de déphasage entre les vecteurs tournants, représentant les tensions de part et d'autre de l'appareil, dépasse la valeur normale

NOTE Les exigences de la présente norme couvrent la grande majorité des applications des disjoncteurs destinés à effectuer des manœuvres lors de discordances de phases. Les angles de discordance de phases correspondant aux tensions de rétablissement à fréquence industrielle spécifiées sont donnés en 6.110.3. Pour des conditions de service extrêmes, voir 8.103.3.

3.1.116
en discordance de phases (utilisé comme qualificatif d'une grandeur caractéristique)
terme qualificatif indiquant que la grandeur caractéristique concerne le fonctionnement du disjoncteur dans les conditions de la discordance de phases

3.1.117
essai sur élément
essai effectué sur un élément de fermeture ou de coupure ou sur un groupe d'éléments au courant établi, ou au courant coupé, spécifié pour l'essai du pôle complet d'un disjoncteur et à la fraction appropriée de la tension appliquée, ou de la tension de rétablissement, spécifiée pour l'essai du pôle complet du disjoncteur

3.1.118
alternance; demi-onde
partie de l'onde de courant comprise entre deux passages successifs par zéro du courant

NOTE On distingue une grande alternance (ou demi-onde) d'une petite, selon que l'intervalle de temps entre deux passages par zéro successifs est plus grand ou plus petit que la demi-période de la composante périodique du courant.

3.1.119
défaut proche en ligne (SLF)
court-circuit sur une ligne aérienne à une distance courte, mais appréciable, des bornes du disjoncteur

NOTE En général, cette distance n'est pas supérieure à quelques kilomètres. C'est pour cette raison que ce type de défaut était antérieurement appelé «défaut kilométrique».

3.1.120
facteur de puissance (d'un circuit)
rapport de la résistance à l'impédance à fréquence industrielle d'un circuit équivalent supposé réduit à une inductance et une résistance en série

3.1.121
isolation externe
distances dans l'air atmosphérique et sur les surfaces des isolations solides d'un matériel en contact avec l'atmosphère qui sont soumises aux contraintes diélectriques et à l'influence des conditions atmosphériques ou d'autres agents externes tels que la pollution, l'humidité, les animaux nuisibles, etc.
[VEI 604-03-02, modifiée]

3.1.122
isolation interne
éléments internes solides, liquides ou gazeux de l'isolation d'un matériel qui sont à l'abri de l'influence des conditions atmosphériques ou d'autres agents externes
[VEI 604-03-03]

3.1.123
isolation auto-régénératrice
isolation qui retrouve intégralement ses propriétés isolantes après une décharge disruptive
[VEI 604-03-04]

3.1.124
isolation non auto-régénératrice
isolation qui perd ses propriétés isolantes, ou ne les retrouve pas intégralement après une décharge disruptive
[VEI 604-03-05]

3.1.125
décharge disruptive
phénomène associé à la défaillance de l'isolation sous l'action d'une contrainte électrique et dans lequel la décharge court-circuite complètement l'isolation en essai, réduisant la tension entre électrodes à une valeur nulle ou presque nulle

NOTE 1 Ce terme s'applique aux claquages diélectriques dans des milieux solides, liquides ou gazeux et à leurs combinaisons.

NOTE 2 Une décharge disruptive dans un diélectrique solide occasionne la perte définitive de la rigidité diélectrique (isolation non auto-régénératrice); dans les diélectriques liquides ou gazeux, cette perte peut n'être que momentanée (isolation auto-régénératrice).

NOTE 3 Le terme «amorçage» est utilisé lorsque la décharge disruptive se produit dans un diélectrique gazeux ou liquide; le terme «contournement» est utilisé lorsque la décharge disruptive longe la surface d'un diélectrique solide entouré d'un gaz ou d'un liquide isolant; le terme «perforation» est utilisé lorsque la décharge disruptive se produit à travers un diélectrique solide.

3.1.126
décharge disruptive non maintenue (NSDD)
décharge disruptive associée à une coupure de courant, qui n'entraîne pas de rétablissement du courant à fréquence industrielle ou, dans le cas d'une coupure de courant capacitif, qui n'entraîne pas de courant dans le circuit de charge principal

NOTE Les oscillations suivant les décharges disruptives non maintenues sont associées à la capacité et à l'inductance parasites à proximité du disjoncteur ou provenant du disjoncteur lui-même. Les décharges disruptives non maintenues peuvent également impliquer la capacité parasite par rapport à la terre des appareils situés à proximité.

3.1.127
performance en réamorçage
probabilité présumée de réamorçage pendant des coupures de courant capacitif, comme démontré par les essais spécifiés

NOTE Des probabilités chiffrées spécifiques ne peuvent pas être valables durant toute la durée de service du disjoncteur.

3.1.128
réseau à neutre effectivement à la terre
réseau qui est mis à la terre par une impédance suffisamment faible de sorte que pour toutes les conditions de réseaux le rapport entre les composantes homopolaire et directe~~ et homopolaire~~ de la réactance (X_0/X_1) est positif et inférieur à 3, et le rapport entre la composante homopolaire de la résistance et la composante directe de la réactance (R_0/X_1) est positif et inférieur à 1. Normalement, ces réseaux sont avec neutre effectivement à la terre ou mis à la terre à travers une faible impédance

NOTE Pour estimer correctement les conditions de mise à la terre, il ne faut pas seulement prendre en compte les conditions physiques de mise à la terre autour du lieu considéré mais aussi celles de tout le réseau.

3.1.129
réseau à neutre non effectivement à la terre
réseau autre que ceux avec neutre effectivement à la terre, ne remplissant pas les conditions données en 3.1.128. Normalement ces systèmes sont à neutre isolé, à neutre non effectivement à la terre ou compensés par bobine d'extinction

NOTE Pour estimer correctement les conditions de mise à la terre, il ne faut pas seulement prendre en compte les conditions physiques de mise à la terre autour du lieu considéré mais aussi celles de tout le réseau.

3.1.130
réallumage (d'un appareil mécanique de connexion à courant alternatif)
[VEI 441-17-45]

3.1.131
réamorçage (d'un appareil mécanique de connexion à courant alternatif)
[VEI 441-17-46]

3.1.132
réseau par câbles
réseau dans lequel la TTR pendant la coupure de défaut aux bornes à 100 % du pouvoir de coupure n'excède pas l'enveloppe à deux paramètres dérivée à partir du Tableau 1 de cette norme

NOTE 1 Cette définition est limitée aux réseaux de tensions supérieures à 1 kV et inférieures à 100 kV.

NOTE 2 Les disjoncteurs d'intérieur avec liaisons par câbles sont généralement dans des réseaux par câbles.

NOTE 3 Les disjoncteurs d'extérieur reliés à des lignes aériennes par câbles sont considérés comme étant dans un réseau par câbles si la longueur totale de câbles (ou longueur équivalente lorsque des condensateurs sont présents) connectés sur le côté alimentation aux disjoncteurs est au moins égale à 100 m. Cependant, si dans un cas particulier, avec une longueur de câble inférieure à 100 m, il peut être montré que la TTR obtenue est couverte par l'enveloppe définie à partir du Tableau 1, alors ce réseau est considéré comme étant un réseau par câbles.

NOTE 4 La capacitance des réseaux par câbles du côté alimentation des disjoncteurs provient des câbles et/ou de condensateurs et/ou de jeux de barres isolés.

3.1.133
réseau aérien
réseau dans lequel la TTR pendant la coupure de défauts aux bornes à 100 % du pouvoir de coupure est définie par l'enveloppe à deux paramètres dérivée à partir du Tableau 2 de cette norme et excède l'enveloppe à deux paramètres dérivée à partir du Tableau 1 de cette norme

NOTE 1 Cette définition est limitée aux réseaux de tensions supérieures ou égales à 15 kV et inférieures à 100 kV.

NOTE 2 Dans les réseaux aériens, aucun câble n'est connecté du côté alimentation du disjoncteur, à l'exception possible d'une longueur de câble inférieure à 100 m entre le disjoncteur et le ou les transformateurs d'alimentation.

NOTE 3 Les réseaux avec des lignes aériennes directement connectées au jeu de barre (sans connexion par câbles) sont des exemples typiques de réseaux aériens.

3.2 Ensembles

Pas de définition particulière.

3.3 Parties d'ensembles

Pas de définition particulière.

3.4 Appareils de connexion

3.4.101
appareil de connexion
[VEI 441-14-01]

3.4.102
appareil mécanique de connexion
[VEI 441-14-02]

3.4.103
disjoncteur
[VEI 441-14-20]

3.4.104
disjoncteur à cuve mise à la terre
[VEI 441-14-25]

3.4.105
disjoncteur à cuve sous tension
[VEI 441-14-26]

3.4.106
disjoncteur à air
[VEI 441-14-27]

3.4.107
disjoncteur à huile
[VEI 441-14-28]

3.4.108
disjoncteur à vide
[VEI 441-14-29]

3.4.109
disjoncteur à gaz comprimé
[VEI 441-14-30]

3.4.110
disjoncteur à hexafluorure de soufre
disjoncteur à SF_6
[VEI 441-14-31]

3.4.111
disjoncteur à air comprimé
[VEI 441-14-32]

3.4.112
disjoncteur classe E1
disjoncteur avec une endurance électrique de base n'entrant pas dans la catégorie de la classe E2 définie en 3.4.113

3.4.113
disjoncteur classe E2
disjoncteur conçu en sorte que, pendant sa durée de service escomptée, les pièces du circuit principal mises en jeu pour l'établissement et la coupure ne nécessitent aucune maintenance et que les autres pièces ne nécessitent qu'une maintenance minimale (disjoncteur à endurance électrique accrue)

NOTE 1 La maintenance minimale peut comprendre la lubrification, le complément de gaz et le nettoyage des surfaces externes, s'il y a lieu.

NOTE 2 Cette définition ne s'applique qu'aux disjoncteurs dont la tension assignée est supérieure à 1 kV et inférieure ou égale à 52 kV. Voir l'Annexe G pour la raison d'être de l'introduction de la classe E2.

3.4.114
disjoncteur classe C1
disjoncteur à faible probabilité de réamorçage pendant la coupure de courant capacitif comme démontré par les essais de type spécifiés

3.4.115
disjoncteur classe C2
disjoncteur à très faible probabilité de réamorçage pendant la coupure de courant capacitif comme démontré par les essais de type spécifiés

3.4.116
disjoncteur classe M1
~~disjoncteur à endurance mécanique ordinaire (essais de type à 2 000 manœuvres mécaniques) n'entrant pas dans la catégorie classe M2 définie en 3.4.117~~

disjoncteur avec une endurance mécanique normale comme démontré par des essais de type spécifiques

3.4.117
disjoncteur classe M2
disjoncteur à manœuvres fréquentes pour des exigences de service spéciales et conçu pour ne nécessiter qu'une maintenance limitée comme démontré par des essais de type spécifiques ~~(disjoncteur à endurance mécanique accrue, ayant réalisés 10 000 manœuvres en essais de type mécanique)~~

~~NOTE Il est possible de combiner les différentes classes de disjoncteurs: endurance électrique, endurance mécanique et probabilité de réamorçage pendant les coupures de courant capacitif. Pour la désignation de ces disjoncteurs, l'indication des différentes classes se fait suivant l'ordre alphabétique, par exemple C1-M2.~~

3.4.118
disjoncteur à déclenchement autonome
disjoncteur déclenché par un courant dans le circuit principal, sans l'aide d'aucune source d'énergie auxiliaire

3.4.119
disjoncteur de classe S1
disjoncteur prévu pour une utilisation dans un réseau par câbles

3.4.120
disjoncteur de classe S2
disjoncteur prévu pour une utilisation dans un réseau aérien ou dans un réseau par câbles avec une connection directe (sans câble) à des lignes aériennes

3.5 Partie de disjoncteur

3.5.101
pôle
[VEI 441-15-01]

3.5.102
circuit principal
[VEI 441-15-02]

3.5.103
circuit de commande
[VEI 441-15-03]

3.5.104
circuit auxiliaire
[VEI 441-15-04]

3.5.105
contact
[VEI 441-15-05]

3.5.106
pièce de contact
[VEI 441-15-06]

3.5.107
contact principal
[VEI 441-15-07]

3.5.108
contact d'arc
[VEI 441-15-08]

3.5.109
contact de commande
[VEI 441-15-09]

3.5.110
contact auxiliaire
[VEI 441-15-10]

3.5.111
interrupteur auxiliaire
[VEI 441-15-11]

3.5.112
contact à fermeture;
contact «a»
[VEI 441-15-12]

3.5.113
contact à ouverture;
contact «b»
[VEI 441-15-13]

3.5.114
contact glissant
[VEI 441-15-15]

3.5.115
contact roulant
[VEI 441-15-16]

3.5.116
déclencheur
[VEI 441-15-17]

3.5.117
chambre d'extinction
[VEI 441-15-18]

3.5.118
indicateur de position
[VEI 441-15-25]

3.5.119
raccord (par boulons ou dispositifs équivalents)
ensemble de pièces conductrices destinées à assurer la continuité permanente d'un circuit lorsqu'elles sont assemblées au moyen de vis, de boulons ou de dispositifs équivalents

3.5.120
borne
composant destiné à raccorder un disjoncteur à des conducteurs extérieurs
[VEI 151-01-03]

3.5.121
élément de fermeture (ou de coupure)
partie d'un disjoncteur qui en elle-même joue le rôle d'un disjoncteur et qui, en série avec un ou plusieurs éléments de fermeture ou de coupure identiques manœuvrés simultanément, forme le disjoncteur complet

NOTE 1 Les éléments de fermeture et les éléments de coupure peuvent être distincts ou non. Chaque élément peut comporter plusieurs contacts.

NOTE 2 Les moyens utilisés pour la répartition de la tension entre les éléments peuvent différer d'un élément à l'autre.

3.5.122
module (d'un pôle de disjoncteur)
ensemble comprenant généralement des éléments de fermeture ou de coupure, des supports isolants et des parties mécaniques. Il est assemblé électriquement et mécaniquement à d'autres ensembles identiques pour constituer un pôle de disjoncteur

3.5.123
enveloppe
partie d'appareillage procurant un degré de protection spécifié (se reporter à la CEI 60529) du matériel contre les influences externes et un degré de protection spécifié contre l'approche des parties actives ou le contact avec elles ou contre le contact avec des pièces en mouvement

[VEI 441-13-01, modifiée]

3.5.124
mécanisme d'entraînement

partie du disjoncteur qui actionne les contacts du circuit principal

3.5.125
chaîne cinématique de puissance

dispositif de liaison mécanique entre le mécanisme d'entraînement, mécanisme d'entraînement inclus, et les contacts mobiles, contacts mobiles inclus

NOTE Voir aussi A.3.5.111 de la CEI 62271-102.

3.5.126
mécanisme d'entraînement alternatif

un mécanisme d'entraînement alternatif est obtenu lorsqu'une modification de la chaîne cinématique de puissance du mécanisme d'entraînement d'origine, ou lorsque l'utilisation d'un mécanisme d'entraînement complètement différent, conduit aux mêmes caractéristiques mécaniques

NOTE 1 Les caractéristiques mécaniques sont définies en 6.101.1.1. L'utilisation des caractéristiques mécaniques et les exigences qui y sont liées sont décrites à l'Annexe N.

NOTE 2 Un mécanisme d'entraînement alternatif peut utiliser un principe d'entraînement différent de celui du mécanisme d'entraînement d'origine (par exemple, le mécanisme alternatif peut être à ressort et celui d'origine peut être hydraulique).

NOTE 3 Une modification de l'équipement secondaire ne constitue pas un mécanisme d'entraînement alternatif. Cependant, il faut vérifier que les modifications de la durée d'ouverture / durée minimale de coupure n'entraînent pas des exigences différentes pour la séquence d'essais T100a (voir 6.102.10).

3.6 Fonctionnement

3.6.101
manœuvre
[VEI 441-16-01]

3.6.102
cycle de manœuvres
[VEI 441-16-02]

3.6.103
séquence de manœuvres
[VEI 441-16-03]

3.6.104
manœuvre de fermeture
[VEI 441-16-08]

3.6.105
manœuvre d'ouverture
[VEI 441-16-09]

3.6.106
refermeture automatique
[VEI 441-16-10]

3.6.107
manœuvre positive d'ouverture
[VEI 441-16-11]

3.6.108
manœuvre effectuée positivement
[VEI 441-16-12]

3.6.109
manœuvre dépendante manuelle
[VEI 441-16-13]

3.6.110
manœuvre dépendante à source d'énergie extérieure
[VEI 441-16-14]

3.6.111
manœuvre à accumulation d'énergie
manœuvre de connexion effectuée au moyen d'énergie emmagasinée dans le mécanisme lui-même avant la manœuvre et suffisante pour achever la séquence de manœuvres spécifiée dans des conditions prédéterminées

3.6.112
manœuvre indépendante manuelle
[VEI 441-16-16]

3.6.113
position de fermeture
[VEI 441-16-22]

3.6.114
position d'ouverture
[VEI 441-16-23]

3.6.115
disjoncteur instantané
[VEI 441-16-32]

3.6.116
déclencheur sous courant de fermeture
déclencheur qui permet l'ouverture d'un disjoncteur sans retard intentionnel, pendant une manœuvre de fermeture, si le courant établi dépasse une valeur prédéterminée, et qui est rendu inopérant lorsque le disjoncteur est en position de fermeture

3.6.117
déclencheur à maximum de courant
[VEI 441-16-33]

3.6.118
déclencheur à maximum de courant à retard indépendant
[VEI 441-16-34]

3.6.119
déclencheur à maximum de courant à temps inverse
[VEI 441-16-35]

3.6.120
déclencheur direct à maximum de courant
[VEI 441-16-36]

3.6.121
déclencheur indirect à maximum de courant
[VEI 441-16-37]

3.6.122
déclencheur shunt
[VEI 441-16-41]

3.6.123
déclencheur à minimum de tension
[VEI 441-16-42]

3.6.124
déclencheur à retour de courant (en courant continu seulement)
[VEI 441-16-43]

3.6.125
courant de fonctionnement (d'un déclencheur à maximum de courant)
[VEI 441-16-45]

3.6.126
courant de réglage (d'un déclencheur à maximum de courant)
[VEI 441-16-46]

3.6.127
domaine du courant de réglage (d'un déclencheur à maximum de courant)
[VEI 441-16-47]

3.6.128
dispositif d'antipompage
[VEI 441-16-48]

3.6.129
dispositif de verrouillage
[VEI 441-16-49]

3.6.130
disjoncteur à fermeture empêchée
[VEI 441-14-23]

3.7 Grandeurs caractéristiques

Les Figures 1 à 7 illustrent quelques définitions de ce paragraphe.

Les durées, voir les définitions 3.7.133 à 3.7.147, sont exprimées en millisecondes ou en cycles. Lorsqu'elles sont exprimées en cycles, il convient que la fréquence industrielle soit donnée entre guillemets. Dans le cas de disjoncteurs qui possèdent des résistances d'ouverture ou de fermeture, on distingue, si applicable, les durées associées aux contacts qui coupent ou établissent le plein courant et celles qui sont associées aux contacts qui coupent ou établissent le courant limité par les résistances d'ouverture ou de fermeture.

Quand cela n'est pas spécifié, la durée est associée aux contacts qui coupent ou établissent le plein courant.

3.7.101
valeur assignée
valeur d'une grandeur fixée, généralement par le constructeur, pour un fonctionnement spécifié d'un composant, d'un dispositif ou d'un matériel

[VEI 151-04-03]

3.7.102
courant présumé (d'un circuit et relatif à un appareil de connexion ou à un fusible)
[VEI 441-17-01]

3.7.103
valeur de crête du courant présumé
valeur de crête de la première grande alternance du courant présumé pendant la période transitoire qui suit son établissement

NOTE La définition implique que le courant est établi par un disjoncteur idéal, c'est-à-dire dont l'impédance entre les bornes de chaque pôle passe instantanément et simultanément de l'infini à zéro. La valeur de crête peut être différente d'un pôle à l'autre; elle dépend de l'instant d'établissement du courant par rapport à l'onde de tension entre les bornes de chaque pôle.

3.7.104
valeur de crête du courant
valeur de crête de la première grande alternance du courant pendant la période transitoire qui suit son établissement

3.7.105
courant symétrique présumé (d'un circuit à courant alternatif)
[VEI 441-17-03]

3.7.106
valeur maximale de crête du courant présumé (d'un circuit à courant alternatif)
[VEI 441-17-04]

3.7.107
courant établi présumé (d'un appareil de connexion)
[VEI 441-17-05]

3.7.108
(valeur de crête du) courant établi
valeur de crête de la première grande alternance du courant dans un pôle de disjoncteur pendant la période transitoire qui suit l'instant d'établissement au cours d'une manœuvre de fermeture

NOTE 1 La valeur de crête peut être différente d'un pôle à l'autre et d'une manœuvre à l'autre car elle dépend de l'instant d'établissement du courant par rapport à l'onde de la tension appliquée.

NOTE 2 Lorsqu'une seule valeur (de crête) du courant établi est indiquée pour un circuit polyphasé, il s'agit de la plus grande valeur dans n'importe quelle phase, sauf indication contraire.

3.7.109
courant coupé présumé (d'un appareil de connexion)
courant présumé évalué à l'instant de l'amorçage de l'arc au cours d'une coupure

3.7.110
courant coupé
[VEI 441-17-07]

3.7.111
courant (coupé) critique
valeur de courant coupé, inférieure au pouvoir de coupure assigné en court-circuit, pour laquelle la durée d'arc est la plus longue, et notablement plus longue qu'au pouvoir de coupure assigné en court-circuit. Ce sera considéré comme tel si la durée d'arc la plus courte obtenue dans une des séquences T10, T30 ou T60, est plus longue d'au moins une demi-période que la durée d'arc minimale des séquences adjacentes

3.7.112
pouvoir de coupure
[VEI 441-17-08]

3.7.113
pouvoir de coupure de lignes à vide
pouvoir de coupure dans les conditions de mise hors tension d'une ligne aérienne fonctionnant à vide

3.7.114
pouvoir de coupure de câbles à vide
pouvoir de coupure dans les conditions de mise hors tension de câbles isolés fonctionnant à vide

3.7.115
pouvoir de coupure de batterie de condensateurs
pouvoir de coupure dans les conditions de mise hors tension d'une batterie de condensateurs

3.7.116
pouvoir de fermeture
[VEI 441-17-09]

3.7.117
pouvoir de fermeture de courant d'appel de condensateurs
pouvoir de fermeture dans les conditions de mise sous tension d'une batterie de condensateurs

3.7.118
pouvoir de fermeture ou de coupure en discordance de phases
pouvoir de fermeture ou de coupure dans les conditions de perte ou de manque de synchronisme entre les éléments d'un réseau électrique situés de chaque côté du disjoncteur lors de sa mise hors ou sous tension

3.7.119
pouvoir de fermeture en court-circuit
[VEI 441-17-10]

3.7.120
pouvoir de coupure en court-circuit
[VEI 441-17-11]

3.7.121
courant de courte durée admissible
[VEI 441-17-17]

3.7.122
valeur de crête du courant admissible
[VEI 441-17-18]

3.7.123
tension appliquée
[VEI 441-17-24]

3.7.124
tension de rétablissement
[VEI 441-17-25]

3.7.125
tension transitoire de rétablissement (TTR)
[VEI 441-17-26]

3.7.126
tension transitoire de rétablissement présumée (d'un circuit)
[VEI 441-17-29]

3.7.127
tension de rétablissement à fréquence industrielle
[VEI 441-17-27]

3.7.128
tension d'arc (valeur de crête)
[VEI 441-17-30]

3.7.129
distance d'isolement
[VEI 441-17-31]

3.7.130
distance d'isolement entre pôles
[VEI 441-17-32]

3.7.131
distance d'isolement à la terre
[VEI 441-17-33]

3.7.132
distance d'isolement entre contacts
[VEI 441-17-34]

3.7.133
durée d'ouverture
durée d'ouverture d'un disjoncteur définie suivant le mode de déclenchement, comme indiqué ci-dessous, tout dispositif de retard faisant partie intégrante du disjoncteur et étant, s'il y a lieu, réglé pour la durée minimale:

a) pour un disjoncteur déclenché par une source quelconque d'énergie auxiliaire, la durée d'ouverture est l'intervalle de temps entre l'instant de mise sous tension du déclencheur, le disjoncteur étant en position de fermeture, et l'instant de séparation des contacts d'arc sur tous les pôles;

b) pour un disjoncteur à déclenchement autonome, la durée d'ouverture est l'intervalle de temps entre l'instant où, le disjoncteur étant en position de fermeture, le courant du circuit principal atteint la valeur de fonctionnement du déclencheur à maximum de courant et l'instant de la séparation des contacts d'arc sur tous les pôles.

NOTE 1 La durée d'ouverture peut varier notablement avec le courant coupé.

NOTE 2 Pour les disjoncteurs à plusieurs éléments de coupure par pôle, l'instant de la séparation des contacts d'arc sur tous les pôles est pris à l'instant de la séparation des contacts du premier élément du dernier pôle.

NOTE 3 La durée d'ouverture comprend la durée de fonctionnement de tout équipement auxiliaire nécessaire au fonctionnement du disjoncteur et qui fait partie intégrante de ce dernier.

3.7.134
durée d'arc (d'un appareil de connexion multipolaire)
intervalle de temps entre l'instant du premier début d'un arc et l'instant de l'extinction finale de l'arc sur tous les pôles

[VEI 441-17-38]

3.7.135
durée de coupure
intervalle de temps entre le début de la durée d’ouverture d’un appareil mécanique de connexion et la fin de la durée d’arc

[VEI 441-17-39, modifié]

3.7.136
durée de fermeture
intervalle de temps entre la mise sous tension du circuit de fermeture, le disjoncteur étant en position d'ouverture, et l'instant où les contacts se touchent dans tous les pôles

NOTE La durée de fermeture comprend la durée de fonctionnement de tout équipement auxiliaire nécessaire au fonctionnement du disjoncteur et qui fait partie intégrante de ce dernier.

3.7.137
durée d'établissement
intervalle de temps entre la mise sous tension du circuit de fermeture, le disjoncteur étant en position d'ouverture, et l'instant où le courant commence à circuler dans le premier pôle
[VEI 441-17-40, modifié]

NOTE 1 La durée d'établissement comprend la durée de fonctionnement de tout équipement auxiliaire nécessaire au fonctionnement du disjoncteur et qui fait partie intégrante de ce dernier.

NOTE 2 La durée d'établissement, par exemple, peut varier à cause de la variation de la durée de préarc.

3.7.138
durée de préarc
lors d’une manœuvre de fermeture, intervalle de temps entre le début de la circulation de courant dans le premier pôle et l'instant où les contacts se touchent dans tous les pôles pour les conditions triphasées, et l’instant où les contacts du pôle qui voit l’arc se touchent pour les conditions monophasées

NOTE 1 La durée de préarc dépend de la valeur instantanée de la tension appliquée pendant une manœuvre de fermeture spécifique et peut donc varier considérablement.

NOTE 2 Il convient de ne pas confondre cette définition de la durée de préarc d'un disjoncteur avec la définition de la durée de préarc d'un fusible.

3.7.139
durée d'ouverture-fermeture (d'une refermeture automatique)
intervalle de temps entre l'instant de séparation des contacts d'arc dans tous les pôles lors d'une manœuvre d'ouverture, et l'instant où les contacts se touchent dans le premier pôle pendant le cycle de refermeture qui lui fait suite

3.7.140
durée de coupure-établissement (d'une refermeture automatique)
intervalle de temps entre l'extinction finale de l'arc dans tous les pôles lors de la manœuvre d'ouverture, et le premier rétablissement du courant dans l'un quelconque des pôles lors de la manœuvre de fermeture qui lui fait suite

NOTE La durée de coupure-établissement, par exemple, peut varier à cause de la variation de la durée de préarc.

3.7.141
durée de refermeture
intervalle de temps entre le début de la durée d'ouverture et l'instant où les contacts se touchent dans tous les pôles pendant le cycle de refermeture qui lui fait suite

3.7.142
durée de réétablissement (d'une refermeture)
intervalle de temps entre le début de la durée d'ouverture et le premier rétablissement du courant dans l'un quelconque des pôles lors de la manœuvre de fermeture qui lui fait suite

NOTE La durée de réétablissement, par exemple, peut varier à cause de la variation de la durée de préarc.

3.7.143
durée de fermeture-ouverture
intervalle de temps entre l'instant où les contacts se touchent dans le premier pôle pendant une manœuvre de fermeture, et l'instant où les contacts d'arc se sont séparés dans tous les pôles pendant la manœuvre d'ouverture qui lui fait suite
[VEI 441-17-42, modifié]

NOTE Sauf indication contraire, on suppose que le déclencheur d'ouverture incorporé dans le disjoncteur est mis sous tension au moment où les contacts se touchent dans le premier pôle pendant la fermeture. Cela représente la durée de fermeture-ouverture minimale.

3.7.144
durée d'établissement-coupure
intervalle de temps entre le début de la circulation du courant dans le premier pôle pendant une manœuvre de fermeture et la fin de la durée d'arc pendant la manœuvre d'ouverture qui lui fait suite

NOTE 1 Sauf indication contraire, on suppose que le déclencheur d'ouverture du disjoncteur est mis sous tension une demi-période après que le courant commence à circuler dans le circuit principal pendant l'établissement. Il convient de noter que l'utilisation de relais ayant des temps de fonctionnement plus courts peut soumettre le disjoncteur à des courants asymétriques plus élevés que ceux prévus en 6.106.5.

NOTE 2 La durée d'établissement-coupure peut varier à cause de la variation de la durée de préarc.

3.7.145
durée de pré-insertion (d'une résistance de fermeture)
~~intervalle de temps durant la manœuvre de fermeture d'un pôle quelconque, entre l'instant où les contacts se touchent dans l'élément de fermeture des résistances, et l'instant où les contacts se touchent dans l'élément de coupure principal~~

~~NOTE Pour les disjoncteurs ayant des éléments de coupure en série, le temps de pré-insertion est l'intervalle de temps entre l'instant où les derniers contacts se touchent dans un quelconque élément de fermeture des résistances, et l'instant où se touchent les derniers contacts dans un quelconque élément de coupure principal.~~

intervalle de temps durant une manœuvre de fermeture, entre l'instant où les contacts se touchent dans les éléments de résistance d'un pôle quelconque, et l'instant où les contacts se touchent dans l'élément de coupure de ce pôle

3.7.146
durée minimale de l'ordre d'ouverture
durée minimale pendant laquelle la tension d'alimentation auxiliaire est appliquée au dispositif d'ouverture pour assurer l'ouverture complète du disjoncteur

3.7.147
durée minimale de l'ordre de fermeture
durée minimale pendant laquelle la tension d'alimentation auxiliaire doit être appliquée au dispositif de fermeture pour assurer la fermeture complète du disjoncteur

3.7.150
courant en service continu
courant que le circuit principal d'un disjoncteur peut supporter indéfiniment dans des conditions prescrites d'emploi et de fonctionnement

3.7.151
facteur de crête (de la tension transitoire sur la ligne)
rapport entre la variation maximale et la valeur initiale de la tension transitoire par rapport à la terre d'une phase d'une ligne aérienne, après l'interruption d'un courant de défaut proche en ligne

NOTE La valeur initiale de la tension transitoire correspond à l'instant de l'extinction de l'arc dans le pôle considéré.

3.7.152
facteur de premier pôle (d'un réseau triphasé)
lors de l'interruption d'un courant triphasé symétrique quelconque, le facteur de premier pôle est le rapport entre la tension à la fréquence du réseau aux bornes du premier pôle qui coupe le courant alors que le courant circule dans les autres pôles, et la tension à la fréquence du réseau aux bornes du ou des pôles après l'interruption complète

3.7.153
facteur d'amplitude
rapport entre l'amplitude maximale de la tension transitoire de rétablissement et la valeur de crête de la tension de rétablissement à fréquence industrielle

3.7.154
niveau d'isolement
caractéristique définie par une ou deux valeurs de tensions de tenue spécifiée de l'isolation du disjoncteur

[VEI 604-03-47, modifié]

3.7.155
tension de tenue à fréquence industrielle
valeur efficace de la tension sinusoïdale à fréquence industrielle que l'isolation du disjoncteur peut supporter lors d'essais faits dans des conditions spécifiées et pendant une durée spécifiée

[VEI 604-03-40, modifié]

3.7.156
tension de tenue aux ondes de choc
valeur de crête de l'onde de tension de choc normalisée que l'isolation du disjoncteur peut supporter lors d'essais faits dans des conditions spécifiées

NOTE Selon la forme de l'onde, cette expression peut être précisée: «tension de tenue aux chocs de manœuvre» ou «tension de tenue aux chocs de foudre».

3.7.157
pression minimale pour la manœuvre
pression rapportée aux conditions atmosphériques normales de +20 °C et de 101,3 kPa, pouvant être exprimée de façon relative ou absolue, à laquelle et au-dessus de laquelle les caractéristiques assignées d'un disjoncteur sont conservées, et à laquelle un complément de remplissage du dispositif de manœuvre devient nécessaire

NOTE Cette pression est souvent appelée pression de verrouillage (se reporter à 3.6.4.6 de la CEI 62271-1).

3.7.158
pression minimale pour la coupure et l'isolement
pression pour la coupure et l'isolement, rapportée aux conditions atmosphériques normales de +20 °C et de 101,3 kPa, pouvant être exprimée de façon relative ou absolue, à laquelle et au-dessus de laquelle les caractéristiques assignées d'un disjoncteur sont conservées, et à laquelle un complément de remplissage du fluide de coupure et/ou d'isolement devient nécessaire

NOTE 1 Voir également 3.6.4.5 de la CEI 62271-1.

NOTE 2 Pour les disjoncteurs avec système à pression scellé (aussi appelé scellé à vie), la pression minimale pour la coupure est celle à laquelle les caractéristiques assignées du disjoncteur sont conservées, en prenant en compte la perte de pression à la fin de la durée de service escomptée.

3.7.159
durée minimale de coupure
somme de la durée minimale d'ouverture, de la durée minimale de la protection par relais (0,5 cycle), et de la durée d'arc minimale d'interruption du courant, dans le cas de coupure après une petite alternance par le premier pôle qui coupe, uniquement au cours de la séquence d'essais T100a, telle que spécifié par le constructeur

NOTE Il y a lieu que cette définition soit utilisée seulement pour la détermination des paramètres d'essais durant les essais de coupure en court-circuit selon la séquence d'essais T100a.

3.7.160
durée d'insertion (d'une résistance d'ouverture)
intervalle de temps pendant une manœuvre d'ouverture entre l'instant de la séparation des contacts d'arc dans les interrupteurs principaux d'un pôle quelconque et l'instant de la séparation des contacts dans les interrupteurs de résistance de ce pôle

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4 Caractéristiques assignées

Les caractéristiques d'un disjoncteur, y compris celles de ses dispositifs de commande et de son équipement auxiliaire, qui doivent servir à fixer les caractéristiques assignées sont les suivantes:

Caractéristiques assignées à indiquer pour tous les disjoncteurs

a) tension assignée;

b) niveau d'isolement assigné;

c) fréquence assignée;

d) courant assigné en service continu;

e) courant de courte durée admissible assigné;

f) valeur de crête du courant admissible assigné;

g) durée de court-circuit assignée;

h) tension assignée d'alimentation des dispositifs de fermeture et d'ouverture et des circuits auxiliaires;

i) fréquence assignée d'alimentation des dispositifs de fermeture et d'ouverture et des circuits auxiliaires;

j) pressions assignées d'alimentation en gaz comprimé et/ou du circuit hydraulique, pour la manœuvre, la coupure et l'isolement là où cela est applicable;

k) pouvoir de coupure assigné en court-circuit;

l) tension transitoire de rétablissement assignée relative au pouvoir de coupure assigné en court-circuit;

m) pouvoir de fermeture assigné en court-circuit;

n) séquence de manœuvres assignée;

o) durées assignées.

Caractéristiques assignées à indiquer dans les cas spécifiés ci-dessous

p) caractéristiques pour défauts proches en ligne liées au pouvoir de coupure assigné en court-circuit, pour les disjoncteurs prévus pour être reliés directement à des lignes aériennes, quel que soit le type de réseau du côté alimentation, de tension assignée égale ou supérieure à 15 kV et de pouvoir de coupure assigné en court-circuit supérieur à 12,5 kA;

q) pouvoir de coupure assigné de lignes à vide, pour les disjoncteurs tripolaires destinés à la mise en et hors circuit des lignes aériennes de transport (obligatoire pour les disjoncteurs de tensions assignées égales ou supérieures à 72,5 kV);

r) pouvoir de coupure assigné de câbles à vide, pour les disjoncteurs tripolaires destinés à la mise en et hors circuit de câbles (obligatoire pour les disjoncteurs de tensions assignées égales ou inférieures à 52 kV).

Caractéristiques assignées à indiquer sur demande

s) pouvoir de coupure assigné en discordance de phases;

t) pouvoir de coupure assigné de batterie unique de condensateurs;

u) pouvoir de coupure assigné de batterie de condensateurs à gradins;

v) pouvoir de fermeture assigné de batterie de condensateurs;

w) pouvoir de fermeture assigné de batterie de condensateurs à gradins.

Les caractéristiques assignées du disjoncteur sont liées à la séquence de manœuvres assignée.

4.1 Tension assignée (U_r)

Le paragraphe 4.1 de la CEI 62271-1 est applicable.

4.2 Niveau d'isolement assigné

Le paragraphe 4.2 de la CEI 62271-1 est applicable avec le complément suivant :

Les valeurs normalisées des tensions de tenue assignées entre les bornes du disjoncteur ouvert sont données dans les Tableaux 1a, 1b, 2a et 2b de la CEI 62271-1.

Cependant, dans le cas de disjoncteurs de tension assignée supérieure ou égale à 300 kV destinés à des manœuvres de synchronisation accompagnées de surtensions transitoires ou temporaires importantes, l'isolation d'un disjoncteur normal peut être insuffisante. Dans ce cas, on suggère l'utilisation d'un disjoncteur normal de tension assignée plus élevée, ou l'utilisation d'un disjoncteur spécial ayant réussi un essai plus sévère en position d'ouverture. La procédure d'essai pour cet essai est décrite en 6.2.7.2. Les valeurs normalisées de la tension de tenue à fréquence industrielle assignée et de la tension de tenue assignée aux chocs de manœuvre entre les bornes du disjoncteur ouvert, sont données dans les colonnes (3) et (6) des Tableaux 2a et 2b de la CEI 62271-1.

Pour des disjoncteurs avec des tensions assignées de 1 100 kV et 1 200 kV, le Tableau 36 s’applique.

Tableau 36 – Niveaux d'isolement assignés pour les tensions assignées 1 100 kV et 1 200 kV

Tension assignée U_r **kV (efficace)**	**Tension de tenue assignée de courte durée à fréquence industrielle** U_d **kV (efficace)**		**Tension de tenue assignée aux chocs de manœuvre** U_s **kV (valeur de crête)**			**Tension de tenue assignée aux chocs de foudre** U_p **kV (valeur de crête)**	
	Entre phase et terre, et entre phases (Note 3)	**Entre contacts ouverts et/ou sur la distance de section-nement** (Notes 1 et 3)	**Entre phase et terre, et entre contacts ouverts**	**Entre phases** (Notes 3 et 4)	**Sur la distance de section-nement** (Notes 2 et 3)	**Entre phase et terre, et entre phases**	**Entre contacts ouverts et/ou sur la distance de sectionnement** (Notes 2 et 3)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1 100	**1 100**	$\frac{1\,100 \times 2}{\sqrt{3}}$	**1 550**	**2 635**	**1 550 + (900)**	**2 250**	**2 250 + (630)**
	1 450	**1 100 + (635)**	**1 800**	**2 880**		**2 400**	**2 400 + (630)**
1 200	**1 200**	$\frac{1\,200 \times 2}{\sqrt{3}}$	**1 800**	**2 970**	**1 675 + (980)**	**2 400**	**2 400 + (685)**
	1 600	1 200 + (695)	**1 950**	**3 120**		2 550	**2 550 + (685)**

NOTE 1 Les valeurs entre parenthèses de la colonne (3) sont des valeurs efficaces.

NOTE 2 Dans la colonne (6), les valeurs entre parenthèses sont les valeurs de crête de la tension à fréquence industrielle $U_r \times \sqrt{2}/\sqrt{3}$ appliquée à la borne opposée (tension combinée).

Dans la colonne (8), les valeurs entre parenthèses sont les valeurs de crête de la tension à fréquence industrielle 0,7 $U_r \times \sqrt{2}/\sqrt{3}$ appliquée à la borne opposée (tension combinée).

NOTE 3 Les valeurs de la colonne (2) sont applicables comme suit:

a) la valeur la plus faible est pour les essais de type, entre phase et terre, et la valeur la plus élevée est pour la tension tenue entre phases;

b) la valeur la plus faible est pour les essais individuels de série, entre phase et terre et entre contacts ouverts.

Les valeurs des colonnes (3), (5), (6) et (8) ne sont applicables que pour les essais de type.

NOTE 4 Ces valeurs sont déduites à l’aide des facteurs multiplicateurs donnés au Tableau 3 de la CEI 60071-1:2006.

4.3 Fréquence assignée *(f_r)*

Le paragraphe 4.3 de la CEI 62271-1 est applicable avec la modification suivante:

Les valeurs normales de la fréquence assignée aux disjoncteurs à haute tension sont 50 Hz et 60 Hz.

4.4 Courant assigné en service continu (I_r) et échauffement

Le paragraphe 4.4 de la CEI 62271-1 est applicable.

Si le disjoncteur est muni d'un accessoire branché en série, tel qu'un déclencheur direct à maximum de courant, le courant assigné en service continu de l'accessoire est la valeur efficace du courant que cet accessoire doit être capable de supporter de façon continue sans détérioration à la fréquence assignée, sans que l'échauffement n'excède les valeurs spécifiées dans le Tableau 3 de la CEI 62271-1.

4.5 Courant de courte durée admissible assigné (I_k)

Le paragraphe 4.5 de la CEI 62271-1 est applicable avec le complément suivant:

Le courant de courte durée admissible assigné est égal au pouvoir de coupure assigné en court-circuit (voir 4.101).

4.6 Valeur de crête du courant admissible assigné (I_p)

Le paragraphe 4.6 de la CEI 62271-1 est applicable avec le complément suivant:

Pour les disjoncteurs avec des tensions assignées supérieures à 800 kV, la constante de temps de la composante apériodique normalisée est de 120 ms et la valeur de crête du courant admissible assigné est égale à 2,7 fois le courant de courte durée admissible assigné pour 50 Hz et 60 Hz.

La valeur de crête du courant admissible assigné est égale au pouvoir de fermeture assigné en court-circuit (voir 4.103).

4.7 Durée de court-circuit assignée (t_k)

Le paragraphe 4.7 de la CEI 62271-1 est applicable~~ avec le complément suivant:~~.

~~Il n'est pas nécessaire de spécifier une courte durée de court-circuit assignée pour les disjoncteurs à déclenchement autonome lorsque les considérations suivantes sont applicables. Lorsqu'ils sont connectés à un circuit, ils doivent être capables de supporter un courant égal à leur pouvoir de coupure assigné pendant la durée de coupure. Cette durée de coupure est celle exigée par le disjoncteur dont le dispositif de déclenchement a été réglé à la temporisation maximale et en cohérence avec sa séquence de manœuvre assignée.~~

~~NOTE Les déclencheurs directs à maximum de courant comprennent les systèmes de déclenchement autonomes.~~

4.8 Tension assignée d'alimentation des dispositifs de fermeture et d'ouverture, des circuits auxiliaires et de commande (U_a)

Le paragraphe 4.8 de la CEI 62271-1 est applicable.

4.9 Fréquence assignée d'alimentation des dispositifs de fermeture et d'ouverture et des circuits auxiliaires

Le paragraphe 4.9 de la CEI 62271-1 est applicable.

4.10 Pression assignée d'alimentation en gaz comprimé pour l'isolement, la manœuvre et/ou la coupure

Le paragraphe 4.10 de la CEI 62271-1 est applicable.

4.101 Pouvoir de coupure assigné en court-circuit (I_{sc})

Le pouvoir de coupure assigné en court-circuit est la valeur la plus élevée du courant de court-circuit que le disjoncteur doit être capable d'interrompre dans les conditions d'emploi et de fonctionnement fixées dans cette norme. On trouve un tel courant dans un circuit dont la tension de rétablissement à fréquence industrielle correspond à la tension assignée du disjoncteur et dont la tension transitoire de rétablissement est égale à la valeur spécifiée en 4.102. Pour un disjoncteur tripolaire, la composante périodique correspond à un court-circuit triphasé. On doit tenir compte des spécifications de 4.105 concernant les défauts proches en ligne lorsqu'elles s'appliquent.

Le pouvoir de coupure assigné en court-circuit est caractérisé par deux valeurs:

– la valeur efficace de sa composante périodique;

– la constante de temps de la composante apériodique du pouvoir de coupure assigné en court-circuit qui entraîne un pourcentage de la composante apériodique à la séparation des contacts.

NOTE 1 Si le pourcentage de la composante apériodique à la séparation des contacts ne dépasse pas 20 %, le pouvoir de coupure assigné en court-circuit est caractérisé seulement par la valeur efficace de sa composante périodique.

NOTE 2 Le pourcentage de la composante apériodique est fonction de la constante de temps de la composante apériodique du pouvoir de coupure assigné en court-circuit (voir 4.101.2) et de l'instant d'initiation du courant de court-circuit.

Pour la détermination de la composante périodique et du pourcentage de la composante apériodique à tout instant à la suite de l'initiation du courant, voir la Figure 8.

Le disjoncteur doit pouvoir couper, dans les conditions indiquées ci-dessus et jusqu'à son pouvoir de coupure assigné en court-circuit, tous les courants de court-circuit avec une composante périodique quelconque mais ne dépassant pas la valeur assignée et avec un pourcentage de la composante apériodique quelconque correspondant à la constante de temps de la composante apériodique spécifiée, mais ne dépassant pas la valeur spécifiée.

Un disjoncteur normal répond aux caractéristiques suivantes:

a) pour les tensions inférieures ou égales à la tension assignée, le disjoncteur doit être capable de couper son pouvoir de coupure assigné en court-circuit;

b) pour les tensions supérieures à la tension assignée, aucun pouvoir de coupure en court-circuit n'est garanti, sauf dans le cas prévu en 4.106.

4.101.1 Composante périodique du pouvoir de coupure assigné en court-circuit

Les valeurs normales de la composante périodique du pouvoir de coupure assignée en court-circuit doivent être choisies dans la série R10 de la CEI 60059.

NOTE La série R10 comprend les nombres 1 – 1,25 – 1,6 – 2 – 2,5 – 3,15 – 4 – 5 – 6,3 – 8 et leurs produits par 10^n.

4.101.2 Constante de temps de la composante apériodique du pouvoir de coupure assigné en court-circuit

a) Pour les disjoncteurs de tensions assignées inférieures ou égales à 800 kV

La constante de temps de la composante apériodique normalisée est de 45 ms. Les constantes de temps de la composante apériodique suivantes sont pour des applications particulières, suivant la tension assignée du disjoncteur:

– 120 ms pour les tensions assignées inférieures ou égales à 52 kV;

– 60 ms pour les tensions assignées comprises entre 72,5 kV et 420 kV inclus ;

– 75 ms pour les tensions assignées ~~supérieures ou égales à~~ de 550 kV et 800 kV.

Ces constantes de temps pour des applications particulières reconnaissent le fait que la valeur normalisée peut être inadaptée pour certains réseaux. Elles sont fournies comme valeurs unifiées pour ces besoins de réseaux spéciaux, prenant en compte les caractéristiques des différentes gammes de tensions assignées, par exemple leurs structures de réseau particulières, la conception des lignes, etc.

NOTE 1 De plus, des applications spéciales peuvent nécessiter des valeurs encore plus élevées, par exemple pour un disjoncteur proche d'un générateur. Dans ces cas, il convient de préciser la valeur de la constante de temps de la composante apériodique spécifiée et toute exigence d'essai additionnelle dans l'appel d'offre.

NOTE 2 Des informations plus détaillées sur l'utilisation de la constante de temps normalisée et des constantes de temps pour des applications particulières sont données dans la note explicative I.2.1. Le pourcentage de la composante apériodique en fonction du temps pour les différentes constantes de temps est indiqué à la Figure 9.

NOTE 3 Le pourcentage de la composante apériodique à la séparation des contacts utilisé dans les éditions antérieures de la CEI 62271-100 ou de la CEI 60056 peut être déduit à l'aide de l'équation donnée en 6.106.5. Le concept du pourcentage de la composante apériodique à la séparation des contacts pour les séquences d'essais symétriques est toujours utilisé dans la présente édition. Pour la séquence d'essais asymétriques T100a, un tel concept a été modifié (voir I.2.1 et les Annexes P et Q).

b) Pour les disjoncteurs de tensions assignées supérieures à 800 kV

La constante de temps de la composante apériodique normalisée est de 120 ms. La Note 3 est également applicable dans ce cas.

4.102 Tension transitoire de rétablissement relative au pouvoir de coupure assigné

La tension transitoire de rétablissement (TTR), associée au pouvoir de coupure assigné en court-circuit conformément à 4.101, est la tension de référence qui constitue la limite de la tension transitoire de rétablissement présumée de circuits que le disjoncteur doit pouvoir couper lors d'un court-circuit à ses bornes.

4.102.1 Représentation des ondes de la TTR

La forme d'ondes des tensions transitoires de rétablissement est variable suivant la configuration des circuits réels.

Dans certains cas, particulièrement dans les réseaux de tensions égales ou supérieures à 100 kV et pour des courants de court-circuit relativement importants par rapport au courant de court-circuit maximal à l'endroit considéré, la tension transitoire de rétablissement comprend une période initiale pendant laquelle la vitesse d'accroissement est élevée, et une période ultérieure pendant laquelle la vitesse d'accroissement est plus réduite. Cette forme d'onde est en général suffisamment bien représentée par une enveloppe constituée de trois segments de droite définis par quatre paramètres. Les méthodes de tracé des enveloppes de la tension transitoire de rétablissement figurent à l'Annexe E.

Dans d'autres cas, particulièrement dans les réseaux de tension inférieure à 100 kV ou bien dans les réseaux de tension supérieure à 100 kV pour des courants de court-circuit relativement faibles par rapport au courant de court-circuit maximal et alimentés au travers de transformateurs, la tension transitoire de rétablissement a une forme proche d'une oscillation amortie à une seule fréquence. Cette forme d'onde est suffisamment bien représentée par une enveloppe constituée par deux segments de droite définis par deux paramètres. Les méthodes de tracé des enveloppes de la tension transitoire de rétablissement figurent à l'Annexe E.

Cette représentation par deux paramètres est un cas particulier de la représentation par quatre paramètres.

L'influence de la capacité au lieu d'installation et du côté de l'alimentation du disjoncteur réduit la vitesse d'accroissement de la tension pendant les quelques premières microsecondes de la TTR. On en tient compte par l'introduction d'un retard.

Il apparaît que chaque période de l'onde de TTR peut influer sur les performances de coupure d'un disjoncteur. Le tout début de la TTR peut être important pour certains types de disjoncteurs. Cette période de la TTR, dénommée TTR initiale (TTRI), est provoquée par une oscillation initiale de faible amplitude due aux réflexions sur la première discontinuité majeure du jeu de barres. Elle est surtout déterminée par la configuration du jeu de barres et par la disposition des appareils au départ de chaque poste. La TTRI est un phénomène physique très semblable au défaut proche en ligne. Par comparaison avec le défaut proche en ligne, la première crête de tension est plutôt basse, mais la durée pour atteindre cette première crête est extrêmement courte et se situe dans les premières microsecondes après le passage à zéro du courant. C'est pourquoi le processus thermique d'interruption peut être influencé.

~~Si le disjoncteur a un pouvoir de coupure en défaut proche en ligne assigné, les exigences de la TTRI sont considérées comme satisfaites si les essais de défaut proche en ligne sont effectués avec une ligne n'introduisant pas de retard (voir 6.104.5.2 et 6.109.3) à moins que les deux bornes ne soient pas identiques d'un point de vue électrique (c'est le cas, par exemple, lorsqu'une capacité supplémentaire est utilisée, comme mentionné dans la Note 4 de 6.109.3). Dans ce cas, on peut utiliser comme alternative des circuits d'essais qui produisent une contrainte de TTR équivalente au disjoncteur.~~

~~Etant donné que la TTRI est proportionnelle à l'impédance d'onde des jeux de barres et au courant, les exigences la concernant peuvent être négligées pour tous les disjoncteurs ayant un pouvoir de coupure assigné inférieur à 25 kA et pour les disjoncteurs de tension assignée inférieure à 100 kV. De plus, les exigences concernant la TTRI peuvent être négligées pour les disjoncteurs installés dans l'appareillage sous enveloppe métallique du fait de la faible impédance d'onde.~~

Si un disjoncteur de tension assignée inférieure ou égale à 800 kV a un pouvoir de coupure en défaut proche en ligne assigné, les exigences de la TTRI sont satisfaites si les essais de défaut proche en ligne sont effectués avec une ligne introduisant un retard inférieur à 100 ns (voir 6.104.5.2 et 6.109.3) à moins que les deux bornes ne soient pas identiques d'un point de vue électrique (c'est le cas, par exemple, lorsqu'une capacité supplémentaire est utilisée, comme mentionné dans la Note 4 de 6.109.3). Lorsque les bornes ne sont pas identiques d'un point de vue électrique, on peut utiliser des circuits d'essai produisant une contrainte de la TTR équivalente au disjoncteur.

Pour les disjoncteurs de tension assignée supérieure à 800 kV, les exigences de la TTRI sont considérées comme satisfaites si les essais de défaut proche en ligne sont effectués avec une ligne ayant un temps de retard inférieur à 100 ns et une impédance d'onde de 450 Ω à moins que les deux bornes ne soient pas identiques d'un point de vue électrique (c'est le cas, par exemple, lorsqu'une capacité supplémentaire est utilisée, comme mentionné dans la Note 4 de 6.109.3). Lorsque les bornes ne sont pas identiques d'un point de vue électrique, on peut utiliser des circuits d'essais produisant une contrainte de la TTR équivalente au disjoncteur.

Étant donné que la TTRI est proportionnelle à l'impédance d'onde des jeux de barres et au courant, les exigences la concernant peuvent être négligées pour tous les disjoncteurs ayant un pouvoir de coupure assigné inférieur à 25 kA et pour les disjoncteurs de tension assignée inférieure à 100 kV. De plus, les exigences concernant la TTRI peuvent être négligées pour les disjoncteurs installés dans l'appareillage sous enveloppe métallique du fait de la faible impédance d'onde. Les exigences concernant la TTRI peuvent également être négligées pour les disjoncteurs directement connectés à un jeu de barres avec une connexion avec une capacité totale côté source supérieure à 800 pF.

4.102.2 Représentation de la TTR

Pour représenter la TTR, les paramètres suivants sont utilisés:

a) Tracé de référence à quatre paramètres (voir Figure 10):

~~u_1 = première tension de référence, en kilovolts;~~

~~t_1 = temps mis pour atteindre u_1, en microsecondes;~~

~~u_c = seconde tension de référence (valeur de crête de la TTR), en kilovolts;~~

~~t_2 = temps mis pour atteindre u_c, en microsecondes.~~

~~Les paramètres de la TTR sont définis en fonction de la tension assignée (U_r), du facteur de premier pôle (k_{pp}) et du facteur d'amplitude (k_{af}) comme suit:~~

$$\cancel{u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}}$$

~~t_1 est déterminé à partir de u_1 et de la vitesse d'accroissement spécifiée u_1/t_1 = VATR;~~

~~t_1 pour la discordance de phases = 2 × t_1 (pour le défaut aux bornes)~~

~~$u_c = k_{af} \times k_{pp} U_r \sqrt{\frac{2}{3}}$, où k_{af} est égal à:~~

~~– 1,4 pour le défaut aux bornes et le défaut proche en ligne;~~

~~– 1,25 pour la discordance de phases.~~

~~t_2 = 4t_1 pour le défaut aux bornes et le défaut proche en ligne;~~

~~t_2 pour la discordance de phases = entre t_2 (pour le défaut aux bornes) et 2 × t_2 (pour le défaut aux bornes).~~

u_1 = première tension de référence, en kilovolts;

t_1 = temps mis pour atteindre u_1, en microsecondes;

u_c = seconde tension de référence (valeur de crête de la TTR), en kilovolts;

t_2 = temps mis pour atteindre u_c, en microsecondes.

Les paramètres de la TTR sont définis en fonction de la tension assignée (U_r), du facteur de premier pôle (k_{pp}) et du facteur d'amplitude (k_{af}) comme suit:

$$u_1 = 0{,}75 \times k_{pp} U_r \sqrt{\frac{2}{3}}$$

t_1 pour le défaut aux bornes est déduit de u_1 et de la vitesse d'accroissement spécifiée u_1/t_1 = VATR;

t_1 pour la discordance de phases = 2 × t_1 (pour le défaut aux bornes).

$$u_c = k_{af} \times k_{pp} U_r \sqrt{\frac{2}{3}}$$

1) Pour des tensions assignées inférieures ou égales à 800 kV, k_{af} est égal à:

   – 1,4 pour le défaut aux bornes et le défaut proche en ligne;

   – 1,25 pour la discordance de phases.

   t_2 = 4t_1 pour le défaut aux bornes et le défaut proche en ligne;

   t_2 pour la discordance de phases = entre t_2 (pour le défaut aux bornes) et 2t_2 (pour le défaut aux bornes).

2) Pour les tensions assignées supérieures à 800 kV:

   Un tracé de référence à quatre paramètres est spécifié pour le défaut aux bornes et les séquences d'essais de défaut proche en ligne et un tracé de référence à deux paramètres (voir b) et la Figure 11) pour les séquences d'essais de discordance de phases. k_{af} est égal à:

– 1,5 pour le défaut aux bornes et le défaut proche en ligne;

– 1,25 pour la discordance de phases.

$t_2 = 3t_1$ pour la séquence d'essais T100 et pour le circuit côté alimentation pour le défaut proche en ligne.

$t_2 = 4{,}5t_1$ pour T60.

Pour les séquences d'essais de discordance de phases OP1 et OP2, le temps t_3 est déduit de u_c et d'une vitesse d'accroissement de 1,54 kV/µs.

b) Tracé de référence à deux paramètres (voir Figure 11):

u_c = tension de référence (valeur de crête de la TTR), en kV;

t_3 = temps, en µs.

Les paramètres de la TTR sont définis en fonction de la tension assignée (U_r), du facteur de premier pôle (k_{pp}) et du facteur d'amplitude (k_{af}) comme suit:

$$u_c = k_{af} \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$$

où k_{af} est égal à

1,4 pour le défaut aux bornes dans le cas de réseaux par câbles;

1,54 pour le défaut aux bornes et le défaut proche en ligne, dans le cas de réseaux aériens;

1,25 pour la discordance de phases;

t_3 pour le circuit d'alimentation du défaut proche en ligne = t_3 (défaut aux bornes);

t_3 pour la discordance de phases = $2 \times t_3$ (défaut aux bornes).

c) Segment définissant le retard de la TTR (voir Figures 10 et 11):

~~t_d = retard, en microsecondes;~~

~~u' = tension de référence, en kilovolts;~~

~~t' = temps mis pour atteindre u', en microsecondes.~~

~~Le segment définissant le retard commence sur l'axe des temps à la valeur du retard assigné, est parallèle à la première partie du tracé de référence de la TTR assignée et se termine à la valeur de tension u' (correspondant à l'abscisse t').~~

~~Pour les tensions inférieures à 100 kV:~~

~~$t_d = 0{,}15 \times t_3$, pour le défaut aux bornes et la discordance de phase dans le cas de réseaux par câbles;~~

~~$t_d = 0{,}05 \times t_3$, pour le défaut aux bornes et le défaut proche en ligne dans le cas de réseaux aériens;~~

~~$t_d = 0{,}15 \times t_3$, pour la discordance de phase dans le cas de réseaux aériens;~~

~~$u' = u_c/3$;~~

~~t' est déterminé à partir de t_d et t_3 selon la Figure 11, $t' = t_d + t_3/3$.~~

~~Pour les tensions assignées supérieures ou égales à 100 kV:~~

~~t_d = 2 µs pour le défaut aux bornes et le circuit d'alimentation pour le défaut proche en ligne;~~

~~t_d = 2 µs à $0{,}1 \times t_1$ pour la discordance de phases;~~

~~$u' = u_1/2$;~~

~~t' est déterminé à partir de u', u_1/t_1 (VATR) et t_d selon la Figure 10, $t' = t_d + t_3$/VATR.~~

t_d = retard, en microsecondes;

u' = tension de référence, en kilovolts;

t' = temps mis pour atteindre u', en microsecondes.

Le segment définissant le retard commence sur l'axe des temps à la valeur du retard assigné, est parallèle à la première partie du tracé de référence de la TTR assignée et se termine à la valeur de tension u' (correspondant à l'abscisse t').

Pour les tensions assignées inférieures à 100 kV:

$t_d = 0{,}15 \times t_3$, pour le défaut aux bornes et la discordance de phases dans le cas de réseaux par câbles;

$t_d = 0{,}05 \times t_3$, pour le défaut aux bornes et le défaut proche en ligne dans le cas de réseaux aériens;

$t_d = 0{,}15 \times t_3$, pour la discordance de phases dans le cas de réseaux aériens;

$u' = u_c/3$;

t' est déduit de t_d et t_3 selon la Figure 11, $t' = t_d + t_3/3$.

Pour les tensions assignées comprises entre 100 kV et 800 kV inclus;

t_d = 2 µs pour le défaut aux bornes et le circuit d'alimentation pour le défaut proche en ligne;

t_d = 2 µs à $0{,}1 \times t_1$ pour la discordance de phases;

$u' = u_1/2$;

t' est déduit de u', u_1/t_1 (VATR) et t_d selon la Figure 10, $t' = t_d + u'/\text{VATR}$.

Pour les tensions assignées supérieures à 800 kV:

t_d = 2 µs pour le défaut aux bornes et le circuit d'alimentation pour le défaut proche en ligne;

$u' = u_1/2$;

t' est déduit de u', u_1/t_1 (VATR) et t_d selon la Figure 10, $t' = t_d + u'/\text{VATR}$.

t_d = *2* µs à $0{,}05 \times t_3$ pour la discordance de phases;

$u' = u_c/3$, t' est déduit de u_c et d'une vitesse d'accroissement de 1,54 kV/µs.

d) TTRI (voir Figure 12):

u_i = tension de référence (valeur de crête de la TTRI), en kilovolts;

t_i = temps mis pour atteindre u_i, en microsecondes.

La vitesse d'accroissement de la TTRI dépend de la valeur du courant de court-circuit interrompu et son amplitude dépend de la distance à la première discontinuité le long du jeu de barres. La TTRI est définie par la tension u_i et le temps t_i. La forme d'onde inhérente doit suivre une ligne droite, tracée à partir des points 20 % et 80 % de la crête de tension de la TTRI, u_i, et de la vitesse d'accroissement de la TTRI spécifiée.

4.102.3 Valeurs normales de la TTR relative au courant de court-circuit assigné

Les valeurs normales de TTR pour les disjoncteurs tripolaires de tension assignée inférieure à 100 kV correspondent à la représentation par deux paramètres. Les valeurs sont indiquées dans

– le Tableau 1 pour les réseaux par câbles;

– le Tableau 2 pour les réseaux aériens.

~~Pour les tensions assignées supérieures ou égales à 100 kV, on utilise la représentation à quatre paramètres. Le Tableau 3 donne les valeurs pour les tensions assignées de 100 kV à 170 kV dans le cas de réseaux à neutre relié effectivement à la terre. Le Tableau 4 donne les valeurs pour les tensions assignées de 100 kV à 170 kV dans le cas de réseaux à neutre relié~~

~~non effectivement à la terre. Le Tableau 5 donne les valeurs pour les tensions assignées supérieures ou égales à 245 kV.~~

Le Tableau 3 donne les valeurs pour les tensions assignées de 100 kV à 170 kV dans le cas de réseaux à neutre relié effectivement à la terre. Le Tableau 4 donne les valeurs pour les tensions assignées de 100 kV à 170 kV dans le cas de réseaux à neutre relié non effectivement à la terre. Le Tableau 5 donne les valeurs pour les tensions assignées supérieures ou égales à 245 kV.

Les valeurs de crête de la TTR données dans les Tableaux 1, 2, 3, 4, 5 et 37 doivent être satisfaites. Les valeurs du facteur d'amplitude ne sont données que pour information.

Les tableaux indiquent également les valeurs de vitesse d'accroissement, telles que u_c/t_3 et u_1/t_1, pour les représentations à deux et à quatre paramètres respectivement, qui, avec la valeur crête de la TTR u_c peuvent être utilisées pour spécifier les TTR.

Les valeurs des tableaux sont des valeurs présumées. Elles s'appliquent aux disjoncteurs destinés à des réseaux triphasés de transport et de distribution, fonctionnant à des fréquences de 50 Hz ou 60 Hz et comportant des transformateurs, des lignes aériennes et des câbles.

Dans les réseaux monophasés ou lorsque des disjoncteurs sont destinés à des installations où l'on peut rencontrer des conditions plus sévères, les valeurs peuvent être différentes, particulièrement dans les cas suivants:

a) disjoncteurs à proximité d'alternateurs;

b) disjoncteurs directement reliés à des transformateurs fournissant un courant supérieur à 50 % du pouvoir de coupure assigné en court-circuit du disjoncteur, sans capacité supplémentaire appréciable entre le disjoncteur et le transformateur. Cependant, le cas particulier de disjoncteurs de tension assignée inférieure à 100 kV et reliés à un transformateur avec une liaison de faible capacité est traité dans l'Annexe M;

c) disjoncteurs situés dans des postes comportant des réactances de limitation (des informations sont données en 8.103.7 et à l'Article L.5 pour les disjoncteurs de tensions assignées inférieures à 100 kV);

d) disjoncteurs utilisés pour lignes compensées série;

e) disjoncteurs situés dans des postes comportant des batteries de condensateurs en gradins.

La tension transitoire de rétablissement correspondante au pouvoir de coupure assigné en court-circuit en cas de défaut aux bornes est utilisée pour les essais de coupure de courant de court-circuit égaux à la valeur assignée. Toutefois, pour les essais de coupure de courant en court-circuit effectués à des valeurs inférieures à 100 % de la valeur assignée, d'autres valeurs de la tension transitoire de rétablissement sont spécifiées (voir 6.104.5). De plus, des exigences complémentaires concernent les disjoncteurs prévus pour être connectés directement à des lignes aériennes, dont la tension assignée est égale ou supérieure à 15 kV et dont le pouvoir de coupure assigné en court-circuit est supérieur à 12,5 kA, et qui peuvent être amenés à fonctionner dans les conditions du défaut proche en ligne (voir 4.105).

Tableau 1 – Valeurs normales de la TTR pour les disjoncteurs de classe S1 – Tensions assignées supérieures à 1 kV et inférieures à 100 kV – Représentation par deux paramètres

Tension assignée U_r kV	Type d'essai	Facteur de premier pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Valeur de crête de la TTR u_c kV	Temps t_3 µs	Temps de retard t_d µs	Tension u' kV	Temps t' µs	VATR [a] u_c/t_3 kV/µs
3,6	Défaut aux bornes	1,5	1,4	6,2	41	6	2,1	20	0,15
	Discordance de phases	2,5	1,25	9,2	82	12	3,1	40	0,11
4,76 [b]	Défaut aux bornes	1,5	1,4	8,2	44	7	2,7	21	0,19
	Discordance de phases	2,5	1,25	12,1	88	13	4,0	43	0,14
7,2	Défaut aux bornes	1,5	1,4	12,3	51	8	4,1	25	0,24
	Discordance de phases	2,5	1,25	18,4	102	15	6,1	49	0,18
8,25 [b]	Défaut aux bornes	1,5	1,4	14,1	52	8	4,7	25	0,27
	Discordance de phases	2,5	1,25	21,1	104	16	7,0	50	0,20
12	Défaut aux bornes	1,5	1,4	20,6	61	9	6,9	29	0,34
	Discordance de phases	2,5	1,25	30,6	122	18	10,2	59	0,25
15 [b]	Défaut aux bornes	1,5	1,4	25,7	66	10	8,6	32	0,39
	Discordance de phases	2,5	1,25	38,3	132	20	12,8	64	0,29
17,5	Défaut aux bornes	1,5	1,4	30	71	11	10,0	34	0,42
	Discordance de phases	2,5	1,25	44,7	142	21	14,9	69	0,31
24	Défaut aux bornes	1,5	1,4	41,2	87	13	13,7	42	0,47
	Discordance de phases	2,5	1,25	61,2	174	26	20,4	84	0,35
25,8 [b]	Défaut aux bornes	1,5	1,4	44,2	91	14	14,7	44	0,49
	Discordance de phases	2,5	1,25	65,8	182	27	21,9	88	0,36
36	Défaut aux bornes	1,5	1,4	61,7	109	16	20,6	53	0,57
	Discordance de phases	2,5	1,25	91,9	218	33	30,6	105	0,42
38 [b]	Défaut aux bornes	1,5	1,4	65,2	109	16	21,7	53	0,60
	Discordance de phases	2,5	1,25	97,0	218	33	32,3	105	0,45
48,3 [b]	Défaut aux bornes	1,5	1,4	82,8	125	19	27,6	60	0,66
	Discordance de phases	2,5	1,25	123	250	38	41,1	121	0,49
52	Défaut aux bornes	1,5	1,4	89,2	131	20	29,7	63	0,68
	Discordance de phases	2,5	1,25	133	262	39	44,2	127	0,51
72,5	Défaut aux bornes	1,5	1,4	124	165	25	41,4	80	0,75
	Discordance de phases	2,5	1,25	185	330	50	61,7	160	0,56

[a] VATR = vitesse d'accroissement de la tension de rétablissement.
[b] Utilisée en Amérique du Nord.

Tableau 2 – Valeurs normales de la TTR [c] pour les disjoncteurs de classe S2 – Tensions assignées égales ou supérieures à 15 kV et inférieures à 100 kV – Représentation par deux paramètres

Tension assignée U_r kV	Type d'essai	Facteur de 1er pôle k_{pp} p.u.	Facteur d'ampli tude k_{af} p.u.	Valeur de crête de la TTR u_c kV	Temps t_3 µs	Temps de retard t_d µs	Tension u' kV	Temps t' µs	VATR [a] u_c/t_3 kV/µs
15 [b]	Défaut aux bornes	1,5	1,54	28,3	31	2	9,4	12	0,91
	Défaut proche en ligne	1	1,54	18,9	31	2	6,3	12	0,61
	Discordance de phases	2,5	1,25	38,3	62	9	12,8	30	0,62
17,5	Défaut aux bornes	1,5	1,54	33,0	34	2	11,0	13	0,97
	Défaut proche en ligne	1	1,54	22,0	34	2	7,3	13	0,65
	Discordance de phases	2,5	1,25	45	68	10	14,9	33	0,65
24	Défaut aux bornes	1,5	1,54	45,3	43	2	15,1	16	1,05
	Défaut proche en ligne	1	1,54	30,2	43	2	10,1	16	0,70
	Discordance de phases	2,5	1,25	61	86	13	20,4	42	0,71
25,8 [b]	Défaut aux bornes	1,5	1,54	48,7	45	2	16,2	17	1,08
	Défaut proche en ligne	1	1,54	32,4	45	2	10,8	17	0,72
	Discordance de phases	2,5	1,25	66	90	14	21,9	44	0,73
36	Défaut aux bornes	1,5	1,54	67,9	57	3	22,6	22	1,19
	Défaut proche en ligne	1	1,54	45,3	57	3	15,1	22	0,79
	Discordance de phases	2,5	1,25	92	114	17	30,6	55	0,81
38 [b]	Défaut aux bornes	1,5	1,54	71,7	59	3	23,9	23	1,21
	Défaut proche en ligne	1	1,54	47,8	59	3	15,9	23	0,81
	Discordance de phases	2,5	1,25	97	118	18	32,3	57	0,82
48,3 [b]	Défaut aux bornes	1,5	1,54	91,1	70	4	30,4	27	1,30
	Défaut proche en ligne	1	1,54	60,7	70	4	20,2	27	0,87
	Discordance de phases	2,5	1,25	123	140	21	41,1	68	0,88
52	Défaut aux bornes	1,5	1,54	98,1	74	4	32,7	28	1,33
	Défaut proche en ligne	1	1,54	65,4	74	4	21,8	28	0,88
	Discordance de phases	2,5	1,25	133	148	22	44,2	72	0,90

Tableau 2 *(suite)*

Tension assignée U_r kV	Type d'essai	Facteur de 1[er] pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Valeur de crête de la TTR u_c kV	Temps t_3 µs	Temps de retard t_d µs	Tension u' kV	Temps t' µs	VATR [a] u_c/t_3 kV/µs
72,5	Défaut aux bornes	1,5	1,54	137	93	5	45,6	36	1,47
	Défaut proche en ligne	1	1,54	91,2	93	5	30,4	36	0,98
	Discordance de phases	2,5	1,25	185	186	28	61,7	90	0,99

[a] VATR = vitesse d'accroissement de la tension de rétablissement.

[b] Utilisée en Amérique du Nord.

[c] Pour les défauts proches en ligne: la TTR et les temps sont ceux du circuit d'alimentation. Le défaut proche en ligne est applicable uniquement aux disjoncteurs prévus pour être connectés directement à des lignes aériennes.

Tableau 3 – Valeurs normales de la TTR [a] – Tensions assignées de 100 kV à 170 kV, cas de réseaux à neutre effectivement à la terre – Représentation par quatre paramètres

Tension assignée U_r kV	Séquence d'essais	Facteur de premier pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Première tension de référence u_1 kV	Temps t_1 µs	Valeur de crête de la TTR u_c kV	Temps t_2 µs	Retard t_d µs	Tension u' kV	Temps t' µs	VATR[b] u_1/t_1 kV/µs
100	Défaut aux bornes	1,3	1,40	80	40	149	160	2	40	22	2
	Défaut proche en ligne	1	1,40	61	31	114	124	2	31	17	2
	Discordance de phases	2	1,25	122	80	204	160-320	2-8	61	48	1,54
123	Défaut aux bornes	1,3	1,40	98	49	183	196	2	49	26	2
	Défaut proche en ligne	1	1,40	75	38	141	152	2	38	21	2
	Discordance de phases	2	1,25	151	98	251	196-392	2-10	75	59	1,54
145	Défaut aux bornes	1,3	1,40	115	58	215	232	2	58	31	2
	Défaut proche en ligne	1	1,40	89	44	166	176	2	44	24	2
	Discordance de phases	2	1,25	178	116	296	232-464	2-12	89	70	1,54

Tableau 3 *(suite)*

Tension assignée U_r kV	Séquence d'essais	Facteur de premier pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Première tension de référence u_1 kV	Temps t_1 µs	Valeur de crête de la TTR u_c kV	Temps t_2 µs	Retard t_d µs	Tension u' kV	Temps t' µs	VATR[b] u_1/t_1 kV/µs
170	Défaut aux bornes	1,3	1,40	135	68	253	272	2	68	36	2
	Défaut proche en ligne	1	1,40	104	52	194	208	2	52	28	2
	Discordance de phases	2	1,25	208	136	347	272-544	2-14	104	81	1,54

[a] Dans le cas de défauts proches en ligne, la TTR et les temps sont ceux du circuit d'alimentation.

[b] VATR = vitesse d'accroissement de la tension de rétablissement.

Tableau 4 – Valeurs normales de la TTR [a] – Tensions assignées de 100 kV à 170 kV, cas de réseaux à neutre non effectivement à la terre – Représentation par quatre paramètres

Tension assignée U_r kV	Séquence d'essais	Facteur de premier pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Première tension de référence u_1 kV	Temps t_1 µs	Valeur de crête de la TTR u_c kV	Temps t_2 µs	Retard t_d µs	Tension u' kV	Temps t' µs	VATR [b] u_1/t_1 kV/µs
100	Défaut aux bornes	1,5	1,40	92	46	171	184	2	46	25	2
	Défaut proche en ligne	1	1,40	61	31	114	124	2	31	17	2
	Discordance de phases	2,5	1,25	153	92	255	184-368	2-9	77	55	1,67
123	Défaut aux bornes	1,5	1,40	113	56	211	224	2	56	30	2
	Défaut proche en ligne	1	1,40	75	38	141	152	2	38	21	2
	Discordance de phases	2,5	1,25	188	112	314	224-448	2-11	94	67	1,67

Tableau 4 *(suite)*

Tension assignée U_r kV	Séquence d'essais	Facteur de premier pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Première tension de référence u_1 kV	Temps t_1 µs	Valeur de crête de la TTR u_c kV	Temps t_2 µs	Retard t_d µs	Tension u' kV	Temps t' µs	VATR [b] u_1/t_1 kV/µs
145	Défaut aux bornes	1,5	1,40	133	67	249	268	2	67	35	2
	Défaut proche en ligne	1	1,40	89	44	166	176	2	44	24	2
	Discordance de phases	2,5	1,25	222	134	370	268-536	2-13	111	79	1,67
170	Défaut aux bornes	1,5	1,40	156	78	291	312	2	78	41	2
	Défaut proche en ligne	1	1,40	104	52	194	208	2	52	28	2
	Discordance de phases	2,5	1,25	260	156	434	312-624	2-16	130	94	1,67

[a] Dans le cas de défauts proches en ligne, la TTR et les temps sont ceux du circuit d'alimentation.

[b] VATR = vitesse d'accroissement de la tension de rétablissement.

Afin d'obtenir les valeurs de VATR et u_c pour les 2e et 3e pôles à couper, un multiplicateur doit être appliqué aux valeurs de VATR et u_c du premier pôle à couper avec le facteur de premier pôle applicable. Les valeurs de ces multiplicateurs sont données dans le Tableau 6.

Les multiplicateurs de VATR sont relatifs à u_1/t_1; les temps t_1 et t_2 sont les mêmes pour les premier, deuxième et dernier pôles.

Tableau 5 – Valeurs normales de la ~~TTR~~ tension transitoire de rétablissement [a] – Tensions assignées supérieures ou égales à 245 kV, cas de réseaux à neutre effectivement à la terre ~~– Représentation par quatre paramètres~~

Tension assignée U_r kV	Séquence d'essais	Facteur de premier pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Première tension de référence u_1 kV	Temps t_1 µs	Valeur de crête de la TTR u_c kV	Temps t_2 µs	Retard t_d µs	Tension u' kV	Temps t' µs	VATR[b] u_1/t_1 kV/µs
245	Défaut aux bornes	1,3	1,40	195	98	364	392	2	98	51	2
	Défaut proche en ligne	1	1,40	150	75	280	300	2	75	40	2
	Discordance de phases	2	1,25	300	196	500	392-784	2-20	150	117	1,54
300	Défaut aux bornes	1,3	1,40	239	119	446	476	2	119	62	2
	Défaut proche en ligne	1	1,40	184	92	343	368	2	92	48	2
	Discordance de phases	2	1,25	367	238	612	476-952	2-24	184	143	1,54
362	Défaut aux bornes	1,3	1,40	288	144	538	576	2	144	74	2
	Défaut proche en ligne	1	1,40	222	111	414	444	2	111	57	2
	Discordance de phases	2	1,25	443	288	739	576-1152	2-29	222	173	1,54
420	Défaut aux bornes	1,3	1,40	334	167	624	668	2	167	86	2
	Défaut proche en ligne	1	1,40	257	129	480	516	2	129	66	2
	Discordance de phases	2	1,25	514	334	857	668-1336	2-33	257	202	1,54
550	Défaut aux bornes	1,3	1,40	438	219	817	876	2	219	111	2
	Défaut proche en ligne	1	1,40	337	168	629	672	2	168	86	2
	Discordance de phases	2	1,25	674	438	1 123	876-1752	2-44	337	263	1,54
800	Défaut aux bornes	1,3	1,40	637	318	1 189	1 272	2	318	161	2
	Défaut proche en ligne	1	1,40	490	245	914	980	2	245	124	2
	Discordance de phases	2	1,25	980	636	1 633	1272-2544	2-64	490	382	1,54

Tableau 5 *(suite)*

Tension assignée U_r kV	Séquence d'essais	Facteur de premier pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Première tension de référence u_1 kV	Temps t_1 µs	Valeur de crête de la TTR u_c kV	Temps t_2 µs	Retard t_d µs	Tension u' kV	Temps t' µs	VATR[b] u_1/t_1 kV/µs
1 100	Défaut aux bornes	1,2	1,50	808	404	1 617	1 212	2	404	204	2
	Défaut proche en ligne	1	1,50	674	337	1 347	1 011	2	337	170	2
	Discordance de phases	2	1,25	-	-	2 245	1 458	2-73	748	559	1,54
1 200	Défaut aux bornes	1,2	1,50	882	441	1 764	1 323	2	441	222	2
	Défaut proche en ligne	1	1,50	735	367	1 470	1 101	2	367	186	2
	Discordance de phases	2	1,25	-	-	2449	1590	2-80	816	610	1,54

[a] Dans le cas de défauts proches en ligne, la TTR et les temps sont ceux du circuit d'alimentation.

[b] VATR = vitesse d'accroissement de la tension de rétablissement.

Tableau 6 – Valeurs normales des multiplicateurs pour la tension transitoire de rétablissement pour les 2^e^ et 3^e^ pôles à couper à des tensions assignées supérieures à 1 kV

Facteur de premier pôle k_{pp}	Multiplicateurs			
	2^e^ pôle à couper		3^e^ pôle à couper	
	VATR	u_c	VATR	u_c
Cas de réseaux à neutre effectivement à la terre				
1,2	0,95	0,95	0,83	0,83
1,3	0,95	0,98	0,70	0,77
Cas de réseaux à neutre non effectivement à la terre				
1,5	0,70	0,58	0,70	0,58

Les multiplicateurs du Tableau 6 ont été calculés à partir des hypothèses suivantes:

– seuls les défauts triphasés à la terre sont pris en compte;

– la vitesse d'accroissement de la tension de rétablissement (VATR) à 100 % du courant de court-circuit dépend principalement des lignes aériennes et est calculée comme le produit du di/dt au passage par zéro du courant par l'impédance d'onde équivalente;

– l'impédance d'onde équivalente est calculée à partir des impédances d'onde homopolaire (Z_0) et directe (Z_1) vues aux bornes du disjoncteur. Une valeur approximative de 2 a été prise pour le rapport Z_0/Z_1;

– la valeur de crête de la TTR (u_c) est proportionnelle à la valeur instantanée de la tension à fréquence industrielle à l'instant de coupure.

Voir aussi les Figures 13 et 14.

NOTE 1 Ce tableau est valable pour les séquences d'essais T10, T30, T60, T100s et T100a. En ce qui concerne la séquence d'essais T100a, il convient d'appliquer la procédure de réduction de la TTR, comme indiqué dans l'Annexe P pour le premier pôle qui coupe. Pour faciliter les essais, et avec l'accord du constructeur, il est possible de ne pas appliquer la réduction de la TTR.

NOTE 2 Les valeurs sont des valeurs arrondies qui dépendent du rapport Z_0/Z_1 des circuits de TTR, de la constante de temps du système et des tensions assignées.

4.102.4 Valeur normale de la TTRI assignée

Tableau 7 – Valeurs normales de la tension transitoire de rétablissement initiale – Tensions assignées supérieures ou égales à 100 kV

Tension assignée U_r kV	Coefficient multiplicateur servant à déterminer u_i en fonction de la valeur efficace du pouvoir de coupure en court-circuit I_{sc}* f_i kV/kA		Temps t_i µs
	50 Hz	60 Hz	
100	0,046	0,056	0,4
123	0,046	0,056	0,4
145	0,046	0,056	0,4
170	0,058	0,070	0,5
245	0,069	0,084	0,6
300	0,081	0,098	0,7
362	0,092	0,112	0,8
420	0,092	0,112	0,8
550	0,116	0,139	1,0
800	0,159	0,191	1,1
1 100	0,173	0,208	1,5
1 200	0,173	0,208	1,5

NOTE Ces valeurs couvrent à la fois les défauts triphasés et monophasés et sont fondées sur l'hypothèse que le jeu de barres, y compris les éléments qui y sont raccordés (supports, transformateurs de courant et de tension, sectionneurs, etc.) peut être approximativement représenté par une impédance d'onde résultante Z_i d'environ 260 Ω dans le cas d'une tension assignée ~~inférieure à~~ de 800 kV ~~et par une~~ pour laquelle l'impédance d'onde résultante Z_i est d'environ 325 Ω ~~dans le cas d'une tension assignée de 800 kV~~. La relation entre f_i et t_i est alors:

$$f_i = t_i \times Z_i \times \omega \times \sqrt{2}$$

où

$\omega = 2\pi f_r$ est la fréquence angulaire correspondant à la fréquence assignée du disjoncteur.

* Les tensions de crête initiale réelles sont obtenues en multipliant les valeurs de ces colonnes par la valeur efficace du ~~pouvoir de coupure en court-circuit~~ courant de court-circuit.

4.103 Pouvoir de fermeture assigné en court-circuit

~~Le pouvoir de fermeture assigné en court-circuit d'un disjoncteur dont les pôles sont manœuvrés simultanément, voir la Figure 8, est celui qui correspond à la tension assignée et à la fréquence assignée. Les valeurs suivantes s'appliquent:~~

– ~~pour une fréquence assignée de 50 Hz et la valeur normalisée de la constante de temps de 45 ms (voir 4.101.2), le pouvoir de fermeture est égal à 2,5 fois la valeur efficace de la composante périodique de son pouvoir de coupure assigné en court-circuit (voir 4.101);~~
– ~~pour une fréquence assignée de 60 Hz et la valeur normalisée de la constante de temps de 45 ms (voir 4.101.2), le pouvoir de fermeture est égal à 2,6 fois la valeur efficace de la composante périodique de son pouvoir de coupure assigné en court-circuit (4.101);~~
– ~~pour toutes les valeurs de la constante de temps des applications particulières (voir 4.101.2), le pouvoir de fermeture est égal à 2,7 fois la valeur efficace de la composante périodique de son pouvoir de coupure assigné en court-circuit, quelle que soit la fréquence assignée du disjoncteur (voir 4.101).~~

Le pouvoir de fermeture assigné en court-circuit (voir Figure 8) d'un disjoncteur est lié à

– la composante périodique du courant de court-circuit assigné;
– la constante de temps de la composante apériodique du courant assigné de court-circuit;
– la fréquence assignée.

Le pouvoir de fermeture assigné en court-circuit est obtenu en multipliant la valeur efficace de la composante périodique du pouvoir de coupure assigné en court-circuit (voir 4.101) par le facteur de crête donnée dans le Tableau 37.

Tableau 37 – Facteurs de crête pour le pouvoir de fermeture assigné en court-circuit

Facteur de crête p.u.	**Fréquence** Hz	**Constante de temps** ms
2,5	50	45
2,6	60	45
2,7	50 ou 60	> 45

4.104 Séquence de manœuvres assignée

Les caractéristiques assignées du disjoncteur sont rattachées à la séquence de manœuvres assignée. Il existe deux variantes de séquences de manœuvres assignées correspondant aux formules suivantes:

a) O – t – CO – t' – CO

Sauf spécification contraire:

t = 3 min pour les disjoncteurs qui ne sont pas prévus pour la refermeture automatique rapide;

t = 0,3 s, pour les disjoncteurs prévus pour fonctionner en refermeture automatique rapide (durée de coupure-établissement);

t' = 3 min.

NOTE Au lieu de t' = 3 min, d'autres valeurs: t' = 15 s et t' = 1 min sont aussi utilisées pour les disjoncteurs prévus pour fonctionner en refermeture automatique rapide.

b) CO – t'' – CO

avec:

t'' = 15 s pour les disjoncteurs qui ne sont pas prévus pour la refermeture automatique rapide

où

O représente une manœuvre d'ouverture;

CO représente une manœuvre de fermeture suivie immédiatement (c'est-à-dire sans délai intentionnel) d'une manœuvre d'ouverture;

t, t' et t''sont les intervalles de temps entre deux manœuvres successives;

il convient que t et t' *soient* toujours exprimés en minutes ou en secondes et que t'' soit toujours exprimé en secondes.

Si la durée de coupure-établissement est réglable, les limites de réglage doivent être spécifiées.

4.105 Caractéristiques pour les défauts proches en ligne

~~Des caractéristiques pour les défauts proches en ligne sont exigées pour les disjoncteurs de classe S2 dont la tension assignée est égale ou supérieure à 15 kV et le pouvoir de coupure assigné en court-circuit supérieur à 12,5 kA. Des caractéristiques pour les défauts proches en ligne sont aussi exigées pour les disjoncteurs dont la tension assignée est supérieur ou égale à 100 kV. Ces caractéristiques correspondent à la coupure d'un défaut monophasé dans un réseau à neutre à la terre, où le facteur de premier pôle est égal à 1,0.~~

Les caractéristiques pour les essais de défaut proche en ligne sont requises pour les disjoncteurs de classe S2 prévus pour être directement raccordés à des lignes aériennes, quel que soit le type de réseau du côté alimentation, et ayant une tension assignée supérieure ou égale à 15 kV et inférieure à 100 kV et un pouvoir de coupure assigné en court-circuit supérieur à 12,5 kA. Des caractéristiques pour les défauts proches en ligne sont également exigées pour tous les disjoncteurs prévus pour être directement raccordés à des lignes aériennes et dont la tension assignée est égale ou supérieure à 100 kV et le pouvoir de coupure assigné en court-circuit supérieur à 12,5 kA.

NOTE Dans cette norme, un essai effectué en monophasé à la tension phase-terre couvre tous les types de défauts proches en ligne (voir ~~Tableau 8~~ L.3).

Le circuit correspondant au défaut proche en ligne se compose d'un circuit d'alimentation du côté où le disjoncteur est relié à la source de puissance et d'une ligne courte du côté de la charge (voir Figure 15), il possède les caractéristiques assignées suivantes:

a) caractéristiques du circuit d'alimentation:

   – tension égale à la tension phase-terre $U_r/\sqrt{3}$ ~~correspondant à la tension assignée U_r~~ du disjoncteur;

   – courant du court-circuit, si l'on réalise un défaut aux bornes, égal au pouvoir de coupure assigné en court-circuit du disjoncteur;

   – tension transitoire de rétablissement présumée, pour le défaut en ligne, correspondant aux valeurs normales du:

     - Tableau 2, pour les disjoncteurs dans les réseaux aériens de tensions assignées supérieures ou égale à 15 kV et inférieures à 100 kV;
     - Tableau 3 et du Tableau 4, pour les disjoncteurs de tensions assignées de 100 kV à 170 kV inclus;
     - Tableau 5, pour les disjoncteurs de tensions assignées supérieures ou égales à 245 kV.

– caractéristiques de la TTRI, pour les disjoncteurs de tension assignée supérieure ou égale à 100 kV, déduites du Tableau 7.

b) caractéristiques de la ligne:

– les valeurs normales du facteur de VATR, basées sur une impédance d'onde de la ligne Z~~, de 450 Ω,~~ du facteur de crête ~~assigné~~ k et du temps de retard côté ligne t_{dL} sont indiquées dans le Tableau 8. Pour la détermination du retard côté ligne et de la vitesse d'accroissement de la tension côté ligne, voir la Figure 16;

– la méthode pour le calcul des tensions transitoires de rétablissement à partir des caractéristiques assignées est donnée dans l'Annexe A.

Tableau 8 – Valeurs normales des caractéristiques de ligne pour les défauts proches en ligne

~~Tension assignée~~	~~Nombre de conducteurs par phase~~	~~Impédance d'onde~~	~~Facteur de crête~~	~~Facteur de VATR~~		~~Retard~~
				~~50 Hz~~	~~60 Hz~~	
~~U_r kV~~		~~Z Ω~~	~~k~~	~~s* (kV/µs)/kA~~		~~t_{dL} µs~~
~~$15 \leq U_r \leq 38$~~	~~1~~	~~450~~	~~1,6~~	~~0,200~~	~~0,240~~	~~0,1~~
~~$48,3 \leq U_r \leq 170$~~	~~1 à 4~~	~~450~~	~~1,6~~	~~0,200~~	~~0,240~~	~~0,2~~
~~$U_r \geq 245$~~	~~1 à 4~~	~~450~~	~~1,6~~	~~0,200~~	~~0,240~~	~~0,5~~

~~NOTE Les valeurs couvrent les cas de défauts en ligne considérés dans cette norme. Pour des lignes très courtes (t_L < 5 t_{dL}), les exigences indiquées dans ce tableau ne peuvent pas être toutes respectées. Les procédures permettant d'aborder le cas des lignes très courtes sont données dans la brochure technique CIGRE 305 [4].~~

~~* Pour le facteur de VATR s, voir Annexe A.~~

Tensions assignées	Impédance d'onde	Facteur de crête	Facteur de VATR		Retard
			50 Hz	60 Hz	
U_r kV	Z Ω	k	s^b (kV/µs)/kA		t_{dL} µs
$15 \leq U_r \leq 38$	450	1,6	0,200	0,240	0,1
$48,3 \leq U_r \leq 170$	450	1,6	0,200	0,240	0,2
$245 \leq U_r \leq 800$	450	1,6	0,200	0,240	0,5
$U_r > 800$	330 [a]	1,6	0,147	0,176	0,5

NOTE Les valeurs couvrent les cas de défauts en ligne considérés dans cette norme. Pour des lignes très courtes ($t_L < 5t_{dL}$), les exigences indiquées dans ce tableau ne peuvent pas être toutes respectées. Les procédures permettant d'aborder le cas des lignes très courtes sont données dans la CEI 62271-306 [4].

[a] Comme décrit en 4.102.1, on peut utiliser une valeur de 450 Ω pendant l'essai pour satisfaire aux exigences de la TTRI.

[b] Pour le facteur de VATR s, voir Annexe A.

4.106 Pouvoir de fermeture et pouvoir de coupure assignés en discordance de phases

Le pouvoir de coupure assigné en discordance de phases est le courant maximal en discordance de phases que le disjoncteur doit pouvoir couper dans les conditions d'utilisation et de fonctionnement exigées dans cette norme et dans un circuit dont la tension de rétablissement est spécifiée ci-après.

La spécification d'un pouvoir de fermeture et d'un pouvoir de coupure assignés en discordance de phases n'est pas obligatoire. Si un tel pouvoir de coupure est spécifié, ce qui suit est applicable:

a) la tension de rétablissement à fréquence industrielle doit être égale à $2{,}0/\sqrt{3}$ fois la tension assignée pour les réseaux avec neutre effectivement à la terre et $2{,}5/\sqrt{3}$ fois la tension assignée pour les autres réseaux;

b) la tension transitoire de rétablissement doit être conforme au;
   - Tableau 1, pour les disjoncteurs dans les réseaux câblés de tensions assignées inférieures à 100 kV;
   - Tableau 2, pour les disjoncteurs dans les réseaux aériens de tensions assignées inférieures à 100 kV;
   - Tableau 3, pour les disjoncteurs de tensions assignées de 100 kV à 170 kV inclus pour réseaux à neutre relié effectivement à la terre;
   - Tableau 4, pour les disjoncteurs de tensions assignées de 100 kV à 170 kV inclus pour réseaux à neutre relié non effectivement à la terre;
   - Tableau 5, pour les disjoncteurs de tensions assignées supérieures ou égales à 245 kV.

c) sauf spécification contraire, le pouvoir de coupure assigné en discordance de phases doit être égal à 25 % du pouvoir de coupure assigné en court-circuit et le pouvoir de fermeture assigné en discordance de phases doit être égal à la valeur de crête du pouvoir de coupure assigné en discordance de phases.

   Les conditions normales d'emploi en ce qui concerne les pouvoirs de fermeture et de coupure assignés en discordance de phases sont les suivantes:
   - manœuvres d'ouverture et de fermeture effectuées conformément aux instructions données par le constructeur en ce qui concerne la manœuvre et l'emploi correct du disjoncteur et de son équipement auxiliaire;
   - conditions de mise à la terre du neutre du réseau correspondant à celles pour lesquelles le disjoncteur a été essayé;
   - absence de défaut de chaque côté du disjoncteur.

4.107 Pouvoir de coupure et pouvoir de fermeture assignés de courants capacitifs

La coupure ou l'établissement de courants capacitifs peut correspondre à une partie ou à toutes les séquences de fonctionnement d'un disjoncteur comme la manœuvre d'une ligne aérienne à vide, d'un câble à vide ou d'une batterie de condensateurs.

Si applicables, les caractéristiques assignées suivantes d'un disjoncteur en manœuvre de courants capacitifs doivent comprendre:

- pouvoir de coupure assigné de lignes à vide;
- pouvoir de coupure assigné de câbles à vide;
- pouvoir de coupure assigné de batterie unique de condensateurs;
- pouvoir de coupure assigné de batteries de condensateurs à gradins;
- pouvoir de fermeture assigné de batterie unique de condensateurs;
- pouvoir de fermeture assigné de batteries de condensateurs à gradins.

Les valeurs préférentielles de pouvoir de coupure et de pouvoir de fermeture assignés de courants capacitifs sont données dans le Tableau 9.

La tension de rétablissement en coupure de courants capacitifs dépend de:

– la mise à la terre du système;
– la mise à la terre de la charge capacitive, par exemple câble avec écran, banc de condensateurs, ligne de transport;
– l'influence mutuelle de phases adjacentes de la charge capacitive, par exemple câbles à ceinture, lignes aériennes;
– influence mutuelle de systèmes adjacents avec des lignes aériennes voisines;
– présence d'un ou deux défauts phase-terre.

Deux classes de disjoncteurs sont définis en fonction de leur caractéristique de réamorçage:

– classe C1: à faible probabilité de réamorçage en coupure de courants capacitifs;
– classe C2: à très faible probabilité de réamorçage en coupure de courants capacitifs.

NOTE 1 La probabilité est liée à la performance obtenue pendant les séries d'essais de type spécifiés en 6.111.

NOTE 2 Un disjoncteur peut être de la classe C2 pour une application (par exemple dans un système à neutre effectivement à la terre) et de classe C1 pour une autre application où la contrainte due à la tension rétablie est plus sévère (par exemple dans les systèmes à neutre non-effectivement à la terre).

NOTE 3 Les disjoncteurs qui ont une probabilité de réamorçage autre que celle des classes C1 ou C2 ne sont pas couverts par cette norme.

4.107.1 Pouvoir de coupure assigné de lignes à vide

Le pouvoir de coupure assigné de lignes à vide est le courant maximal de lignes à vide que le disjoncteur doit être capable de couper sous sa tension assignée dans les conditions d'utilisation et de fonctionnement exigées dans cette norme. La spécification d'un pouvoir de coupure assigné de lignes à vide est obligatoire pour les disjoncteurs de tensions assignées supérieures ou égales à 72,5 kV.

4.107.2 Pouvoir de coupure assigné de câbles à vide

Le pouvoir de coupure assigné de câbles à vide est le courant maximal de câbles à vide que le disjoncteur doit être capable de couper sous sa tension assignée dans les conditions d'utilisation et de fonctionnement exigées dans cette norme. La spécification d'un pouvoir de coupure assigné de câbles à vide n'est pas obligatoire; elle est exigée uniquement pour les disjoncteurs auxquels est attribuée la classe C1 ou C2 pour l'établissement et la coupure de courants de câbles à vide.

4.107.3 Pouvoir de coupure assigné de batterie unique de condensateurs

Le pouvoir de coupure assigné de batterie unique de condensateurs est le courant maximal de batterie unique de condensateurs que le disjoncteur doit être capable de couper sous sa tension assignée dans les conditions d'utilisation et de fonctionnement exigées dans cette norme. Ce pouvoir de coupure se rapporte à la coupure de batteries de condensateurs shunt lorsqu'il n'y a pas de condensateur shunt connecté sur le côté source du disjoncteur.

Tableau 9 – Valeurs préférentielles de pouvoir de coupure et de pouvoir de fermeture assignés de courants capacitifs

	Ligne	Câble	Batterie unique de condensateurs	Batterie de condensateurs à gradins		
Tension assignée	Pouvoir de coupure assigné de lignes à vide	Pouvoir de coupure assigné de câbles à vide	Pouvoir de coupure assigné de batterie unique de condensateurs	Pouvoir de coupure assigné de batterie de condensateurs à gradins	Pouvoir de fermeture assigné de batterie de condensateurs à gradins	Fréquence du courant d'appel
U_r kV, eff.	I_l A, eff.	I_c A, eff.	I_{sb} A, eff.	I_{bb} A, eff.	I_{bi} kA, crête	f_{bi} Hz
3,6	10	10	400	400	20	4 250
4,76	10	10	400	400	20	4 250
7,2	10	10	400	400	20	4 250
8,25	10	10	400	400	20	4 250
12	10	25	400	400	20	4 250
15	10	25	400	400	20	4 250
17,5	10	31,5	400	400	20	4 250
24	10	31,5	400	400	20	4 250
25,8	10	31,5	400	400	20	4 250
36	10	50	400	400	20	4 250
38	10	50	400	400	20	4 250
48,3	10	80	400	400	20	4 250
52	10	80	400	400	20	4 250
72,5	10	125	400	400	20	4 250
100	20	125	400	400	20	4 250
123	31,5	140	400	400	20	4 250
145	50	160	400	400	20	4 250
170	63	160	400	400	20	4 250
245	125	250	400	400	20	4 250
300	200	315	400	400	20	4 250
362	315	355	400	400	20	4 250
420	400	400	400	400	20	4 250
550	500	500	400	400	20	4 250
800	900					
1 100	1 200	-	-	-	-	-
1 200	1 300	-	-	-	-	-

NOTE 1 Les valeurs de ce tableau sont choisies dans un but de normalisation. Il s'agit de valeurs préférentielles et elles couvrent la majorité des applications types. Si des valeurs différentes sont nécessaires, toute valeur appropriée peut être spécifiée comme valeur assignée.

NOTE 2 Dans des cas réels, le courant d'appel peut être calculé à partir de l'Annexe H.

NOTE 3 Si des essais de manœuvre de batteries de condensateurs à gradins sont effectués, les essais de manœuvre d'une batterie unique de condensateurs ~~n'est~~ ne sont pas exigée.

NOTE 4 En fonction des conditions du système, la valeur de crête du courant d'appel et la fréquence du courant d'appel peuvent être plus élevées ou plus basses que les valeurs préférentielles données ci-dessus, par exemple selon que des réactances de limitation du courant sont utilisées ou non.

NOTE 5 Les valeurs préférentielles pour des tensions assignées de 1 100 kV et 1 200 kV sont fondées sur des applications à 50 Hz. Des valeurs supérieures de courant seront possibles dans l'avenir dans des systèmes fonctionnant à 60 Hz, l'expérience montre toutefois que ces courants supérieurs ne conduisent pas à une plus grande contrainte pour le disjoncteur car la tension de rétablissement est généralement le facteur dominant pour la coupure.

4.107.4 Pouvoir de coupure assigné de batterie de condensateurs à gradins

Le pouvoir de coupure assigné de batterie de condensateurs à gradins est le courant maximal de condensateurs que le disjoncteur doit être capable de couper sous sa tension assignée dans les conditions d'utilisation et de fonctionnement exigées dans cette norme.

Ce pouvoir de coupure se rapporte à la manœuvre d'une batterie de condensateurs shunt lorsqu'une ou plusieurs batteries de condensateurs sont connectées du côté source du disjoncteur, fournissant un courant d'appel établi égal au pouvoir de fermeture assigné de batterie de condensateurs à gradins.

NOTE Des conditions similaires sont, en principe, applicables à la coupure des câbles.

4.107.5 Pouvoir de fermeture assigné de batterie unique de condensateurs

Aucune caractéristique assignée ni valeur préférentielle n'est définie. Ceci est dû au fait que les courants d'appel associés aux batteries uniques de condensateurs ne sont pas considérés comme critiques.

4.107.6 Pouvoir de fermeture assigné de batterie de condensateurs à gradins

Le pouvoir de fermeture assigné de batteries de condensateurs à gradins est la valeur de crête du courant que le disjoncteur doit être capable d'établir sous sa tension assignée et avec une fréquence du courant d'appel appropriée aux conditions de service (voir Tableau 9).

4.108 Manœuvre de charges inductives

Aucune caractéristique assignée n'est spécifiée. Voir la CEI 62271-110.

4.109 Durées assignées

Se référer aux Figures 1, 2, 3, 4, 5, 6 et 7.

Des valeurs assignées peuvent être données pour les durées suivantes:

– durée d'ouverture (à vide);
– durée de coupure;
– durée de fermeture (à vide);
– durée d'ouverture-fermeture (à vide);
– durée de refermeture (à vide);
– durée de fermeture-ouverture (à vide);
– durée de pré-insertion (à vide).

Les durées assignées se rapportent

– à la tension assignée d'alimentation des dispositifs de fermeture et d'ouverture et des circuits auxiliaires et de commande (voir 4.8);
– à la fréquence assignée d'alimentation des dispositifs de fermeture et d'ouverture et des circuits auxiliaires (voir 4.9);
– aux pressions assignées d'alimentation en gaz comprimé pour la manœuvre, pour l'isolement et pour la coupure, si applicable (voir 4.10);
– à la pression assignée d'alimentation hydraulique pour la manœuvre;
– à la température de l'air ambiant de 20 °C ± 5 °C.

NOTE Assigner une durée d'établissement ou une durée d'établissement-coupure n'a habituellement pas d'utilité pratique à cause de la variation de la durée d’arc et de la durée de préamorçage.

4.109.1 Durée de coupure assignée

~~La durée de coupure maximale déterminée pendant les séquences d'essais T30, T60 et T100s de 6.106.2, 6.106.3 et 6.106.4 ne doit pas dépasser la durée de coupure assignée, le disjoncteur étant manœuvré d’une part avec la tension et la fréquence d'alimentation auxiliaire à leurs valeurs assignées, et d’autre part avec la valeur assignée de la pression d’alimentation hydraulique ou pneumatique à la température de l'air ambiant de 20 °C ± 5 °C.~~

~~NOTE 1 Conformément à 6.102.3.1, il est recommandé d'effectuer les principales séquences d'essais en court-circuit, à l'exception de la séquence T100a, aux valeurs minimales de tension et/ou de pression pour la manœuvre et/ou la coupure. Afin de vérifier la durée de coupure assignée pendant ces séquences d'essais et pour tenir compte du fait que la tension d'alimentation auxiliaire et la pression sont plus basses, il convient de modifier la durée de coupure maximale enregistrée de la façon suivante:~~

$$\cancel{t_b \geq t_1 - (t_2 - t_3)}$$

~~où~~

~~t_b est la durée de coupure assignée;~~

~~t_1 est la durée de coupure maximale enregistrée pendant les séquences d'essais T30, T60 et T100s;~~

~~t_2 est la durée d'ouverture maximale enregistrée à vide avec la tension d'alimentation auxiliaire et les pressions pour la manœuvre et/ou la coupure égales à celles utilisées durant les séquences d'essais T30, T60 et T100s;~~

~~t_3 est la durée d'ouverture assignée.~~

~~Si la durée de coupure déterminée selon cette procédure dépasse la durée de coupure assignée, la séquence d'essais qui a donné la durée de coupure la plus longue peut être répétée avec la tension et la fréquence d'alimentation auxiliaire et la pression assignée pour la manœuvre et/ou la coupure égales à leurs valeurs assignées.~~

~~NOTE 2 Pour les essais en monophasé représentant une manœuvre triphasée, la durée de coupure enregistrée, modifiée conformément à la Note 1, peut dépasser la durée de coupure assignée de un dixième de période car les zéros de courant se produisent moins fréquemment dans ces conditions qu'en triphasé.~~

~~NOTE 3 Il convient que la durée de coupure pendant un cycle de manœuvre d'établissement-coupure de la séquence d'essais T100s ne dépasse pas, en principe, la durée de coupure assignée de plus d’une demi-période.~~

La durée de coupure assignée d'un disjoncteur est l'intervalle maximum entre la mise sous tension du circuit de déclenchement et l'interruption de courant dans le circuit principal pendant les séquences d'essais T30, T60 et T100s dans tous les pôles dans les conditions suivantes:

– tension et fréquence assignées auxiliaires;
– pressions assignées pour la manœuvre, pour l'isolement et pour la coupure;
– température de l'air ambiant de (20 ± 5) °C.

Conformément à 6.102.3.1, il convient d'effectuer les principales séquences d'essais en court-circuit, à l'exception de la séquence T100a, aux valeurs minimales de tension auxiliaire et/ou de pression pour la manœuvre et/ou la coupure. Pour la commodité de l'essai, la tension d'alimentation auxiliaire peut être la valeur assignée ou maximale dans la mesure où elle n'influe pas sur le pouvoir de fermeture ou de coupure. (Les durées de manœuvre de certains disjoncteurs peuvent varier en fonction de la tension d'alimentation des circuits auxiliaires). Afin de vérifier la durée de coupure assignée pendant ces séquences d'essais et pour tenir compte du fait que la tension d'alimentation des circuits auxiliaires et les pressions sont plus basses, il convient de modifier la durée de coupure maximale de la façon suivante:

$$t_{bmax} = t_{bm} + t_w - (t_{om} - t_{or})$$

où

t_{bmax} est la durée de coupure maximale déterminée;

t_{bm} est la plus longue des durées de coupure minimales enregistrées pendant les séquences d'essais T30, T60 et T100s;

Noter que t_{bm} correspond au dernier pôle qui coupe dans le cas d'un essai triphasé.

t_w est la fenêtre d'arc nécessaire, exprimée en ms;

– pour les essais monophasés en substitution des essais triphasés
  - réseaux à neutre non effectivement reliés à la terre: t_{we} = 150 – dα
  - réseaux à neutre effectivement reliés à la terre: t_{we} = 180 – dα

– pour les essais triphasés
  - t_{we} = 60 – dα

t_{we} est exprimé en degrés électriques

$t_w = T \times t_{we}/360$

T période de la fréquence industrielle (20 ms pour 50 Hz, 16,7 ms pour 60 Hz)

dα est le pas de variation de l'ordre d'ouverture pour la recherche de la durée d'arc minimale, il est égal à 18 degrés électriques

t_{om} est la durée d'ouverture maximale enregistrée à vide avec la tension minimale d'alimentation des circuits auxiliaires et les pressions minimales pour la manœuvre et/ou la coupure.

t_{or} est la durée d'ouverture maximale enregistrée à vide, avec la tension d'alimentation auxiliaire et les pressions pour la manœuvre avec les conditions assignées.

Si la durée de coupure maximale déterminée selon cette procédure dépasse la durée de coupure assignée, la séquence d'essais qui a donné la durée de coupure la plus longue peut être répétée avec la tension et la fréquence d'alimentation des circuits auxiliaires et la pression assignée pour la manœuvre et/ou la coupure égales à leurs valeurs assignées.

La durée de coupure assignée est définie en se fondant sur la durée d'arc minimale, car la durée d'arc enregistrée la plus longue pendant les essais peut être plus longue que dans les conditions réelles sur site.

NOTE La durée de coupure pendant une manœuvre d'établissement-coupure peut être plus longue que celle d'une simple manœuvre de coupure pour certaines conceptions de disjoncteurs. Ces durées de coupure plus longues peuvent influer sur la stratégie de protection et la stabilité du réseau si le retard est plus long que la durée de relayage. Il convient que les utilisateurs informent le constructeur de la durée de coupure maximale admissible pendant les manœuvres d'établissement-coupure.

4.110 Nombre de manœuvres mécaniques

Un disjoncteur doit être capable d'effectuer le nombre de manœuvres suivant en tenant compte du programme de maintenance spécifié par le constructeur:

Disjoncteur standard (endurance mécanique normale) **classe M1**	2 000 séquences de manœuvres
Disjoncteur pour des exigences spéciales de service (endurance mécanique accrue) **classe M2**	10 000 séquences de manœuvres

4.111 Classification des disjoncteurs en fonction de leur endurance électrique

Les disjoncteurs pour lesquels une endurance électrique est exigée, prévus pour le réenclenchement automatique comme il est d'usage dans les réseaux de lignes aériennes, et pour des tensions assignées inférieures ou égales à 52 kV, font partie de la classe E2 définie en 3.4.113 et sont essayés comme indiqué en 6.112.2 et au Tableau 33.

Les disjoncteurs pour lesquels une endurance électrique est exigée, mais prévus pour être utilisés sans réenclenchement automatique, par exemple dans les réseaux avec liaisons par câbles, et pour des tensions assignées inférieures ou égales à 52 kV, font partie de la classe E2 définie en 3.4.113 et sont essayés comme indiqué en 6.112.1.

La classe E2 désigne une endurance électrique accrue.

Les disjoncteurs pour lesquels une endurance électrique n'est pas exigée font partie de la classe E1 définie en 3.4.112 et désignant une endurance électrique de base.

NOTE Pour les disjoncteurs de tensions assignées supérieures à 72,5 kV des lignes directrices sont données dans la CEI 62271-310 [5].

5 Conception et construction

5.1 Exigences pour les liquides utilisés dans les disjoncteurs

Le paragraphe 5.1 de la CEI 62271-1 est applicable.

5.2 Exigences pour les gaz utilisés dans les disjoncteurs

Le paragraphe 5.2 de la CEI 62271-1 est applicable.

5.3 Raccordement à la terre des disjoncteurs

Le paragraphe 5.3 de la CEI 62271-1 est applicable.

5.4 Equipements auxiliaires

Le paragraphe 5.4 de la CEI 62271-1 est applicable avec les compléments suivants:

– lorsque des déclencheurs shunt d'ouverture et de fermeture sont utilisés, des mesures appropriées doivent être prises pour éviter d'endommager les déclencheurs quand des ordres sont maintenus en permanence à l'ouverture ou à la fermeture. Par exemple des contacts de commande en série peuvent être utilisés pour que lorsque le disjoncteur est fermé, le contact du déclencheur de fermeture (contact « b » ou contact d'ouverture) est ouvert et le contact de commande du déclencheur d'ouverture (contact « a » ou contact de fermeture) est fermé, et lorsque le disjoncteur est ouvert, le contact de commande du déclencheur d'ouverture est ouvert et le contact de commande du déclencheur de fermeture est fermé;

NOTE 1 Des systèmes autres que des contacts sont possibles et peuvent être utilisés.

– pour les déclencheurs shunt de fermeture, des mesures de protection des déclencheurs de fermeture, comme indiqué dans le premier alinéa ci-dessus, ne doivent pas fonctionner avant la durée minimale de l'ordre de fermeture (3.7.147) exigée par le disjoncteur, et plus tard que la durée de fermeture assignée;

NOTE 2 Si le courant du déclencheur shunt de fermeture est coupé par le contact de commande, il y a lieu que la durée de l'ordre de fermeture soit, de façon sûre, plus longue que la durée de fermeture assignée.

– pour les déclencheurs shunt d'ouverture, des mesures de protection des déclencheurs d'ouverture, comme indiqué dans le premier alinéa ci-dessus, ne doivent pas fonctionner avant la durée minimale de l'ordre d'ouverture (3.7.146) exigée par le disjoncteur et au plus tard 20 ms après la séparation des contacts principaux;

– dans le cas d'exigences de courte durée de fermeture-ouverture, des mesures de protection des déclencheurs d'ouverture, comme indiqué dans le premier alinéa ci-dessus, ne doivent pas fonctionner avant que les contacts principaux ne se soient fermés et doivent fontionner au plus tard un demi-cycle après la fermeture des contacts principaux;
– lorsque des contacts auxiliaires sont utilisés comme indicateurs de position, ils doivent indiquer la position finale du disjoncteur au repos, ouvert ou fermé. La signalisation doit être maintenue;
– les connexions doivent supporter les contraintes imposées par le disjoncteur, spécialement celles qui sont dues aux efforts mécaniques pendant les manœuvres;
– dans le cas de disjoncteurs pour l'extérieur, tous les équipements auxiliaires, y compris la filerie, doivent être protégés correctement contre la pluie et l'humidité;
– lorsqu'on utilise un équipement de commande particulier pour les disjoncteurs, il doit fonctionner dans les limites spécifiées pour les tensions d'alimentation des circuits auxiliaires et de commande, et pour les fluides de manœuvre et coupure et/ou d'isolement, de plus il doit pouvoir manœuvrer les charges indiquées par le constructeur du disjoncteur;
– les équipements auxiliaires spéciaux tels qu'indicateurs de niveau de liquide, indicateurs de pression, soupapes de sécurité, équipement de remplissage et de vidange, chauffage et contacts de verrouillage, doivent fonctionner dans les limites spécifiées des tensions d'alimentation des circuits auxiliaires et de commande et/ou dans les limites d'utilisation des fluides de manœuvre et de coupure et/ou d'isolement;
– la puissance consommée par les résistances de chauffage à la tension assignée doit avoir la valeur indiquée par le constructeur à ± 10 % près;
– lorsque des dispositifs d'anti-pompage font partie du schéma de commande du disjoncteur et si l'installation en comporte plus d'un, ils doivent agir sur chaque circuit de commande;
– lorsqu'un schéma de contrôle de discordance de phases fait partie du disjoncteur, la position des pôles, ouvert ou fermé, doit être surveillée. En fonction de l'application, la temporisation doit pouvoir être ajustée entre 0,1 s et 3 s.

5.5 Fermeture dépendante à source d'énergie extérieure

Le paragraphe 5.5 de la CEI 62271-1 est applicable avec le complément suivant:

– un disjoncteur comportant un dispositif de fermeture dépendante à source d'énergie extérieure doit aussi être capable de s'ouvrir immédiatement après la manœuvre de fermeture au pouvoir de fermeture assigné en court-circuit.

5.6 Fermeture à accumulation d'énergie

Le paragraphe 5.6 de la CEI 62271-1 est applicable avec le complément suivant au premier alinéa.

Un disjoncteur comportant un dispositif de fermeture à accumulation d'énergie doit aussi être capable de s'ouvrir immédiatement après la manœuvre de fermeture au pouvoir de fermeture assigné en court-circuit.

5.7 Manœuvre manuelle indépendante

Le paragraphe 5.7 de la CEI 62271-1 ne s'applique pas aux disjoncteurs.

5.8 Fonctionnement des déclencheurs

Le paragraphe 5.8 de la CEI 62271-1 est applicable avec les compléments suivants:

5.8.101 Déclencheur à maximum de courant

5.8.101.1 Courant de fonctionnement

Un déclencheur à maximum de courant doit porter l'indication de son courant assigné en service continu et de son domaine de courant de réglage.

Dans les limites du domaine du courant de réglage, le déclencheur à maximum de courant doit toujours fonctionner pour des courants supérieurs ou égaux à 110 % du courant de réglage et ne doit jamais fonctionner pour des courants inférieurs ou égaux à 90 % de ce courant de réglage.

5.8.101.2 Durée de manœuvre

Pour un déclencheur à maximum de courant à temporisation inverse, la durée de manœuvre doit être mesurée à partir de l'instant où la surintensité est établie, jusqu'à l'instant où le déclencheur actionne le mécanisme d'ouverture du disjoncteur.

Le constructeur doit fournir des tableaux ou des courbes, chacun avec les tolérances applicables, indiquant la durée de manœuvre en fonction du courant entre deux et six fois le courant de fonctionnement. Ces tableaux ou ces courbes doivent être fournis pour des valeurs limites de réglage du courant de fonctionnement et de la temporisation.

5.8.101.3 Courant de retour à la position initiale

Si le courant dans le circuit principal tombe au-dessous d'une certaine valeur avant que l'intervalle de temps correspondant à la temporisation du déclencheur à maximum de courant se soit écoulé, le déclencheur ne doit pas poursuivre son fonctionnement et doit revenir à sa position initiale.

L'indication correspondante doit être donnée par le constructeur.

5.8.102 Déclencheurs multiples

Si le disjoncteur est équipé avec des déclencheurs multiples de même fonction, un défaut sur un déclencheur ne doit pas influer sur le fonctionnement des autres. Les déclencheurs qui sont utilisés pour la même fonction doivent être physiquement distincts, c'est-à-dire découplés magnétiquement.

Il convient que les disjoncteurs de tension assignée égale ou supérieure à 72,5 kV soient prévus pour autoriser l'équipement d'un déclencheur additionnel de fermeture et d'un déclencheur additionnel d'ouverture.

5.8.103 Limites de fonctionnement des déclencheurs

La durée minimale d'ouverture des déclencheurs shunt d'ouverture et la durée minimale de commande des déclencheurs shunt de fermeture à la tension d'alimentation assignée ne doit pas être inférieure à 2 ms.

La tension minimale d'alimentation pour la manœuvre des déclencheurs shunt ne doit pas être inférieure à 20 % de la tension d'alimentation assignée.

5.8.104 Puissance consommée par les déclencheurs

Il convient que la puissance consommée par les déclencheurs shunt, d'ouverture ou de fermeture, d'un disjoncteur tripolaire ne dépasse pas 1 200 VA. Pour certaines conceptions de disjoncteurs, des valeurs plus élevées peuvent être exigées.

5.8.105 Relais intégrés pour disjoncteurs autodéclenchants

Lorsqu'un relais intégré est utilisé pour des disjoncteurs autodéclenchants, il doit être conforme à la CEI 60255-3. La grandeur d'alimentation d'entrée est le courant qui traverse les contacts principaux.

5.9 Verrouillages à basse et à haute pression

Le paragraphe 5.9 de la CEI 62271-1 est remplacé par ce qui suit:

Tous les disjoncteurs à accumulation d'énergie dans des réservoirs à gaz ou dans des accumulateurs oléopneumatiques (voir 5.6.1 de la CEI 62271-1) et tous les disjoncteurs utilisant un gaz comprimé pour la coupure (voir 5.103), à l'exception des appareils à pression scellés, doivent être équipés d'un dispositif de verrouillage à basse pression, et peuvent aussi être équipés d'un dispositif de verrouillage à haute pression, réglés pour fonctionner aux valeurs limites appropriées de la pression ou à l'intérieur des limites de pression indiquées par le constructeur.

5.10 Plaques signalétiques

Le paragraphe 5.10 de la CEI 62271-1 est applicable avec les compléments suivants: les plaques signalétiques du disjoncteur et de ses organes de manœuvre doivent porter des indications conformes au Tableau 10.

Les bobines des dispositifs de manœuvre doivent porter un repère permettant de retrouver les indications complètes chez le constructeur.

Les déclencheurs doivent porter les indications appropriées.

La plaque signalétique doit être visible dans les positions de service et de montage normales.

Tableau 10 – Indications de la plaque signalétique

	Abrévia-tion	Unité	Disjonc-teur	Dispositif de manœuvre	Condition: marquage seulement si
1	**2**	**3**	**4**	**5**	**6**
Constructeur			X	X	
Désignation du type et numéro de série			X	X	
Tension assignée	U_r	kV	X		
Tension de tenue assignée aux chocs de foudre	U_p	kV	X		
Tension de tenue assignée aux chocs de manœuvre	U_s	kV	y		Tension assignée supérieure ou égale à 300 kV
Fréquence assignée	f_r	Hz	y		Les caractéristiques assignées ne sont pas applicables à 50 Hz et 60 Hz
Courant assigné en service continu	I_r	A	X		
Durée de court-circuit assignée	t_k	s	y		Différente de 1 s
Pouvoir de coupure assigné en court-circuit	I_{sc}	kA	X		
Constante de temps de la composante apériodique du pouvoir de coupure assigné en court-circuit	τ	ms	y		Différente de 45 ms
Composante continue du pouvoir de coupure assigné en court-circuit à la séparation des contacts correspondant à la constante de temps de la composante apériodique du pouvoir de coupure assigné en court-circuit	p_{CS}	%	y		Supérieure à 20 %
Facteur de premier pôle	k_{pp}		y		Différent de 1,3 pour les tensions assignées 100 kV à 170 kV
Pouvoir de coupure assigné en discordance de phases	I_d	kA	(X)		
Pouvoir de coupure assigné de lignes à vide	I_l	A	y		Tension assignée supérieure ou égale à 72,5 kV
Pouvoir de coupure assigné de câbles à vide	I_c	A	(X)		
Pouvoir de coupure assigné de batterie unique de condensateurs	I_{sb}	A	(X)		
Pouvoir de coupure assigné de batteries de condensateurs à gradins	I_{bb}	A	(X)		
Pouvoir de fermeture assigné de batteries de condensateurs à gradins	I_{bi}	kA	(X)		
Pression assignée pour la manœuvre	p_{rm}	MPa		(X)	
Pression assignée pour la coupure	p_{re}	MPa	(X)		
Tension assignée d'alimentation des dispositifs de manœuvre pour la fermeture et l'ouverture	U_{op}	V		(X)	
Fréquence assignée d'alimentation des dispositifs de manœuvre pour la fermeture et l'ouverture		Hz		(X)	
Tension assignée d'alimentation des circuits auxiliaires	U_a	V		(X)	

Tableau 10 *(suite)*

	Abrévia-tion	**Unité**	**Disjonc-teur**	**Dispositif de manœuvre**	**Condition: marquage seulement si**
1	**2**	**3**	**4**	**5**	**6**
Fréquence assignée d'alimentation des circuits auxiliaires		Hz		(X)	
Masse (y compris l'huile pour les disjoncteurs à huile)	M	kg	y	y	Plus de 300 kg
Masse du fluide	m	kg	y		Si le disjoncteur contient du fluide
Séquence de manœuvres assignée			X		
Année de fabrication			X		
Classe de température			y	y	Différente de – 5 °C pour l'intérieur – 25 °C pour l'extérieur
Classe			y		Si différent de E1, M1, S1 pour les tensions assignées inférieures à 100 kV Si différent de E1, M1 pour les tensions assignées supérieures ou égales à 100 kV
Date de diffusion de la norme de référence			X	X	

X = le marquage de ces valeurs est obligatoire; pour ces valeurs, les indications qui n'apparaissent pas sur la plaque sont supposées avoir une valeur nulle.

(X) = le marquage de ces valeurs est facultatif.

y = le marquage de ces valeurs dépend des conditions figurant à la colonne 6.

NOTE Les abréviations de la colonne 2 peuvent être utilisées à la place des termes de la colonne 1. Lorsque les termes de la colonne 1 sont employés, il n'est pas nécessaire de faire apparaître le mot «assigné».

5.11 Verrouillages

Le paragraphe 5.11 de la CEI 62271-1 est applicable.

5.12 Indicateur de position

Le paragraphe 5.12 de la CEI 62271-1 est applicable.

5.13 Degrés de protection procurés par les enveloppes

Le paragraphe 5.13 de la CEI 62271-1 est applicable.

5.14 Lignes de fuite

Le paragraphe 5.14 de la CEI 62271-1 est applicable.

5.15 Etanchéité au gaz et au vide

Le paragraphe 5.15 de la CEI 62271-1 est applicable.

5.16 Etanchéité au liquide

Le paragraphe 5.16 de la CEI 62271-1 est applicable.

5.17 Risque de feu (ininflammabilité)

Le paragraphe 5.17 de la CEI 62271-1 est applicable.

5.18 Compatibilité électromagnétique

Le paragraphe 5.18 de la CEI 62271-1 est applicable.

5.19 Emission de rayons X

Le paragraphe 5.19 de la CEI 62271-1 est applicable.

5.20 Corrosion

Le paragraphe 5.20 de la CEI 62271-1 est applicable.

5.101 Exigences concernant la simultanéité des pôles pendant des manœuvres simples de fermeture et d'ouverture

S'il n'y a pas d'exigence particulière concernant le fonctionnement simultané des pôles, la différence maximale entre les instants d'entrée en contact à la fermeture dans les pôles individuels ne doit pas dépasser un quart de cycle à la fréquence assignée. Si un pôle possède plusieurs éléments de coupure connectés en série, la différence maximale entre les instants d'entrée en contact des éléments de coupure en série ne doit pas dépasser un sixième de cycle à la fréquence assignée. Lorsque des résistances de fermeture sont utilisées, la différence maximale entre les instants d'entrée en contact à la fermeture dans les inséreurs de résistances de fermeture individuelles ne doit pas dépasser une moitié de cycle à la fréquence assignée. Si, sur un pôle, plus d'une résistance de fermeture individuelle est utilisée, chacune étant attribuée à l'un des éléments de coupure connectés en série, la différence maximale entre les instants d'entrée en contact dans les inséreurs de résistances de fermeture en série ne doit pas dépasser un tiers de cycle à la fréquence assignée.

S'il n'y a pas d'exigence particulière concernant le fonctionnement simultané des pôles, la différence maximale entre les instants de séparation des contacts à l'ouverture ne doit pas dépasser un sixième de cycle à la fréquence assignée. Si un pôle possède plusieurs éléments de coupure connectés en série, la différence maximale entre les instants de séparation des contacts des éléments de coupure en série ne doit pas dépasser un huitième de cycle à la fréquence assignée.

NOTE Pour un disjoncteur ayant des pôles séparés, cette exigence est applicable lorsque ces pôles manœuvrent dans les mêmes conditions; après une manœuvre de refermeture unipolaire, les conditions de fonctionnement des trois mécanismes peuvent ne pas être identiques.

5.102 Exigence générale de fonctionnement

Un disjoncteur muni de ses organes de manœuvre doit pouvoir effectuer sa séquence de manœuvres assignée (4.104) conformément aux indications correspondantes de 5.5 à 5.9 et de 5.103, pour toute température ambiante de sa classe comme défini à l'Article 2 de la CEI 62271-1.

Cette exigence n'est pas applicable aux organes de manœuvre manuels auxiliaires; lorsqu'ils sont fournis, ils ne doivent être utilisés que pour l'entretien et pour des manœuvres de secours sur un circuit hors tension.

Les disjoncteurs munis de dispositifs de chauffage doivent être conçus pour autoriser une manœuvre d'ouverture à la température ambiante minimale, définie par la classe de température, lorsque le chauffage ne fonctionne pas pendant une durée minimale de 2 h.

5.103 Limites de pression des fluides pour la manœuvre

Le constructeur doit indiquer les pressions minimales et maximales du fluide pour la manœuvre pour lesquelles le disjoncteur est capable de fonctionner suivant ses caractéristiques assignées et auxquelles les dispositifs de verrouillage à basse et haute pressions doivent être réglés (voir 5.9). Le constructeur doit indiquer les pressions minimales pour la manœuvre et pour la coupure et l'isolement (voir 3.7.157 et 3.7.158).

Le constructeur peut spécifier les limites de pression pour lesquelles le disjoncteur est capable d'effectuer chacune des performances suivantes:

a) la coupure de son pouvoir de coupure assigné en court-circuit, c'est-à-dire une manœuvre «O»;

b) l'établissement de son pouvoir de fermeture assigné en court-circuit, suivi immédiatement de la coupure de son pouvoir de coupure assigné en court-circuit, c'est-à-dire un cycle de manœuvre «CO»;

c) pour les disjoncteurs prévus pour la refermeture automatique rapide: la coupure de son pouvoir de coupure assigné en court-circuit suivie, après un intervalle de temps *t* de la séquence de manœuvres assignée (4.104), par l'établissement de son pouvoir de fermeture assigné en court-circuit, immédiatement suivi par une nouvelle coupure de son pouvoir de coupure assigné en court-circuit, c'est-à-dire une séquence de manœuvres «O-*t*-CO».

Le disjoncteur doit comporter des réserves d'énergie de capacité suffisante pour lui permettre d'accomplir de façon satisfaisante les manœuvres appropriées aux valeurs indiquées des pressions minimales correspondantes.

5.104 Orifice d'évacuation

Les orifices d'évacuation sont des dispositifs qui permettent un échappement de l'huile ou du gaz contenu dans le disjoncteur pendant la manœuvre.

NOTE Cela est applicable aux disjoncteurs à air comprimé et à huile.

Les orifices d'évacuation des disjoncteurs doivent être placés de telle sorte que l'évacuation des vapeurs d'huile, du gaz ou des deux, ne provoque pas d'amorçage électrique et soit dirigée en dehors de toute zone dans laquelle une personne quelconque est susceptible de se trouver. La distance nécessaire de sécurité doit être indiquée par le constructeur.

La construction doit être telle que le gaz ne puisse s'accumuler à un endroit quelconque où l'inflammation peut être provoquée, pendant ou après la manœuvre, par des étincelles dues à la manœuvre normale du disjoncteur ou de ses équipements auxiliaires.

6 Essais de type

L'Article 6 de la CEI 62271-1 est applicable avec les compléments suivants:

Les essais de type de disjoncteurs sont donnés dans le Tableau 11. Le nombre de spécimens d'essais est donné en 6.1.1 et en 6.102.2. Pour les essais de type, les tolérances sur les paramètres d'essais sont données dans l'Annexe B.

En principe, chaque essai de type doit être effectué sur un disjoncteur à l'état neuf et propre. Dans le cas de disjoncteurs qui utilisent le SF_6 pour l'isolement, la coupure et/ou la manœuvre, la qualité du gaz doit au moins satisfaire aux critères d'acceptation de la CEI 60480.

La responsabilité du constructeur est limitée aux valeurs spécifiées et non aux valeurs obtenues au cours des essais de type.

L'incertitude des mesures effectuées par un oscillographe ou par des équipements équivalents (par exemple enregistreur transitoire), incluant tous ses dispositifs associés, sur les grandeurs qui définissent les caractéristiques assignées (par exemple courant en court-circuit, tension appliquée et tension de rétablissement) doit être comprise entre ±5 % (soit un facteur d'élargissement de 2,0).

NOTE La signification du facteur d'élargissement est donnée dans le Guide ISO sur les incertitudes de mesure (1995) [6].

Tableau 11 – Essais de type

Essais de type obligatoires		**Paragraphes**
Essais diélectriques		6.2
Mesurage de la résistance du circuit principal		6.4
Essais d'échauffement		6.5
Essais au courant de courte durée admissible et à la valeur de crête du courant admissible		6.6
Essais complémentaires sur les circuits auxiliaires et de commande		6.10
Essais mécaniques à température ambiante		6.101.2.1 à 6.101.2.3
Essais d'établissement et de coupure en court-circuit		6.102 à 6.106
Essais de type dépendant de l'application, des caractéristiques assignées ou de la conception	**Condition nécessitant un essai de type**	**Paragraphes**
Essais de tension de perturbation radioélectrique	$U_r \geq 123$ kV	6.3
Vérification du degré de protection	Classe IP assignée	6.7
Essai d'étanchéité	Systèmes à pression contrôlés, scellés ou fermés	6.8
Essais de compatibilité électromagnétique (CEM)	Les équipements ou composants électroniques sont inclus dans le système secondaire	6.9
Essais d'endurance mécanique accrue pour les disjoncteurs prévus pour des conditions spéciales de service *#	Caractéristiques assignées de Classe M2	6.101.2.4
Essais à haute et à basse températures	Classe de température assignée	6.101.3
Essai d'humidité	Isolation soumise à des contraintes de tension et de condensation	6.101.4
Essais avec des efforts statiques sur les bornes	Disjoncteur pour l'extérieur avec $U_r \geq 52$ kV	6.101.6
Essais au courant critique	Comportement du disjoncteur par rapport aux conditions de 6.107.1	6.107
Défaut proche en ligne * #	$U_r \geq 15$ kV et $I_{sc} > 12{,}5$ kA, ~~dans le~~ en cas ~~d'un raccordement~~ de connexions directes à des lignes aériennes ~~dans des réseaux à neutre à la terre~~	6.109
Essais d'établissement et de coupure en discordance de phases *#	Caractéristiques assignées en discordance de phases	6.110
Essais d'endurance électrique (uniquement pour $U_r \leq 52$ kV) *	Caractéristiques assignées de Classe E2	6.112
Essais pour vérifier le fonctionnement dans des conditions sévères de formation de glace *#	Disjoncteurs pour l'extérieur avec une épaisseur de glace assignée (10 mm/ 20 mm)	6.101.5
Essais en monophasé *#	Réseaux à neutre effectivement à la terre	6.108
Essais de défaut biphasé à la terre *#	Réseaux à neutre non-effectivement à la terre	6.108

Tableau 11 *(suite)*

Essais de type dépendant de l'application, des caractéristiques assignées ou de la conception	Condition nécessitant un essai de type	Paragraphes
Essais d'établissement et de coupure de courants capacitifs: – essais de coupure de courants de lignes à vide * – essais de coupure de courants de câbles à vide *# – essais d'établissement et de coupure de courants de batterie unique de condensateur *# – essais d'établissement et de coupure de courants de batterie de condensateurs à gradins *#	Caractéristiques et classification applicables assignées (C1 ou C2)	6.111.5.1 6.111.5.1 6.111.5.2 6.111.5.2
Manœuvre de réactances shunt et de moteurs *#	Caractéristiques assignées de coupure	CEI 62271-110
NOTE 1 Les essais de type obligatoires, présentés dans la partie supérieure du tableau, sont exigés pour tous les disjoncteurs, quelle que soit la tension assignée, la conception ou l'utilisation prévue. Les autres essais de type, présentés dans la partie inférieure du tableau, sont exigés pour tous les disjoncteurs pour lesquels les caractéristiques assignées associées sont spécifiées, par exemple l'établissement et la coupure en discordance de phases, ou pour lesquels une condition spécifique est satisfaite, par exemple la RIV n'est exigée que pour les tensions assignées supérieures ou égales à 123 kV. NOTE 2 Dans la partie inférieure du tableau, certains essais sont marqués par * ou #. Dans le cas de disjoncteurs de tension assignée inférieure ou égale à 52 kV, * est utilisé pour le marquage et, pour les disjoncteurs de tension assignée supérieure ou égale à 72,5 kV, # est utilisé pour le marquage. Pour chaque essai marqué, un spécimen d'essai supplémentaire peut être utilisé.		

6.1 Généralités

6.1.1 Groupement des essais

Le paragraphe 6.1.1 de la CEI 62271-1 est applicable.

6.1.2 Informations pour l'identification des spécimens d'essai

Le paragraphe 6.1.2 de la CEI 62271-1 est applicable.

6.1.3 Informations à inclure dans les rapports d'essais

Le paragraphe 6.1.3 de la CEI 62271-1 est applicable avec le complément suivant:

D'autres détails, concernant les enregistrements et les rapports d'essais de type d'établissement ou coupure de courant, et de tenue au courant de courte durée et à la valeur de crête du courant admissible, sont donnés à l'Annexe C.

6.1.101 Essais non valables

Dans le cas d'essais non valables, il peut devenir nécessaire d'effectuer un nombre d'essais supérieur à celui qu'exige la présente norme. Un essai non valable est un essai au cours duquel au moins un paramètre d'essai spécifié par la norme n'est pas atteint. Ceci comprend, par exemple, dans le cas d'essais d'établissement, de coupure ou de manœuvre, les courants, les tensions et les temps, ainsi que les exigences sur l'onde (si spécifié) et les particularités complémentaires des essais synthétiques comme la manœuvre correcte du disjoncteur auxiliaire et le temps d'injection correct.

L'écart par rapport à la norme peut rendre l'essai plus ou moins sévère. Quatre cas de figure sont envisagés dans le Tableau 12.

La partie non valable d'une séquence d'essais peut être répétée sans remise en état du disjoncteur. Cependant, en cas de défaillance du disjoncteur au cours de cet essai supplémentaire, ou à l'initiative du constructeur, le disjoncteur peut être remis en état et la séquence d'essais complète répétée. Dans ces cas, le rapport d'essai doit comprendre la référence à l’essai non valable. Dans le cas où le disjoncteur n'a pas été remis en état, le rapport d'essais doit indiquer la partie des essais qui n'est pas valable.

NOTE Dans une séquence de manœuvres à refermeture automatique rapide, le O – *t* – CO est considéré comme une partie, et le CO suivant est considéré comme une autre partie.

Un disjoncteur de classe E2 peut être remis en état, mais dans ce cas, la série d’essais complète doit être refaite.

Si l’enregistrement d’une manœuvre ne peut pas être produit pour des raisons techniques, cette manœuvre est considérée comme valable, dans la mesure où il peut être démontré que le disjoncteur n’a pas été en défaut et que les valeurs d’essai spécifiées étaient conformes.

Tableau 12 – Essais non valables

Conditions d’essais par rapport aux normes	Disjoncteur	
	Réussit	**Echoue**
Plus sévère	Essai valable, résultat accepté	Essais à refaire avec les paramètres corrects Modification de la conception du disjoncteur non nécessaire
Moins sévère	Essais à refaire avec les paramètres corrects Modification de la conception du disjoncteur non nécessaire	Le disjoncteur n’a pas réussi l’essai. Modification de la conception du disjoncteur nécessaire, pour améliorer les performances Essais à refaire avec le disjoncteur modifié La modification peut effecter les résultats des essais de type déjà effectués

6.2 Essais diélectriques

6.2.1 Conditions de l'air ambiant pendant les essais

Le paragraphe 6.2.1 de la CEI 62271-1 est applicable.

6.2.2 Modalité des essais sous pluie

Le paragraphe 6.2.2 de la CEI 62271-1 est applicable avec la note suivante:

NOTE Pour les disjoncteurs à cuve mise à la terre, les essais sous pluie peuvent être omis lorsque les traversées ont été essayées au préalable suivant la norme CEI applicable.

6.2.3 Etat du disjoncteur pendant les essais diélectriques

Le paragraphe 6.2.3 de la CEI 62271-1 est applicable.

6.2.4 Conditions de réussite aux essais

Le paragraphe 6.2.4 de la CEI 62271-1 est applicable avec le complément suivant:

Si des décharges disruptives se produisent et si la preuve que les décharges disruptives étaient exclusivement sur l’isolation autorégénératrice ne peut être donnée au cours de l’essai, le disjoncteur doit être démonté et inspecté après les séries d’essais diélectriques. Si des dommages de l'isolation (par exemple cheminement, perforation, etc.) non auto-régénératrice sont observés, le disjoncteur n’a pas satisfait aux essais.

NOTE 1 Si le facteur de correction atmosphérique K_t est inférieur à 1,00 mais supérieur à 0,95, il est autorisé de suivre les critères indiqués en 6.2.4 de la CEI 62271-1 si le facteur de correction n'est pas appliqué pendant les essais. Ensuite, si une ou deux décharges disruptives sur un ensemble de 15 chocs se produisent dans l'isolation externe, la série d'essais particulière présentant un ou des amorçages est répétée avec le facteur de correction approprié, de telle sorte qu'aucune décharge disruptive externe ne se produise.

NOTE 2 Pour les disjoncteurs d'appareillages à isolation gazeuse essayés avec des traversées qui ne font pas partie du disjoncteur, il convient de ne pas prendre en compte les amorçages sur les traversées d'essais.

6.2.5 Application de la tension d'essai et conditions d'essai

Le paragraphe 6.2.5 de la CEI 62271-1 est applicable.

6.2.6 Essais des disjoncteurs de $U_r \leq 245$ kV

Le paragraphe 6.2.6 de la CEI 62271-1 est applicable.

6.2.6.1 Essais de tension à fréquence industrielle

Le paragraphe 6.2.6.1 de la CEI 62271-1 est applicable avec la note suivante:

NOTE Dans le cas de disjoncteurs à cuve mise à la terre, les essais sous pluie peuvent être omis lorsque les traversées ont été essayées au préalable suivant la norme CEI applicable.

6.2.6.2 Essais de tension de choc de foudre

Le paragraphe 6.2.6.2 de la CEI 62271-1 est applicable.

6.2.7 Essais des disjoncteurs de $U_r > 245$ kV

Le paragraphe 6.2.7 de la CEI 62271-1 est applicable.

6.2.7.1 Essais de tension à fréquence industrielle

Le paragraphe 6.2.7.1 de la CEI 62271-1 est applicable avec le complément suivant:

La procédure d'essai qui suit la méthode en variante est plus sévère que celle qui suit la méthode préférentielle.

6.2.7.2 Essais de tension de choc de manœuvre

Le paragraphe 6.2.7.2 de la CEI 62271-1 est applicable avec le complément suivant:

Pour les disjoncteurs d'usage extérieur, les essais à sec doivent être effectués seulement à la polarité positive. Le disjoncteur étant en position de fermeture, on doit appliquer une tension d'essai égale à la tension de tenue assignée par rapport à la terre, pour chaque condition d'essai du Tableau 9 de la CEI 62271-1.

Le disjoncteur étant en position d'ouverture, on doit appliquer une tension d'essai égale à la tension de tenue assignée par rapport à la terre, pour chaque condition d'essai du Tableau 9 de la CEI 62271-1.

Pour les disjoncteurs prévus pour des applications spéciales, selon 4.2, une seconde série d'essais doit être effectuée avec les tensions d'essai de la colonne 6 du Tableau 2a ou 2b de la CEI 62271-1. Pour chaque condition d'essai du Tableau 11 de la CEI 62271-1, une borne doit être alimentée à la tension de choc de manœuvre et la borne opposée à la tension à fréquence industrielle.

Sous réserve de l'approbation du fabricant, l'essai avec le disjoncteur ouvert peut être effectué en évitant d'utiliser la source de tension à fréquence industrielle. Cette série d'essais consiste en une application, à chaque borne à tour de rôle, d'impulsions à une tension égale à la somme de la tension de choc de manœuvre et de la valeur de crête indiquée à la colonne 6 des Tableaux 2a et 2b dans la CEI 62271-1, la borne opposée étant reliée à la masse.

Le point b) de 6.2.5.2 de la CEI 62271-1 doit être pris en compte. En général, cet essai est plus sévère que celui de la procédure d'essais spécifiée.

6.2.7.3 Essais de tension de choc de foudre

Le paragraphe 6.2.7.3. de la CEI 62271-1 s'applique avec le complément suivant:

Le disjoncteur étant en position de fermeture, une tension d'essai égale à la tension de tenue assignée par rapport à la terre doit être appliquée, pour chaque condition d'essai du Tableau 9 de la CEI 62271-1.

Le disjoncteur étant en position d'ouverture, une tension d'essai égale à la tension de tenue assignée sur l'appareil ouvert doit être appliquée, pour chaque condition d'essai du Tableau 11 de la CEI 62271-1.

Sous réserve de l'approbation du constructeur, l'essai avec le disjoncteur ouvert peut être effectué en évitant d'utiliser la source de tension à la fréquence industrielle. Cette série d'essais applique à chaque borne à tour de rôle (ou sur une borne si la disposition des bornes est symétrique par rapport à la base), 15 chocs consécutifs à une tension égale à la somme de la tension de tenue au choc de foudre et de la valeur de crête indiquée à la colonne 8 du Tableau 2a ou 2b de la CEI 62271-1, la borne opposée étant reliée à la terre. Les points a) et b) de la CEI 62271-1 doivent être pris en compte. En général, cet essai est plus sévère que celui de la procédure d'essais spécifiée.

6.2.8 Essais de pollution artificielle

Le paragraphe 6.2.8 de la CEI 62271-1 est applicable.

6.2.9 Essais de décharges partielles

Le paragraphe 6.2.9 de la CEI 62271-1 est applicable avec le complément suivant:

La réalisation d'essais de décharges partielles sur le disjoncteur complet n'est normalement pas demandée. Toutefois, pour les disjoncteurs comportant des éléments auxquels s'applique une norme particulière de la CEI prévoyant des mesurages de décharges partielles (par exemple les traversées, voir la CEI 60137), le constructeur doit prouver que ces éléments ont satisfait aux essais de décharges partielles prévus par la norme particulière de la CEI.

6.2.10 Essais des circuits auxiliaires et de commande

Le paragraphe 6.2.10 de la CEI 62271-1 est applicable.

6.2.11 Essais de tension comme vérification d'état

Le paragraphe 6.2.11 de la CEI 62271-1 n'est pas applicable; les essais spécifiés ici sont remplacés par les suivants:

~~Lorsque, après des essais mécaniques ou d'environnement (voir 6.101.1.4), les propriétés d'isolement entre les contacts ouverts d'un disjoncteur ne peuvent pas être vérifiées avec suffisamment de confiance par examen visuel, un essai de tenue de tension à fréquence industrielle à sec, conformément à 6.2.11 de la CEI 62271-1, entre les bornes du disjoncteur ouvert, doit être appliqué comme vérification d'état. De plus, un essai de tenue de tension à la terre du disjoncteur en position fermée est exigé pour les disjoncteurs "dead tank" et GIS.~~

~~Pour les disjoncteurs avec ampoule à vide dans une enveloppe remplie de gaz, l'essai de tension comme vérification d'état peut ne pas être suffisant. Dans de tels cas l'intégrité du vide doit être démontrée.~~

~~Lorsque, après des essais d'établissement, de coupure ou de manœuvre (voir 6.102.9), un essai de tension est réalisé comme vérification d'état, les conditions suivantes doivent s'appliquer:~~

~~Pour les disjoncteurs ayant un arrangement asymétrique des pièces de passage du courant les connexions doivent être interverties. Les essais complets doivent être effectués une fois pour chaque disposition des connexions.~~

– ~~Disjoncteurs avec~~ $\cancel{U_r \leq 72{,}5\ \text{kV}}$

– ~~Un essai de tension à la fréquence industrielle de 1 min doit être effectué. La tension d'essai doit être égale à 80 % de la valeur indiquée dans le Tableau 1a, colonne (2) de la CEI 62271-1.~~

– ~~Disjoncteurs avec~~ $\cancel{72{,}5\ \text{kV} < U_r \leq 245\ \text{kV}}$

– ~~Un essai de tension de choc doit être effectué. La valeur de crête de la tension de choc doit être égale à 60 % de la valeur la plus élevée applicable du Tableau 1a, colonne (4) de la CEI 62271-1.~~

– ~~Disjoncteurs avec~~ $\cancel{300\ \text{kV} \leq U_r \leq 420\ \text{kV}}$

– ~~Un essai de tension de choc doit être effectué. La valeur de crête de la tension de choc doit être égale à 80 % de la tension assignée de tenue aux chocs de manœuvre indiquée au Tableau 2a de la CEI 62271-1. Dans le cas de disjoncteurs de GIS, la valeur de crête de la tension de choc doit être égale à 80 % de la tension assignée de tenue aux chocs de manœuvre indiquée au Tableau 103 de la CEI 62271-203.~~

– ~~Disjoncteurs avec~~ $\cancel{550\ \text{kV} \leq U_r \leq 800\ \text{kV}}$

– ~~Un essai de tension de choc doit être effectué. La valeur de crête de la tension de choc doit être égale à 90 % de la tension assignée de tenue aux chocs de manœuvre indiquée au Tableau 2a de la CEI 62271-1. Dans le cas de disjoncteurs de GIS, la valeur de crête de la tension de choc doit être égale à 90 % de la tension assignée de tenue aux chocs de manœuvre indiquée au Tableau 103 de la CEI 62271-203~~

~~Lorsqu'un essai de tension de choc doit être effectué, la forme d'onde de la tension de choc doit être soit celle d'un choc de manœuvre normalisé soit la forme d'onde de la TTR spécifiée pour la séquence d'essai de type de défaut aux bornes T10. Cinq chocs de chaque polarité doivent être appliqués. Le disjoncteur doit être considéré comme ayant réussi l'essai, s'il ne se produit aucune décharge disruptive. Dans le cas ou les équipements d'un laboratoire d'essais synthétiques sont utilisés, des tolérances temporelles sur la forme d'onde de TTR de –10 % et +200 % sur le temps~~ $\cancel{t_3}$ ~~sont autorisées.~~

~~NOTE 1 Quel que soit l'état du disjoncteur, la comparaison des essais a montré qu'il n'y a pratiquement pas de différence dans le comportement des disjoncteurs, à l'état neuf ou usagé, quand l'essai est effectué avec des chocs de manœuvre normalisés ou avec des impulsions de type TTR avec une forme d'onde conforme au défaut aux bornes T10.~~

~~NOTE 2 Si l'essai est effectué avec des impulsions de type TTR avec la forme d'onde T10, l'équivalence avec l'impulsion de choc de manœuvre est maintenue si les règles suivantes sont appliquées:~~

– ~~il y a lieu que l'amortissement de la tension transitoire soit tel que la deuxième crête de l'oscillation de la tension transitoire ne dépasse pas 80 % de la première;~~

– ~~environ 2,5 ms après la crête, il convient que la valeur réelle de la tension de rétablissement soit de l'ordre de 50 % de la valeur de crête.~~

Lorsque, après des essais mécaniques ou d'environnement (voir 6.101.1.4), les propriétés d'isolement entre les contacts ouverts d'un disjoncteur ne peuvent pas être vérifiées avec suffisamment de confiance par examen visuel, un essai de tenue de tension à fréquence industrielle à sec, conformément à 6.2.11 de la CEI 62271-1, entre les bornes du disjoncteur ouvert, doit être appliqué comme vérification d'état. Pour les conditions d'essais des disjoncteurs de GIS et des disjoncteurs à cuve mise à la terre, se référer au Tableau 38.

Pour les disjoncteurs avec ampoule à vide dans une enveloppe remplie de gaz, l'essai de tension comme vérification d'état peut ne pas être suffisant. Dans de tels cas l'intégrité du vide doit être démontrée.

Lorsque, après des essais d'établissement, de coupure ou d'établissement-coupure (voir 6.102.9), un essai de tension est réalisé comme vérification d'état, les conditions suivantes doivent s'appliquer:

Pour les disjoncteurs ayant un arrangement asymétrique des pièces de passage du courant les connexions doivent être interverties. Les essais complets doivent être effectués une fois pour chaque disposition des connexions. Pour les disjoncteurs à cuve mise à la terre et les disjoncteurs de GIS ayant un arrangement symétrique des pièces de passage du courant, un essai de tenue de tension à la terre du disjoncteur en position fermée est exigé. Lorsqu'un essai de tenue de tension à la terre est exigé, les tensions d'isolement assignées entre des contacts ouverts et à la terre peuvent être différentes. Dans de tels cas, chacune des valeurs assignées correspondant à la condition d'essai doit être utilisée comme valeur de référence pour la détermination de la tension d'essai. Ces exigences sont résumées dans le Tableau 38.

– Disjoncteurs avec $U_r \leq 72{,}5$ kV

  Un essai de tension à la fréquence industrielle de 1 min doit être effectué. La tension d'essai doit être égale à 80 % de la valeur indiquée dans les Tableaux 1a ou 1b, colonne (2) de la CEI 62271-1.

– Disjoncteurs avec 72,5 kV < $U_r \leq 245$ kV

  Un essai de tension de choc doit être effectué. La valeur crête de la tension de choc doit être égale à 60 % de la valeur la plus élevée applicable dans les Tableaux 1a ou 1b, colonne (4) of de la CEI 62271-1.

– Disjoncteurs avec 300 kV ≤ $U_r \leq 420$ kV

  Un essai de tension de choc doit être effectué. La valeur de crête de la tension de choc doit être égale à 80 % de la tension assignée de tenue aux chocs de manœuvre indiquée dans les Tableaux 2a ou 2b de la CEI 62271-1. Dans le cas de disjoncteurs de GIS, la valeur de crête de la tension de choc doit être égale à 80 % de la tension assignée de tenue aux chocs de manœuvre indiquée au Tableau 103 de la CEI 62271-203.

– Disjoncteurs avec 550 kV ≤ $U_r \leq 800$ kV

  Un essai de tension de choc doit être effectué. La valeur de crête de la tension de choc doit être égale à 90 % de la tension assignée de tenue aux chocs de manœuvre indiquée dans les Tableaux 2a ou 2b de la CEI 62271-1. Dans le cas de disjoncteurs de GIS, la valeur de crête de la tension de choc doit être égale à 90 % de la tension assignée de tenue aux chocs de manœuvre indiquée au Tableau 103 de la CEI 62271-203.

– Disjoncteurs avec $U_r > 800$ kV

  Un essai de tension de choc doit être effectué. La valeur de crête de la tension de choc doit être égale à 90 % de la tension assignée de tenue aux chocs de manœuvre indiquée au Tableau 2a de la CEI 62271-1. Dans le cas de disjoncteurs de GIS, la valeur de crête de la tension de choc doit être égale à 90 % de la tension assignée de tenue aux chocs de manœuvre. Des exemples de valeurs de tension assignée de tenue aux chocs de manœuvre pour du matériel de GIS sont donnés dans le Tableau G.1 de la CEI 62271-203:2011.

Lorsqu'un essai de tension de choc doit être effectué, la forme d'onde de la tension de choc doit être soit celle d'un choc de manœuvre normalisé soit la forme d'onde de la TTR spécifiée pour la séquence d'essai de type de défaut aux bornes T10. Cinq chocs de chaque polarité doivent être appliqués. Le disjoncteur doit être considéré comme ayant réussi l'essai, s'il ne se produit aucune décharge disruptive. Dans le cas où la forme d'onde T10 est utilisée, des tolérances temporelles sur la forme d'onde de la TTR de -10 % et de +200 % sur le temps t_3 sont autorisées.

NOTE 1 Quel que soit l'état du disjoncteur, la comparaison des essais a montré qu'il n'y a pratiquement pas de différence dans le comportement des disjoncteurs, à l'état neuf ou usagé, quand l'essai est effectué avec des chocs de manœuvre normalisés ou avec des impulsions de type TTR avec une forme d'onde conforme au défaut aux bornes T10.

NOTE 2 Si les essais sont effectués avec des impulsions de type TTR avec la forme d'onde T10, l'équivalence avec l'impulsion de choc de manœuvre est maintenue si les règles suivantes sont appliquées:

– il convient que l'amortissement de la TTR soit tel que la deuxième crête de l'oscillation de la TTR ne dépasse pas 80 % de la première;
– il convient que la tension soit de l'ordre de 50 % de la valeur de crête 2,5 ms après le temps à la crête.

Tableau 38 – Exigences d'essai pour les essais de tension comme vérification d'état pour les disjoncteurs de GIS et les disjoncteurs à cuve mise à la terre

Nombre d'éléments de coupure en série	Disposition du circuit de passage du courant	Position du disjoncteur		
		Ouvert (un côté)	Ouvert (autre côté)	Fermé
Unique	Symétrique	O	N	O
	Asymétrique	O	O	N
Multiple	Symétrique	O	N	O
	Asymétrique	O	O	O
O: nécessaire d'appliquer la tension. N: pas nécessaire d'appliquer la tension.				

6.3 Essais de tension de perturbation radioélectrique

Le paragraphe 6.3 de la CEI 62271-1 est applicable avec le complément suivant:

Les essais peuvent être effectués sur un pôle du disjoncteur dans les deux positions de fermeture et d'ouverture. Pendant les essais le disjoncteur doit être équipé de tous les accessoires tels que condensateurs de répartition, anneaux de garde, connecteurs HT, etc., qui peuvent influencer la performance de tension de perturbation radioélectrique.

6.4 Mesurage de la résistance du circuit principal

Le paragraphe 6.4 de la CEI 62271-1 est applicable.

6.5 Essais d'échauffement

6.5.1 Etat du disjoncteur en essai

Le paragraphe 6.5.1 de la CEI 62271-1 est applicable.

6.5.2 Disposition de l'appareil

Le paragraphe 6.5.2 de la CEI 62271-1 est applicable avec le complément suivant:

Dans le cas d'un disjoncteur non muni d'accessoires branchés en série, l'essai doit être effectué avec le courant assigné en service continu du disjoncteur.

Dans le cas d'un disjoncteur muni d'accessoires branchés en série possédant une gamme de courants assignés en service continu, il doit être procédé aux essais suivants:

a) un essai sur le disjoncteur muni d'accessoires ayant un courant assigné en service continu égal à celui du disjoncteur, et effectué au courant assigné en service continu du disjoncteur;
b) une série d'essais sur le disjoncteur muni des accessoires prévus, et effectués avec des courants égaux au courant assigné en service continu de chaque accessoire.

NOTE Si les accessoires peuvent être retirés du disjoncteur, et s'il est évident que l'échauffement du disjoncteur et des accessoires ne s'affectent pas mutuellement de façon appréciable, l'essai en b) ci-dessus peut être remplacé par une série d'essais sur les seuls accessoires.

6.5.3 Mesurage de la température et de l'échauffement

Le paragraphe 6.5.3 de la CEI 62271-1 est applicable.

6.5.4 Température de l'air ambiant

Le paragraphe 6.5.4 de la CEI 62271-1 est applicable.

6.5.5 Essais d'échauffement des équipements auxiliaires et de commande

Le paragraphe 6.5.5 de la CEI 62271-1 est applicable.

6.5.6 Interprétation des essais d'échauffement

Le paragraphe 6.5.6 de la CEI 62271-1 est applicable.

6.6 Essais au courant de courte durée et à la valeur de crête du courant admissible

Le paragraphe 6.6 de la CEI 62271-1 est applicable.

6.6.1 Disposition du disjoncteur et du circuit d'essai

Le paragraphe 6.6.1 de la CEI 62271-1 est applicable avec le complément suivant:

Si le disjoncteur est équipé de déclencheurs directs à maximum de courant, ceux-ci doivent être disposés en essai avec la bobine correspondant au courant de fonctionnement minimal réglée pour fonctionner au courant maximal et au temps de retard maximal; la bobine doit être reliée au côté source du circuit d'essai. Si le disjoncteur peut être utilisé sans déclencheurs directs à maximum de courant, il doit également être essayé sans eux.

Pour d'autres disjoncteurs à déclenchement autonome, le déclencheur à maximum de courant doit être disposé en essai avec les réglages correspondant au fonctionnement au courant maximal et au temps de retard maximal. Si le disjoncteur peut être utilisé sans déclencheur, il doit également être essayé sans eux.

6.6.2 Valeurs du courant d'essai et de sa durée

Le paragraphe 6.6.2 de la CEI 62271-1 est applicable~~ avec le complément suivant:~~.

~~Pour les disjoncteurs à déclenchement autonome, la séquence de manœuvres assignée, limitée aux seules manœuvres d'ouverture, doit être effectuée. La moyenne des valeurs efficaces des composantes périodiques du courant coupé pour l'ensemble des phases et des~~

~~manœuvres doit être considérée comme étant la valeur efficace du courant de courte durée admissible bien qu'il soit possible d'utiliser des valeurs de courant présumé lorsque l'essai est effectué à la tension assignée.~~

6.6.3 Comportement du disjoncteur au cours de l'essai

Le paragraphe 6.6.3 de la CEI 62271-1 est applicable.

6.6.4 Etat du disjoncteur après l'essai

Le paragraphe 6.6.4 de la CEI 62271-1 est applicable avec le complément suivant:

Après les essais des disjoncteurs à déclenchement autonome, l'état du disjoncteur doit être conforme à 6.102.9 et il doit être démontré que le déclencheur à maximum de courant est encore capable de fonctionner correctement. Un essai d'injection à 110 % du courant minimal de déclenchement et dans les conditions (monophasé ou triphasé), tels que déclarés par le constructeur, constitue une démonstration satisfaisante.

6.7 Vérification du degré de protection

6.7.1 Vérification de la codification IP

Le paragraphe 6.7.1 de la CEI 62271-1 s'applique à toutes les parties des disjoncteurs qui sont accessibles en service normal.

6.7.2 Essai aux impacts mécaniques

Le paragraphe 6.7.2 de la CEI 62271-1 s'applique.

6.8 Essais d'étanchéité

Le paragraphe 6.8 de la CEI 62271-1 s'applique.

Dans le cas d'un disjoncteur à vide, la vérification d'étanchéité de l'isolation par le vide doit être réalisée à l'aide d'un essai à fréquence industrielle conformément à 6.2.11 ou par un essai équivalent.

6.9 Essais de compatibilité électromagnétique

Le paragraphe 6.9 de la CEI 62271-1 s'applique.

6.9.3.1 Essai d'immunité à l'ondulation résiduelle sur entrée de puissance à courant continu

Le paragraphe 6.10.5 de la CEI 62271-1 est applicable avec le complément suivant:

Si aucun composant électronique n'est utilisé dans l'élément de commande et si l'essai de fonctionnement mécanique à la température de l'air ambiant conformément à 6.101.2 est effectué sur le disjoncteur complet, muni de son élément de commande entier, l'essai d'immunité à l'ondulation résiduelle sur entrée de puissance à courant continu conformément à 6.9.3.1 de la CEI 62271-1 est considéré comme couvert et les essais complémentaires doivent être omis. Lorsque les essais du disjoncteur complet ne sont pas réalisables en pratique, les essais de composants conformément à 6.101.1.2 sont acceptables.

Lorsque les composants électroniques sont utilisés, les essais conformément à 6.9.3.1 de la CEI 62271-1 sur les composants individuels sont suffisants.

NOTE Ce paragraphe est applicable à la fois aux cartes électroniques complètes (par exemple modules de commande) et aux dispositifs contenant au moins un composant électronique (par exemple relais de temporisation électroniques).

6.9.3.2 Essais d'immunité aux creux de tension, coupures brèves et variations de tension sur entrée de puissance à courant continu

Le paragraphe 6.9.3.2 de la CEI 62271-1 est applicable.

6.10 Essais complémentaires sur les circuits auxiliaires et de commande

6.10.1 Généralités

Le paragraphe 6.10.1 de la CEI 62271-1 est applicable.

6.10.2 Essais fonctionnels

Le paragraphe 6.10.2 de la CEI 62271-1 est applicable avec le complément suivant:

Si l'essai de fonctionnement mécanique à la température de l'air ambiant conformément à 6.101.2 est effectué sur le disjoncteur complet, muni de son élément de commande entier, les essais fonctionnels conformément à 6.10.2 de la CEI 62271-1 sont considérés comme couverts et les essais complémentaires doivent être omis. Lorsque les essais du disjoncteur complet ne sont pas réalisables en pratique, les essais de composants conformément à 6.101.1.2 sont acceptables.

6.10.3 Essai de continuité électrique des parties métalliques reliées à la terre

Le paragraphe 6.10.3 de la CEI 62271-1 est applicable.

6.10.4 Vérification des caractéristiques de fonctionnement des contacts auxiliaires

Le paragraphe 6.10.4 de la CEI 62271-1 est applicable.

6.10.5 Essais d'environnement

Le paragraphe 6.10.5 de la CEI 62271-1 est applicable avec complément suivant:

Si l'essai de fonctionnement mécanique à la température de l'air ambiant conformément à 6.101.2, les essais à haute et à basse températures conformément à 6.101.3 et, si applicable, l'essai d'humidité conformément à 6.101.4 sont effectués sur le disjoncteur complet, muni de son élément de commande entier ou, dans le cas de l'essai d'humidité, sur l'équipement de commande respectivement, les essais d'environnement conformément à 6.10.7 de la CEI 62271-1 sont considérés comme couverts et les essais complémentaires peuvent être omis. Lorsque les essais du disjoncteur complet ne sont pas réalisables en pratique, les essais de composants conformément à 6.101.1.2 sont acceptables.

NOTE Les essais de tenue aux séismes ne sont pas couverts. Si un essai de tenue aux séismes est exigé, il convient qu'il soit effectué après accord entre le constructeur et l'utilisateur.

6.101 Essais mécaniques et climatiques

6.101.1 Dispositions diverses pour les essais mécaniques et climatiques

6.101.1.1 Caractéristiques mécaniques

Au début des essais de type, les caractéristiques mécaniques du disjoncteur doivent être déterminées, par exemple, en enregistrant les courbes de déplacement à vide. Ceci peut également être effectué par l'utilisation de paramètres caractéristiques, par exemple la vitesse momentanée après une certaine course, etc. Les caractéristiques mécaniques servironT de référence pour la caractérisation du comportement mécanique du disjoncteur. De plus, les caractéristiques mécaniques doivent être utilisées pour confirmer que les différents spécimens d'essais utilisés durant les essais de type mécaniques, d'établissement, de coupure et de manœuvre sont identiques au niveau mécanique. L'essai dans lequel cette référence est obtenue est désigné comme un essai à vide de référence et les courbes ou autres paramètres résultant de cet essai sont désigné(e)s comme des caractéristiques mécaniques de référence. L'essai à vide de référence peut être n'importe quel essai à vide effectué pendant un essai de type individuel.

Les caractéristiques fonctionnelles suivantes doivent être enregistrées:

– caractéristiques mécaniques pendant l'ouverture et la fermeture;
– durée de fermeture;
– durée d'ouverture.

Les caractéristiques mécaniques doivent être produites au cours d'un essai à vide effectué avec une seule manœuvre O et une seule manœuvre C à la tension d'alimentation assignée des dispositifs de commande et des circuits auxiliaires et de commande, à la pression de fonctionnement assignée et, pour des raisons pratiques d'essais, à la pression de fonctionnement minimale pour la coupure.

La durée d'ouverture et la durée de fermeture enregistrées lors de l'essai de référence à vide doivent être utilisées comme durées de référence. Les écarts acceptables par rapport à ces durées de référence correspondent aux tolérances données par le constructeur, lorsque les essais sont effectués dans les mêmes conditions que celles utilisées pour la procédure définie pour produire les caractéristiques mécaniques de référence.

L'Annexe N donne des exigences et une explication sur l'utilisation des caractéristiques mécaniques.

6.101.1.2 Essais de composants

Lorsque l'essai du disjoncteur complet n'est pas pratique, des essais de composants peuvent être acceptés comme essais de type. Il convient que le constructeur détermine les composants à soumettre aux essais.

Les composants sont des sous-ensembles fonctionnels séparés qui peuvent être manœuvrés indépendamment du disjoncteur complet (par exemple pôle, unité de coupure, organe de manœuvre).

Lors des essais de composants, le constructeur doit apporter la preuve que les contraintes mécanique et climatique exercée sur le composant pendant les essais ne sont pas inférieurs à celles que subit le même composant lors de l'essai du disjoncteur complet. Les essais de composants doivent couvrir les différents types de composants du disjoncteur complet, à condition qu'ils soient applicables aux dits composants. Les conditions des essais de type de composants doivent être les mêmes que celles qui pourraient être utilisées pour le disjoncteur complet.

Les pièces des équipements auxiliaires et des équipements de commande, fabriquées en conformité avec des normes particulières, doivent être conformes à celles-ci. Le bon fonctionnement de telles pièces doit être vérifié et en liaison avec le bon fonctionnement des autres pièces du disjoncteur.

6.101.1.3 Caractéristiques et réglages du disjoncteur à enregistrer avant et après les essais

Avant et après les essais, les caractéristiques et réglages de fonctionnement suivants doivent être enregistrés ou évalués:

a) durée de fermeture;

b) durée d'ouverture;

c) intervalle de temps entre les unités d'un pôle;

d) intervalle de temps entre les pôles (pour un essai multipolaire);

e) durée de recharge du dispositif fonctionnel;

f) consommation du circuit de commande;

g) consommation des dispositifs de déclenchement, enregistrement possible de l'intensité des déclencheurs;

h) durée de l'impulsion de commande d'ouverture et de fermeture;

i) étanchéité, le cas échéant;

j) densités ou pressions des gaz, le cas échéant;

k) résistance du circuit principal;

l) graphique temps/déplacement;

m) autres caractéristiques et réglages importants, spécifiés par le fabricant.

Les caractéristiques de fonctionnement ci-dessus doivent être enregistrées:

– la tension d'alimentation assignée et la pression assignée de remplissage pour la manœuvre;
– la tension d'alimentation maximale et la pression maximale de remplissage pour la manœuvre;
– la tension d'alimentation maximale et la pression minimale pour la manœuvre;
– la tension d'alimentation minimale et la pression minimale pour la manœuvre;
– la tension d'alimentation minimale et la pression maximale de remplissage pour la manœuvre.

6.101.1.4 Etat du disjoncteur pendant et après les essais

Pendant et après les essais, l'état du disjoncteur doit lui permettre de fonctionner normalement, de conduire son courant nominal normal, d'ouvrir et de fermer son courant assigné de courte durée et de maintenir les valeurs de tension conformément à son niveau d'isolation assignée.

En général, ces exigences sont satisfaites si

– pendant les essais, le disjoncteur fonctionne sur commande et ne fonctionne pas sans commande;
– après les essais, les caractéristiques mesurées selon 6.101.1.3 se situent dans les tolérances données par le fabricant;
– après les essais, aucune pièce, y compris les contacts, ne montre d'usure excessive;
– après les essais, les contacts plaqués sont tels qu'une couche du matériau de placage reste sur la zone de contact. Si ce n'est pas le cas, les contacts doivent être considérés comme nus et les exigences d'essai ne sont remplies que si l'échauffement des contacts pendant l'essai d'échauffement (selon 6.5) ne dépasse pas la valeur admise pour les contacts nus;
– pendant et après les essais, une distorsion quelconque des parties mécaniques n'affecte pas négativement le fonctionnement du disjoncteur ou n'empêche pas le montage correct des pièces de remplacement;

– après les essais, les propriétés isolantes du disjoncteur en position ouverte sont pour l'essentiel au même niveau qu'avant les essais. Un contrôle visuel du disjoncteur après les essais est en général suffisant pour vérifier les propriétés isolantes. Pour les disjoncteurs scellés à vie, l'essai de tension comme vérification d'état suivant 6.2.11 peut être nécessaire.

6.101.1.5 Condition des équipements auxiliaires et de commande pendant et après les essais

Pendant et après les essais, les conditions suivantes pour les équipements auxiliaires et de commande doivent être respectées:

– pendant les essais, il convient de prendre des précautions pour empêcher tout échauffement excessif;
– pendant les essais, un jeu de contacts (contacts auxiliaires travail et repos) doit être disposé pour commuter le courant des circuits à commander (voir 5.4);
– pendant et après les essais, les équipements auxiliaires et de commande doivent remplir leurs fonctions;
– pendant et après les essais, la capacité des circuits auxiliaires des interrupteurs auxiliaires et des équipements de commande ne doit pas être diminuée. En cas de doute, les essais selon 6.2.10 de la CEI 62271-1 doivent être effectués;
– pendant et après les essais, la résistance de contact des interrupteurs auxiliaires ne doit pas être affectée négativement. L'échauffement lors du transit du courant assigné ne doit pas dépasser les valeurs spécifiées (voir Tableau 3 de la CEI 62271-1).

6.101.2 Essai de fonctionnement mécanique à la température de l'air ambiant

6.101.2.1 Généralités

L'essai de fonctionnement mécanique doit être effectué à la température de l'air ambiant à l'emplacement d'essai. Il convient d'enregistrer cette température de l'air ambiant dans le rapport d'essai. Les équipements auxiliaires formant partie intégrante des dispositifs de manœuvre sont inclus.

L'essai de fonctionnement mécanique comporte 2 000 séquences de manœuvres.

A l'exception des disjoncteurs équipés de déclencheurs à maximum de courant, l'essai doit être effectué sans tension ni courant dans le circuit principal.

Pour les disjoncteurs équipés de déclencheurs à maximum de courant, environ 10 % du nombre total de séquences de manœuvres doivent être effectués avec le dispositif d'ouverture alimenté par le courant du circuit principal. Ce courant est le courant minimal nécessaire pour faire fonctionner le déclencheur à maximum de courant. Pour ces essais, le courant alimentant les déclencheurs à maximum de courant peut être fourni par une source à basse tension appropriée.

Pendant l'essai, la lubrification est autorisée conformément aux instructions du constructeur, mais aucun réglage mécanique ni maintenance d'aucune sorte n'est permis.

NOTE Une conception de disjoncteur peut être munie de plusieurs variantes d'équipements auxiliaires (déclencheurs shunt et moteurs) afin de de satisfaire aux diverses tensions et fréquences de commande assignées indiquées en 4.8 et 4.9. Il n'est pas nécessaire que ces variantes soient soumises aux essais si elles sont de conception similaire et si les caractéristiques mécaniques à vide résultantes se situent dans la tolérance donnée dans l'Annexe N.

6.101.2.2 Etat du disjoncteur avant l'essai

Le disjoncteur destiné aux essais doit être monté sur son propre support et son mécanisme de commande doit être manœuvré de la façon indiquée. Il doit être essayé selon son dispositif de manœuvre de la façon suivante:

Un disjoncteur multipolaire manœuvré par un seul dispositif de manœuvre, et/ou dont tous les pôles sont montés sur un châssis commun, doit être essayé comme une unité complète.

Les essais doivent être effectués à la pression assignée de remplissage pour la coupure conformément à 6.101.1.3, point j).

Un disjoncteur multipolaire dans lequel chaque pôle ou même chaque colonne est manœuvré par un dispositif séparé doit, de préférence, être essayé comme un disjoncteur multipolaire complet. Cependant, l'on peut, pour des raisons de commodité ou de limitation de l'emplacement d'essai, effectuer les essais sur un seul pôle, à condition que ce pôle soit, pour l'ensemble des essais, équivalent au disjoncteur multipolaire complet; ou tout au moins qu'il ne soit pas dans une condition plus favorable que ce disjoncteur multipolaire, en ce qui concerne par exemple:

– les caractéristiques de déplacement mécanique de référence ;
– la puissance et la robustesse du mécanisme de fermeture et d'ouverture;
– la rigidité de la structure.

6.101.2.3 Description de l'essai de la classe M1 de disjoncteurs

Le disjoncteur doit être essayé conformément au Tableau 13.

Tableau 13 – Nombre de séquences de manœuvres

Séquence de manœuvres	Tension d'alimentation et pression de service	Nombre de séquences de manœuvres	
		Disjoncteurs pour réenclenchement automatique	Disjoncteurs sans réenclenchement automatique
C – t_a – O – t_a	Minimale	500	500
	Assignée	500	500
	Maximale	500	500
O – t – CO – t_a – C – t_a	Assignée	250	–
CO – t_a	Assignée	–	500

O = ouverture;

C = fermeture;

CO = manœuvre de fermeture immédiatement suivie (c'est-à-dire sans temporisation délibérée) d'une manœuvre d'ouverture;

t_a = durée entre deux manœuvres qui est nécessaire pour rétablir les conditions initiales et/ou empêcher un échauffement excessif des pièces du disjoncteur (cette durée peut être différente selon le type de fonctionnement);

t = 0,3 s pour les disjoncteurs destinés à un réenclenchement automatique rapide, sauf spécification contraire.

6.101.2.4 Essais d'endurance mécanique accrue sur les disjoncteurs de classe M2 en cas d'exigences spéciales de service

En cas d'exigences spéciales de service dans le cas de disjoncteurs fréquemment actionnés, des essais d'endurance mécanique poussée peuvent être effectués, comme suit.

Les essais doivent être effectués selon 6.101.1, 6.101.2.1, 6.101.2.2 et 6.101.2.3 avec l'ajout suivant:

– les essais doivent consister en 10 000 séquences de manœuvres comprenant cinq fois la série pertinente d'essais spécifiée au Tableau 13;
– entre les séries d'essais spécifiés, certaines interventions de maintenance, lubrification et réglage mécanique par exemple, sont autorisées et elles doivent être effectuées conformément aux instructions du fabricant. Il n'est pas permis de changer les contacts;
– le programme de maintenance pendant les essais doit être défini par le fabricant avant les essais et consigné dans le procès-verbal d'essai.

6.101.2.5 Critères d'acceptation pour les essais de manœuvre mécanique

Les critères donnés ci-après sont applicables aux essais de manœuvre mécanique des disjoncteurs de classe M1 et M2.

a) Avant et après tout le programme d'essai, les manœuvres suivantes doivent être effectuées:
   – cinq cycles de fermeture-ouverture à la tension d'alimentation assignée des dispositifs de fermeture et d'ouverture et des circuits auxiliaires et de contrôle et/ou à la pression de manœuvre assignée;
   – cinq cycles de fermeture-ouverture à la tension d'alimentation minimale des dispositifs de fermeture et d'ouverture et des circuits auxiliaires et de contrôle et/ou à la pression de manœuvre minimale;
   – cinq cycles de fermeture-ouverture à la tension d'alimentation maximale des dispositifs de fermeture et d'ouverture et des circuits auxiliaires et de contrôle et/ou à la pression de manœuvre maximale.

   Pendant ces cycles de manœuvres, les caractéristiques de fonctionnement (voir 6.101.1.3) doivent être consignées et évaluées. Il n'est pas nécessaire de publier tous les oscillogrammes enregistrés. Cependant pour chaque condition d'essai donnée ci-dessus, au moins un oscillogramme doit être inclus dans le rapport d'essai.

   En outre, les vérifications et mesures suivantes doivent être effectuées (voir 10.2.102):

   – mesures des pressions de fluide caractéristiques et des consommations pendant les manœuvres, le cas échéant;
   – vérification de la séquence de manœuvre assignée;
   – contrôle de certaines manœuvres spécifiques, le cas échéant.

   La variation entre les valeurs moyennes de chaque paramètre mesuré avant et après les essais d'endurance mécanique poussée doit se situer dans les tolérances données par le fabricant.
b) Après chaque série de 2 000 séquences de manœuvres, on doit enregistrer les caractéristiques de fonctionnement significatives a), b), c), d), e) et l) de 6.101.1.3.
c) Après la totalité du programme d'essai, l'état du disjoncteur doit être conforme à 6.101.1.4.

6.101.3 Essais à haute et à basse températures

6.101.3.1 Généralités

Il n'est pas nécessaire d'exécuter les deux essais successivement et l'ordre dans lequel ils sont effectués est arbitraire. Pour les disjoncteurs d'intérieur de classe –5 °C et pour les disjoncteurs d'extérieur de classe –10 °C, l'essai à basse température n'est pas exigé.

Pour les disjoncteurs sous enveloppe unique ou les disjoncteurs sous enveloppes multiples à organe de manœuvre commun, les essais doivent être effectués en tripolaire. Pour les disjoncteurs sous enveloppes multiples à pôles indépendants (séparés), il est permis d'effectuer l'essai d'un pôle complet.

Du fait des limitations des installations d'essai, les disjoncteurs sous enveloppes multiples peuvent être essayés, suivant une ou plusieurs des variantes suivantes à condition que le disjoncteur, dans sa disposition pour les essais, ne soit pas placé dans des conditions plus favorables que les conditions normales pour le fonctionnement mécanique (voir 6.101.2.2):

a) longueur réduite d'isolement par rapport à la terre;

b) distance réduite entre pôles;

c) nombre réduit de modules.

Si des sources de chaleur sont exigées, elles doivent être en service.

Les alimentations des liquides ou des gaz nécessaires pour la manœuvre du disjoncteur sont à la température de l'air ambiant à moins que la conception du disjoncteur n'exige une source de chaleur pour ces alimentations.

Pendant l'essai aucune maintenance, remplacement de pièces, lubrification ou réglage du disjoncteur n'est autorisé.

NOTE 1 Afin de déterminer les caractéristiques de température, le vieillissement, etc., des essais de plus longue durée que ceux spécifiés dans les paragraphes suivants peuvent être nécessaires.

En variante des méthodes données dans cette norme, un constructeur peut établir la conformité aux conditions de fonctionnement pour un type de disjoncteur bien connu, en fournissant une documentation sur l'expérience satisfaisante en réseau, au moins en un lieu où les températures de l'air ambiant sont fréquemment égales ou supérieures à la température maximale de l'air ambiant spécifiée de 40 °C et au moins en un endroit avec une expérience satisfaisante sur le terrain avec une température ambiante minimale spécifiée en fonction de la classe du disjoncteur (voir l'Article 2 de la CEI 62271-1).

Le disjoncteur a réussi l'essai si les conditions mentionnées en 6.101.1.4 et 6.101.1.5 sont remplies. De plus, les conditions de 6.101.3.3 et 6.101.3.4 doivent être satisfaites et les taux de fuite enregistrés ne doivent pas dépasser les limites données au Tableau 12 de la CEI 62271-1. Dans le rapport d'essai, les conditions d'essais et l'état du disjoncteur avant, pendant et après l'essai doivent être indiqués. Les grandeurs enregistrées doivent être présentées de façon appropriée et les oscillogrammes relevés doivent être indiqués. Afin de réduire le nombre d'oscillogrammes dans le rapport d'essai, il est permis de présenter un seul oscillogramme représentatif de chaque type correspondant de manœuvre dans chaque condition d'essai spécifiée.

Les disjoncteurs à vide sont exclus des essais de vérification d'étanchéité au cours des essais à haute et à basse températures. L'intégrité du vide sera vérifiée par un essai de tension à fréquence industrielle (ou équivalent) après les essais à haute et à basse températures. Cependant, si le disjoncteur à vide est utilisé dans une enveloppe remplie de gaz isolant, par exemple du SF_6, les essais de vérification d'étanchéité pendant les essais à haute et à basse température doivent être réalisés sur cette enveloppe.

NOTE 2 Une conception de disjoncteur peut être munie de plusieurs variantes d'équipements auxiliaires (déclencheurs shunt et moteurs) afin de satisfaire aux diverses tensions et fréquences de commande assignées indiquées en 4.8 et 4.9. Il n'est pas nécessaire que ces variantes soient soumises aux essais si elles sont de conception similaire et si les caractéristiques mécaniques à vide résultantes se situent dans la tolérance donnée en 6.101.1.1.

6.101.3.2 Mesurage de la température de l'air ambiant

La température de l'air ambiant de l'environnement proche d'essai doit être mesurée à mi-hauteur du disjoncteur et à une distance de 1 m de celui-ci.

L'écart maximal de température le long de la hauteur du disjoncteur ne doit pas excéder 5 K.

6.101.3.3 Essai à basse température

Le schéma représentant les séquences d'essais et l'indication des points d'application des essais spécifiés sont donnés dans la Figure 17a.

Si l'essai à basse température est effectué immédiatement après l'essai à haute température, l'essai à basse température peut commencer après la fin du point u) de l'essai à haute température, en omettant les points a) et b) suivants.

a) Le disjoncteur en essai est réglé conformément aux instructions du constructeur.

b) Les caractéristiques et les réglages du disjoncteur doivent être consignés selon 6.101.1.3 et à une température ambiante de 20 °C ± 5 °C (T_A). L'essai d'étanchéité (le cas échéant) doit être effectué selon 6.8.

c) Le disjoncteur en position fermée, la température de l'air doit être abaissée à la température ambiante minimale appropriée (T_L), selon la classe de disjoncteur, comme indiqué en 2.1.1, 2.1.2 et 2.2.3 de la CEI 62271-1. Le disjoncteur doit être maintenu en position fermée pendant 24 h après stabilisation de la température ambiante à T_L.

d) Pendant cette période de 24 h où le disjoncteur est en position fermée à la température T_L, un essai d'étanchéité doit être effectué (le cas échéant). Une augmentation du taux de fuite est acceptable, à condition qu'il revienne à sa valeur initiale quand le disjoncteur est ramené à la température ambiante T_A et qu'il est thermiquement stable. L'augmentation temporaire du taux de fuite ne doit pas dépasser le taux de fuite temporaire admis du Tableau ~~12~~ 13 de la CEI 62271-1.

   NOTE 1 Un essai d'étanchéité est applicable si les gaz sont utilisés pour la manœuvre, la coupure et/ou l'isolement. Dans le cas de disjoncteurs à vide, aucun essai d'étanchéité n'est exigé. Cependant, si le disjoncteur à vide est utilisé dans une enveloppe remplie de gaz isolant, par exemple du SF_6, les essais de vérification d'étanchéité sont à réaliser sur cette enveloppe.

e) Après avoir été soumis pendant 24 h à la température T_L, le disjoncteur doit être ouvert, puis fermé aux valeurs assignées de la tension d'alimentation et de la pression de fonctionnement. Les durées d'ouverture et de fermeture doivent être enregistrées afin de déterminer les caractéristiques de fonctionnement à basse température. Il convient, si cela est possible, d'enregistrer la vitesse des contacts.

f) Le comportement à basse température du disjoncteur et de ses systèmes d'alarme et de verrouillage doit être vérifié en interrompant l'alimentation de tous les dispositifs de chauffage, y compris les éléments de chauffage pour l'anti-condensation, pendant une durée t_x. Pendant cette période, le déclenchement d'une alarme est acceptable mais pas celui du verrouillage. A la fin de cette période t_x, un ordre d'ouverture doit être donné à la valeur de la tension assignée d'alimentation et à la pression de fonctionnement. Le disjoncteur doit alors s'ouvrir. Le temps d'ouverture doit être enregistré (et les caractéristiques du déplacement mécanique pendant l'ouverture mesurées si cela est possible) afin d'évaluer la capacité d'interruption.

   Le constructeur doit indiquer la valeur de t_x (pas moins de 2 h) pendant lequel le disjoncteur peut encore fonctionner malgré l'absence de chauffage. En l'absence d'une telle déclaration, la valeur préférentielle doit être de 2 h.

   NOTE 2 La mesure des caractéristiques mécaniques est réalisable si un emplacement est accessible pour le capteur de déplacement à utiliser.

g) Le disjoncteur doit être laissé en position d'ouverture pendant 24 h.

h) Pendant cette période de 24 h où le disjoncteur est en position ouverte à la température T_L, un essai d'étanchéité doit être effectué (le cas échéant). Une augmentation du taux de fuite est acceptable, à condition qu'il revienne à sa valeur initiale quand le disjoncteur est ramené à la température ambiante T_A et qu'il est thermiquement stable. L'augmentation temporaire du taux de fuite ne doit pas dépasser le taux de fuite temporaire admis du Tableau ~~12~~ 13 de la CEI 62271-1.

i) A l'issue de la période de 24 h, 50 manœuvres de fermeture et 50 manœuvres d'ouverture doivent être effectuées, aux valeurs assignées de la tension d'alimentation et de la pression de fonctionnement, le disjoncteur étant maintenu à la température $T_{L.}$ Un intervalle d'au moins 3 min doit être observé pour chaque cycle ou séquence. Les premières manœuvres de fermeture et d'ouverture sont enregistrées afin de déterminer les caractéristiques de fonctionnement à basse température. Il convient, si cela est possible, d'enregistrer la vitesse des contacts. Après la première manœuvre de fermeture (C) et la première manœuvre d'ouverture (O), trois cycles opératoires CO (sans temporisation délibérée) doivent être effectués. Les manœuvres supplémentaires doivent être effectuées par des séquences de manœuvres C – t_a – O – t_a (t_a est défini dans le Tableau 13).

j) Après réalisation des 50 manœuvres de fermeture et des 50 manœuvres d'ouverture, la température de l'air doit être augmentée à la température de l'air ambiant T_A, avec une vitesse de variation d'environ 10 K par heure.

Pendant la période de transition de la température, le disjoncteur doit être soumis alternativement aux séquences opératoires C – t_a – O – t_a – C et O – t_a – C – t_a – O aux valeurs nominales de tension d'alimentation et de pression de service. Il convient d'effectuer les séquences de manœuvres alternées à 30 min d'intervalle, afin que le disjoncteur reste dans les positions d'ouverture et de fermeture pendant ces périodes de 30 mm entre les séquences de manœuvres.

k) Après stabilisation thermique du disjoncteur à la température de l'air ambiant T_A, on doit vérifier à nouveau les réglages du disjoncteur, les caractéristiques de fonctionnement et d'étanchéité, comme aux points a) et b), afin de les comparer avec les caractéristiques initiales.

La fuite cumulée pendant la séquence complète de l'essai à basse température depuis le point b) jusqu'au point j) ne doit pas être telle que la pression de blocage soit atteinte (atteindre la pression d'alarme est autorisé).

6.101.3.4 Essai à haute température

Le schéma représentant les séquences d'essais et l'indication des points d'application des essais spécifiés sont donnés dans la Figure 17b.

Si l'essai à haute température est effectué immédiatement après l'essai à basse température, l'essai à haute température peut commencer après la fin du point j) de l'essai à basse température, en omettant les points l) et m) suivants.

l) Le disjoncteur en essai est réglé conformément aux instructions du constructeur.

m) Les caractéristiques et les réglages du disjoncteur doivent être enregistrés conformément à 6.101.1.3 et à une température de l'air ambiant de 20 °C ± 5 °C (T_A). L'essai d'étanchéité (s'il est applicable) est effectué selon 6.8.

n) Le disjoncteur étant en position de fermeture, la température de l'air doit être augmentée à la valeur appropriée de la température d'air ambiant maximale (T_H), correspondant à la limite supérieure de la température d'air ambiant donnée en 2.1.1, 2.1.2 et 2.2.3 de la CEI 62271-1. Le disjoncteur doit être maintenu en position de fermeture pendant 24 h après stabilisation de la température de l'air ambiant à T_H.

NOTE 1 L'influence du rayonnement solaire n'est pas prise en considération.

o) Pendant la période de 24 h durant laquelle le disjoncteur est en position de fermeture à la température T_H, un essai d'étanchéité doit être effectué (s'il est applicable). Un taux de fuite accru est acceptable pourvu qu'il reprenne sa valeur initiale lorsque le disjoncteur est ramené à la température de l'air ambiant T_A et qu'il est thermiquement stable. Le taux de fuite accru temporairement ne doit pas excéder la valeur admissible spécifiée au Tableau 13 de la CEI 62271-1.

NOTE 2 Un essai d'étanchéité est applicable si les gaz sont utilisés pour la manœuvre, la coupure et/ou l'isolement. Dans le cas de disjoncteurs à vide, aucun essai d'étanchéité n'est exigé. Cependant, si le disjoncteur à vide est utilisé dans une enveloppe remplie de gaz isolant, par exemple du SF_6, les essais de vérification d'étanchéité sont à réaliser sur cette enveloppe.

p) Après avoir été soumis pendant 24 h à la température T_H, le disjoncteur doit être ouvert, puis fermé aux valeurs assignées de la tension d'alimentation et de la pression de fonctionnement. Les durées d'ouverture et de fermeture doivent être enregistrées afin de déterminer les caractéristiques de fonctionnement à haute température. Il convient, si cela est possible, d'enregistrer la vitesse des contacts.

NOTE 3 La mesure des caractéristiques mécaniques est réalisable si un emplacement est accessible pour le capteur de déplacement à utiliser.

q) Le disjoncteur doit être ouvert et laissé en position d'ouverture pendant 24 h à la température T_H.

r) Pendant la période de 24 h durant laquelle le disjoncteur est en position d'ouverture à la température T_H, un essai d'étanchéité est effectué (si cela est applicable). Un taux de fuite accru est acceptable pourvu qu'il reprenne sa valeur initiale lorsque le disjoncteur est ramené à la température de l'air ambiant T_A et qu'il est thermiquement stable. Le taux de fuite temporairement accru ne doit pas excéder le taux de fuite temporairement admissible du Tableau ~~12~~ 13 de la CEI 62271-1.

s) A l'issue de la période de 24 h, 50 manœuvres de fermeture et 50 manœuvres d'ouverture doivent être effectuées, aux valeurs assignées de la tension d'alimentation et de la pression de fonctionnement, le disjoncteur étant maintenu à la température T_H. Un intervalle d'au moins 3 min doit être observé pour chaque cycle ou séquence. Les premières manœuvres de fermeture et d'ouverture doivent être enregistrées afin de déterminer les caractéristiques de fonctionnement à haute température. Il convient, si cela est possible, d'enregistrer la vitesse des contacts.

   Après la première manœuvre de fermeture (C) et la première manœuvre d'ouverture (O), trois cycles opératoires CO (sans temporisation délibérée) doivent être effectués. Les opérations supplémentaires doivent être effectuées par des séquences opératoires C – t_a – O – t_a (t_a est défini dans le Tableau 13).

t) Après réalisation des 50 manœuvres de fermeture et des 50 manœuvres d'ouverture, la température de l'air doit être ramenée à la température de l'air ambiant T_A, avec une vitesse de variation d'environ 10 K/h.

   Pendant la période de variation de température, le disjoncteur doit être soumis à des séquences de manœuvres alternées C – t_a – O – t_a – C et O – t_a – C – t_a – O, aux valeurs assignées de la tension d'alimentation et de la pression de fonctionnement. Il convient d'effectuer les séquences de manœuvres alternées à 30 min d'intervalle, afin que le disjoncteur reste dans les positions d'ouverture et de fermeture pendant des périodes de 30 min entre les séquences de manœuvres.

u) Après stabilisation thermique du disjoncteur à la température de l'air ambiant T_A, on doit vérifier à nouveau les réglages du disjoncteur, les caractéristiques de fonctionnement et d'étanchéité comme aux points l) et m), afin de les comparer avec les caractéristiques initiales.

   La fuite cumulée pendant la séquence complète de l'essai à haute température depuis le point l) jusqu'au point t) ne doit pas être telle que la pression de blocage soit atteinte (atteindre la pression d'alarme est autorisé).

6.101.4 Essai à l'humidité

6.101.4.1 Généralités

L'essai d'humidité ne doit pas s'appliquer aux équipements destinés à être directement exposés à des précipitations, par exemple les pièces primaires des disjoncteurs d'extérieur. L'essai doit être effectué sur les disjoncteurs ou sur les composants des disjoncteurs, lorsqu'en raison de changements brusques de la température, de la condensation risque de se produire sur les surfaces isolantes qui sont sous contrainte galvanique continue. C'est principalement l'isolation de la filerie secondaire des disjoncteurs d'intérieur. Il n'est pas non plus nécessaire lorsque des moyens effectifs contre la condensation sont prévus, par exemple, armoires de commande avec système de chauffage anti-condensation.

En appliquant la procédure d'essai décrite en 6.101.4.2, la tenue de l'objet sous essai, surtout des composants de disjoncteur, aux effets de l'humidité qui peuvent produire de la condensation sur la surface de l'échantillon, est déterminée de façon accélérée.

6.101.4.2 Procédure d'essai

L'objet soumis à l'essai doit être disposé dans une enceinte d'essai contenant de l'air en circulation et dans laquelle la température et l'humidité doivent suivre le cycle indiqué ci-dessous:

Pendant environ la moitié du cycle, les surfaces de l'objet sous essai doivent être humides, et elles doivent être sèches pendant l'autre moitié. Pour ce faire, le cycle d'essai consiste en une période t_4 à basse température de l'air (T_{min} = 25 °C ± 3 °C) et une période t_2 à haute température de l'air (T_{max} = 40 °C ± 2 °C) à l'intérieur de l'enceinte d'essai. Ces deux périodes doivent être de durée égale. La production de brouillard doit être maintenue pendant la moitié du cycle (voir Figure 18) où la température basse de l'air est appliquée.

Le début de la production de brouillard coïncide en principe avec le début de la période à basse température. Cependant, pour humidifier les surfaces verticales des matériaux avec une constante de temps thermique élevée, il peut être nécessaire de commencer la production de brouillard plus tard pendant la période à basse température.

La durée du cycle d'essai dépend des caractéristiques thermiques des objets en essai et elle doit être suffisamment longue, à haute température comme à basse température pour permettre de mouiller et de sécher toutes les surfaces isolantes. Pour obtenir ces conditions, il convient d'injecter de la vapeur directement dans l'enceinte d'essai ou de pulvériser de l'eau chaude; l'élévation de température de 25 °C à 40 °C peut être obtenue par l'apport de chaleur provenant de la vapeur ou de l'eau pulvérisée ou, si nécessaire, avec un chauffage supplémentaire. Des cycles préliminaires doivent être effectués avec l'objet sous essai placé dans l'enceinte d'essai afin d'observer et de vérifier ces conditions.

NOTE Pour les composants à basse tension des disjoncteurs à haute tension ayant en général des constantes de temps inférieures à 10 min, la durée des intervalles de temps donnés à la Figure 18 sont: t_1 = 10 min, t_2 = 20 min, t_3 = 10 min et t_4 = 20 min.

Le brouillard s'obtient par pulvérisation continue ou intermittente de 0,2 l à 0,4 l d'eau (avec les caractéristiques de résistivité données ci-dessous) à l'heure et par mètre cube de volume de l'enceinte d'essai. Le diamètre des gouttelettes doit être inférieur à 10 µm; il est possible d'obtenir ce type de brouillard avec des atomiseurs mécaniques. La direction de pulvérisation doit être telle que les surfaces de l'objet en essai ne sont pas directement arrosées. L'eau ne doit pas goutter du plafond sur l'objet en essai. Pendant la production du brouillard, l'enceinte d'essai doit être fermée et aucune circulation d'air pulsé supplémentaire n'est autorisée.

L'eau utilisée pour créer l'humidité doit être telle que l'eau collectée dans l'enceinte d'essai ait une résistivité égale ou supérieure à 100 Ωm et qu'elle ne contienne ni sel (NaCl) ni quelconque élément corrosif.

La température et l'humidité relative de l'air dans l'enceinte d'essai doivent être mesurées dans le voisinage immédiat de l'objet en essai et elles doivent être enregistrées pendant toute la durée de l'essai. Aucune valeur d'humidité relative n'est spécifiée pendant la baisse de la température, cependant, l'humidité doit être supérieure à 80 % pendant la période où la température est maintenue à 25 °C. L'air doit circuler afin d'obtenir une répartition uniforme de l'humidité dans l'enceinte d'essai.

Le nombre de cycles doit être de 350.

Pendant et après l'essai, les caractéristiques de fonctionnement des objets en essai ne doivent pas être affectées. Les circuits auxiliaires et de commande doivent résister à une tension à fréquence industrielle de 1 500 V pendant 1 min. Il est recommandé d'indiquer le degré de corrosion éventuel dans le procès-verbal des essais.

6.101.5 Essai pour vérifier le fonctionnement dans des conditions sévères de formation de glace

L'essai dans des conditions sévères de formation de glace est applicable seulement aux disjoncteurs d'extérieur ayant des parties mobiles externes et pour lesquels il a été spécifié une classe d'épaisseur de glace de 10 mm ou 20 mm. L'essai doit être effectué dans les conditions décrites dans la CEI 62271-102.

6.101.6 Essai avec efforts statiques sur les bornes

6.101.6.1 Généralités

L'essai avec efforts statiques sur les bornes est uniquement applicable aux disjoncteurs pour l'extérieur.

Il n'est pas nécessaire d'effectuer des essais si le constructeur peut démontrer par des calculs que le disjoncteur peut supporter les contraintes spécifiées.

L'essai avec efforts statiques sur les bornes est effectué pour démontrer que le disjoncteur fonctionne correctement quand des contraintes résultant de la glace, du vent et du raccordement des conducteurs lui sont appliquées.

La couche de glace et la pression de vent sur le disjoncteur doivent être conformes aux indications de 2.1.2 de la CEI 62271-1.

Quelques exemples d'efforts dus ~~à~~ au vent, à la glace et au poids sur des conducteurs flexibles et tubulaires raccordés (ne comprenant pas les efforts dus au vent ou à la glace ou les efforts dynamiques sur le disjoncteur lui-même) sont donnés à titre de lignes directrices dans le Tableau 14.

L'effort de traction dû aux conducteurs raccordés est supposé s'appliquer à l'extrémité de la borne du disjoncteur.

Les efforts F_{sr1}, F_{sr2}, F_{sr3} et F_{sr4} (voir Figure 19) résultant respectivement des actions simultanées de la glace, du vent et des conducteurs raccordés sont définis comme efforts statiques assignés sur les bornes.

6.101.6.2 Essais

Les essais doivent être effectués à la température de l'air ambiant du local d'essai.

Il convient de réaliser les essais sur au moins un pôle complet du disjoncteur. Si le constructeur peut démontrer qu'il n'y a pas d'interaction des forces entre les différentes colonnes d'un pôle, l'essai d'une seule colonne est suffisant. Il suffit d'essayer, à l'effort statique assigné sur les bornes, une seule borne des disjoncteurs qui sont symétriques par rapport à l'axe vertical du centre du pôle. Pour les disjoncteurs qui ne sont pas symétriques, chaque borne doit être essayée.

Deux méthodes d'essais sont disponibles:

a) Les essais doivent être effectués avec les efforts F_{sr1}, F_{sr2}, F_{sr3} et F_{sr4} résultant des 3 composantes: verticale, longitudinale et transversale (tel que défini à la Figure 20). Les essais suivants doivent être effectués:
   - Essai 1 avec: $F_{\mathrm{sr1}} = F_{\mathrm{th\,A}} + F_{\mathrm{th\,B1}} + F_{\mathrm{tv\,C2}} + F_{\mathrm{wh}}$
   - Essai 2 avec: $F_{\mathrm{sr2}} = F_{\mathrm{th\,A}} + F_{\mathrm{th\,B1}} + F_{\mathrm{tv\,C1}} + F_{\mathrm{wh}}$

– Essai 3 avec: $F_{sr3} = F_{th\ A} + F_{th\ B\ 2} + F_{tv\ C2} + F_{wh}$

– Essai 4 avec: $F_{sr4} = F_{th\ A} + F_{th\ B2} + F_{tv\ C1} + F_{wh}$

Pour faciliter les essais, l'ordre des essais individuels est arbitraire. Si la structure du disjoncteur est symétrique par rapport à l'axe longitudinal de ses éléments de coupure, soit les essais 2 et 4, soit les essais 1 et 3, peuvent être omis.

b) En variante, les essais peuvent être réalisés séparément, en appliquant les forces ultérieurement comme suit:
   - avec un effort horizontal, F_{shA}, appliqué dans l'axe longitudinal des bornes (directions A_1 et A_2 de la Figure 20);
   - avec un effort horizontal, F_{shB}, appliqué successivement dans deux directions orthogonales à l'axe longitudinal des bornes (directions B_1 et B_2 de la Figure 20);
   - avec un effort vertical, F_{sv}, appliqué successivement dans deux directions (directions C_1 et C_2 de la Figure 20).

Dans le cas d'un disjoncteur tripolaire avec un châssis de base commun, il convient de soumettre aux essais le pôle central.

Pour éviter l'application d'un effort spécial représentant l'effort du vent qui s'appliquerait au centre du disjoncteur, cet effort de vent peut être appliqué à la borne (voir Figure 19) et réduit en amplitude proportionnellement à l'augmentation du bras de levier (il convient que le moment de flexion à la partie la plus basse du disjoncteur soit le même).

Avant et après chacun des essais individuels d'efforts sur les bornes, deux cycles de manœuvre (manœuvre CO) doivent être effectués. A cet effet, il peut être nécessaire de remplir le disjoncteur en gaz. Pour des raisons de sécurité, la pression peut être réglée sur n'importe quelle valeur appropriée.

L'essai est considéré comme satisfaisant si le disjoncteur fonctionne normalement lorsque la charge mécanique est appliquée. Cette condition est satisfaite si la course du contact, la durée d'ouverture et de fermeture après la série d'essais, ne présentent aucun changement significatif par rapport aux valeurs enregistrées avant les essais; les règles données en 6.101.1.1 et à l'Annexe N doivent être appliquées en conséquence.

NOTE Etant donné que la pression dans le disjoncteur pour les essais avec des efforts statiques sur les bornes peut s'écarter de la valeur exigée pour l'essai spécifié en 6.101.1.1 et à l'Annexe N, une comparaison directe des paramètres mécaniques enregistrés au cours des essais avec des efforts statiques sur les bornes avec les caractéristiques mécaniques de référence n'est pas réalisable en pratique. Cependant, les règles données en 6.101.1.1 et à l'Annexe N peuvent s'appliquer de façon adaptée.

Après les essais, aucune fuite ni détérioration des joints ne doivent se produire.

Tableau 14 – Exemples d'efforts statiques horizontaux et verticaux pour l'essai avec efforts statiques aux bornes

Gamme de tensions assignées U_r kV	Gamme de courants assignés I_r A	Effort statique horizontal F_{th} Longitudinal F_{thA} N	Transversal F_{thB} N	Effort statique vertical (vers le haut ou vers le bas) F_{tv} N
< 100	800 – 1 250	500	400	500
< 100	1 600 – 2 500	750	500	750
100 – 170	1 250 – 2 000	1 000	750	750
100 – 170	2 500 – 4 000	1 250	750	1 000
245 – 362	1 600 – 4 000	1 250	1 000	1 250
420 – 800	2 000 – 4 000	1 750	1 250	1 500

Gamme de tensions assignées	Gamme de courants assignés	Effort statique horizontal F_{th}		Effort statique vertical (vers le haut ou vers le bas)
U_r	I_r	Longitudinal F_{thA}	Transversal F_{thB}	F_{tv}
kV	A	N	N	N
1 100 – 1 200	4 000 – 6 300	3 500	3 000	2 500

6.102 Dispositions diverses pour les essais d'établissement et de coupure

Les paragraphes suivants sont applicables à tous les essais d'établissement et de coupure, sauf spécification contraire dans les articles correspondants.

Lorsque cela est applicable, avant le début des essais, le fabricant doit donner les valeurs des

– conditions minimales de fonctionnement du mécanisme d'entraînement garantissant la séquence de manœuvres assignée (par exemple, la pression minimale pour la manœuvre dans le cas d'un mécanisme oléopneumatique);
– conditions minimales de fonctionnement des dispositifs de coupure garantissant la séquence de manœuvres assignée (par exemple, la pression minimale pour l'interruption dans le cas d'un disjoncteur au SF_6).

6.102.1 Généralités

Les disjoncteurs doivent être capables d'établir et de couper tous les courants de court-circuit, symétriques et asymétriques, jusques et y compris leur pouvoir de coupure assigné en court-circuit: cela est vérifié lorsque les disjoncteurs établissent et coupent les courants triphasés symétriques et asymétriques spécifiés compris entre 10 % (ou les valeurs plus faibles de courant spécifiées en 6.107.2 si 6.107.1 est applicable) et 100 % du pouvoir de coupure assigné en court-circuit à la tension assignée.

De plus, les disjoncteurs prévus pour être utilisés sur un réseau à neutre effectivement à la terre, ou pour un fonctionnement unipolaire, doivent établir et couper les courants de court-circuit monophasés compris entre 10 % (ou les valeurs plus faibles de courant spécifiées en 6.107.2 si 6.107.1 est applicable) et 100 % du pouvoir de coupure assigné en court-circuit à la tension phase-terre ($U_r/\sqrt{3}$). De plus, les disjoncteurs doivent être capables de couper des courants de court-circuit dans le cas de double défaut à la terre (voir 6.108).

Les disjoncteurs, auxquels des caractéristiques de coupure de courants capacitifs ont été assignés, doivent être capables de couper des courants capacitifs jusques et y compris le pouvoir de coupure assigné de courants capacitifs à un niveau de tension jusques et y compris la tension spécifiée (voir 6.111.7). Cela est démontré lorsque les disjoncteurs coupent le courant capacitif assigné de coupure à la tension d'essai spécifiée.

Il convient que les exigences concernant l'établissement et la coupure en triphasé soient vérifiées, de préférence, avec des circuits triphasés.

Si les essais sont effectués dans un laboratoire, la tension appliquée, le courant, la tension transitoire de rétablissement et la tension de rétablissement à fréquence industrielle peuvent être obtenus à partir d'une source unique de puissance (essais directs) ou à partir de plusieurs sources de telle sorte que la totalité du courant, ou sa majeure partie, soit obtenue à partir d'une source, et que la tension transitoire de rétablissement, ou sa majeure partie, soit obtenue à partir d'une ou de plusieurs autres sources séparées (essais synthétiques).

Si, par suite des limitations des installations d'essais, les caractéristiques de court-circuit du disjoncteur ne peuvent pas être vérifiées comme indiqué ci-dessus, plusieurs méthodes utilisant les méthodes d'essais directs ou synthétiques peuvent être employées seules ou combinées, en fonction du type de disjoncteur:

a) essais unipolaires (voir 6.102.4.1);

b) essais sur éléments séparés (voir 6.102.4.2);

c) essais en plusieurs parties (voir 6.102.4.3).

La durée de manœuvre de certains disjoncteurs peut varier lorsque l'alimentation des bobines est à la valeur minimale spécifiée en 5.8 de la CEI 62271-1, tandis que les durées de manœuvre sont raisonnablement constantes à leurs tensions d'alimentation assignées. L'exécution d'une séquence d'essais avec des durées d'arc correctes peut être difficile à réaliser dans ce cas, en particulier lorsqu'il est nécessaire d'effectuer des pas de 18 degrés électriques pour vérifier la fenêtre d'arc. De plus, la dispersion de la durée de fermeture peut empêcher de pouvoir effectuer l'essai d'établissement avec le pouvoir de fermeture assigné en court-circuit.

Pour des disjoncteurs pour lesquels la manœuvre des bobines n'a pas d'influence sur les caractéristiques de déplacement de contact, il est autorisé d'augmenter la tension d'alimentation des bobines depuis la valeur minimale jusqu'à 110 % de la tension d'alimentation assignée. Les manœuvres à vide effectuée à la tension d'alimentation assignée et à la tension d'alimentation minimale doivent être incluses dans le rapport d'essai pour montrer que les caractéristiques de déplacement de contact ne sont pas affectées par l'augmentation de tension de la bobine.

Au moins une manœuvre d'établissement et une manœuvre de coupure doivent être effectuées pour la séquence d'essais T100s avec une tension d'alimentation minimale pour montrer l'aptitude du disjoncteur à fonctionner correctement jusqu'à son courant assigné de court-circuit dans les conditions de tension de commande minimale.

6.102.2 Nombre de spécimens d'essai

Le paragraphe 6.1.1 de la CEI 62271-1 s'applique avec le complément suivant:

La pratique recommandée pour les essais d'établissement et de coupure en court-circuit et de manœuvre (incluant les défauts aux bornes, les défauts proches en ligne, manœuvres en discordance de phases et sur courants capacitifs lorsque cela est applicable) est qu'un seul spécimen d'essais devrait être utilisé. Lorsque cela est requis, il convient qu’une remise en état soit admise et soit effectuée tel que permis entre chacune des séquences d'essais dans le cas des essais en court-circuit et entre chaque série d'essais pour les essais autres que ceux en court-circuit. Le fabricant doit fournir au laboratoire d'essais la liste des pièces qui peuvent être remises en état durant les essais.

Cependant, il est reconnu que dans le cas où plusieurs séquences d'essais sont réalisées dans la même station d'essais durant une seule période d'essais, les restrictions données au paragraphe précédent peuvent causer des contraintes économiques. Dans ces circonstances, il est permis d'utiliser jusqu'à deux spécimens d'essais pour réaliser tous les essais mentionnés ci-avant. Dans un tel cas, l'identification des deux spécimens d'essais doit être réalisée selon les exigences de 6.1.2 de la CEI 62271-1; de plus, les caractéristiques de déplacement mécanique des deux spécimens doivent être selon les tolérances données en 6.101.1.1.

A titre de concession supplémentaire, limitée aux disjoncteurs ayant des mécanismes d'entraînement indépendants pour chacun des pôles, essayés au complet en monophasé, des chambres de coupures supplémentaires jusqu'à un maximum de deux pôles peuvent être utilisées en plus des deux spécimens d'essais.

Si des essais sont effectués sur un ou des éléments séparés d'un pôle, le nombre total d'éléments impliqués dans un essai individuel, considérant les exigences de 6.102.4.2.3, est considéré comme étant un spécimen d'essais. Dans ce cas, deux spécimens d'essais avec leur mécanisme de manœuvre respectif et jusqu'à deux spécimens d'essais supplémentaires (éléments de coupure appropriés) peuvent être utilisés.

La Figure 21 illustre le nombre de spécimens permis pour les essais d'établissement et de coupure. La définition d'un spécimen d'essais selon 3.2.1 de la CEI 62271-1 est présentée à la Figure 22.

Cette concession supplémentaire est permise à condition que l'inspection de l'équipement après les essais montre qu'il n'y a pas eu de dommage significatif aux pièces non interchangeables, ce qui pourrait diminuer la capacité du disjoncteur à tenir la série complète d'essais de type sans changement de ces pièces non interchangeables. Si ce n'est pas le cas, les essais doivent être répétés en utilisant le même spécimen et en ne remplaçant que les pièces interchangeables, telles qu'indiquées dans la liste du fabricant.

Lorsque des essais supplémentaires non obligatoires sont réalisés, l'utilisation de spécimens d'essais supplémentaires, en plus du nombre spécifié ci-dessus, est permise (voir Tableau 11).

6.102.3 Disposition du disjoncteur pour les essais

6.102.3.1 Généralités

Le disjoncteur à essayer doit être monté sur son propre support ou sur un support équivalent. Un disjoncteur fourni comme partie intégrante d'une cellule doit être monté sur son propre support, dans la cellule complète comprenant les équipements de sectionnement et les évents faisant partie de la cellule et, lorsque cela est possible, les jeux de barres et les principales connexions.

Son dispositif de commande doit être actionné dans les conditions spécifiées et, en particulier, si le mécanisme est à commande électrique ou à ressorts, le solénoïde de fermeture ou les déclencheurs shunt de fermeture et les déclencheurs shunt d'ouverture doivent être alimentés à leurs tensions minimales respectives garantissant une manœuvre réussie (85 % de la tension assignée pour le solénoïde de fermeture ou les déclencheurs shunts de fermeture, 85 % de la tension assignée en c.a. ou 70 % en c.c. pour les déclencheurs d'ouverture). Pour faciliter l'obtention d'un contrôle stable des manœuvres d'ouverture et de fermeture, les déclencheurs doivent être alimentés à la tension maximale pour la manœuvre lors de la séquence d'essais T100a, des essais d'établissement et de coupure de courants capacitifs, des essais d'établissement et de coupure de courants inductifs faibles et pour les essais monophasés spécifiés en 6.108. Les mécanismes qui ont une condition minimale de manœuvre (c'est-à-dire pression, énergie, etc.), doivent être actionnés à la condition minimale pour la manœuvre au début de la séquence de manœuvres assignée tel que spécifié en 4.104, à moins d'indications contraires dans les articles particuliers. Dans les cas où les séquences d'essais ou les limitations de la station d'essais permettent des séquences comprenant des manœuvres séparées O, séquences de manœuvres CO et O – t – CO, la procédure suivante s'applique aux dispositifs de commande pneumatiques et hydrauliques:

a) avant les essais d'établissement et de coupure, et partant de la pression minimale pour la manœuvre définie en 3.7.157, toutes les pressions durant la séquence de manœuvres assignée effectuée à vide doivent être enregistrées;

b) les valeurs enregistrées doivent être comparées avec les valeurs minimales garanties par le fabricant pour les manœuvres séparées réussies O, CO et O – t – CO;

c) les essais doivent être réalisés à la pression pour la manœuvre ajustée à la valeur minimale résultant de a) et b) ci-dessus, quelle que soit la plus basse, pour la manœuvre correspondante dans la séquence d'essais; les valeurs de pression doivent être indiquées dans le rapport d'essais.

Les dispositifs de verrouillage associés aux pressions doivent être rendus inopérants durant les essais s'ils interfèrent avec l'objectif de l'essai.

On doit démontrer que le disjoncteur fonctionne correctement à vide lorsqu'il est manoeuvré dans les conditions ci-dessus, tel que spécifié en 6.102.6. La pression du gaz comprimé utilisé pour la coupure doit être ajustée à sa valeur minimale telle que définie en 3.7.158.

Le disjoncteur doit être essayé selon son type tel que spécifié en 6.102.3.2 et 6.102.3.3.

6.102.3.2 Disjoncteur à enveloppe unique

Un disjoncteur tripolaire ayant tous ses contacts d'arc dans une enveloppe unique doit être essayé comme un disjoncteur tripolaire complet à l'aide d'un circuit triphasé, en prenant en compte l'Annexe O.

Les raisons sont les suivantes:

– possibilité de décharge disruptive entre pôles ou à la terre due à l'influence des gaz d'échappement;
– différences possibles de l'état du fluide d'extinction (pressions, températures, niveaux de pollution, etc.);
– plus grande influence entre phases due aux efforts électrodynamiques en cas de défaut triphasé;
– possibilité de contraintes différentes sur le mécanisme d'entraînement.

6.102.3.3 Disjoncteur à enveloppes multiples

Un disjoncteur tripolaire constitué de trois appareils de connexions unipolaires indépendants peut être essayé en monophasé conformément à 6.102.4.1. Le fabricant doit prouver par des essais la conformité à 5.101.

Un disjoncteur tripolaire dont les pôles ne sont pas complètement indépendants doit être essayé de préférence comme un disjoncteur tripolaire complet. Cependant, pour des raisons de limitation des possibilités d'essais dont on dispose, on peut essayer un seul pôle du disjoncteur, à condition que ce pôle soit, pour toute la gamme d'essais, en particulier, pour les contraintes électriques et mécaniques appliquées durant les essais, équivalent au disjoncteur tripolaire complet ou tout au moins qu'il ne soit pas dans une situation plus favorable que ce disjoncteur tripolaire, en ce qui concerne

– les caractéristiques de déplacement mécanique lors d'une manœuvre de fermeture (pour la méthode d'évaluation, voir 6.102.4.1);
– les caractéristiques de déplacement mécanique lors d'une manœuvre d'ouverture (pour la méthode d'évaluation, voir 6.102.4.1);
– la disponibilité du fluide d'extinction;
– la puissance et la robustesse des dispositifs de fermeture et d'ouverture;
– la rigidité de la structure.

6.102.3.4 Disjoncteurs à déclenchement autonome

Pour les disjoncteurs à déclenchement autonome, en considérant les exigences de 6.103.4, le déclencheur à maximum de courant doit être rendu inopérant durant les essais d'établissement, de coupure et de manœuvre et le déclencheur de courant ou les transformateurs de courant doivent être raccordés du côté sous tension du circuit d'essais.

6.102.4 Conditions générales concernant les méthodes d'essais

6.102.4.1 Essais unipolaires d'un pôle de disjoncteur tripolaire

Selon cette méthode, un pôle d'un disjoncteur tripolaire est essayé en monophasé en lui appliquant le même courant et pratiquement la même tension à fréquence industrielle que subirait le pôle le plus sollicité durant l'établissement et la coupure en triphasé par le disjoncteur tripolaire complet dans des conditions correspondantes.

Dans les cas où la conception du disjoncteur permet des essais unipolaires pour représenter des conditions triphasées et où le disjoncteur est muni d'un mécanisme d'entraînement unique pour tous les pôles, un ensemble tripolaire complet doit être fourni pour les essais.

Pour les essais en court-circuit, de façon à établir si la conception du disjoncteur permet les essais en monophasé pour simuler les conditions triphasées, des essais de vérification consistant en une manœuvre de fermeture sur un courant asymétrique et symétrique et en une manœuvre de coupure doivent être réalisés. De plus, on doit vérifier que les caractéristiques de fonctionnement du disjoncteur à essayer en monophasé sont conformes aux exigences de 6.101.1.1.

L'essai de vérification pour la coupure consiste à effectuer un essai d'interruption de courant de court-circuit triphasé au même niveau de courant que celui prescrit pour la séquence d'essais T100s, sans TTR, à une tension d'essais convenable et avec la durée d'arc la plus longue prévue pour le dernier pôle qui coupe le courant.

L'essai de vérification pour la fermeture consiste en deux manœuvres triphasées de fermeture dans les mêmes conditions que celles données en 6.104.2. Pour une des manœuvres de fermeture, le plein courant symétrique et la durée de préamorçage maximale doivent être obtenus dans un pôle. Pour l'autre manœuvre de fermeture, l'asymétrie maximale doit être obtenue sur un pôle; dans ce cas, la manœuvre de fermeture doit être effectuée à une tension réduite convenable.

Durant ces essais de vérification pour l'établissement et la coupure, la courbe de déplacement des contacts est enregistrée. Elle doit être utilisée comme référence pour la procédure suivante (voir Figure 23a). Le capteur utilisé pour l’enregistrement du déplacement des contacts doit être monté à un endroit approprié permettant d’obtenir au mieux le déplacement des contacts, soit directement soit indirectement.

A partir de cette courbe de référence, deux courbes enveloppes doivent être tracées depuis l’instant de séparation des contacts jusqu’à la fin du déplacement des contacts, dans le cas d’une manœuvre de coupure, et depuis le début de la course des contacts jusqu’à l’instant de l’entrée en contact, dans le cas d’une manœuvre d’établissement. La distance entre les deux enveloppes et la courbe de déplacement d’origine doit être de ±5 % du déplacement total évalué lors de l'essai de vérification en triphasé (voir Figure 23b).

Durant l'essai monophasé sous les mêmes conditions (séquence d'essais T100s avec la durée d'arc la plus longue et la durée de préamorçage la plus longue), la courbe de déplacement des contacts doit être enregistrée. Si la courbe de déplacement des contacts durant l'essai en monophasé est à l'intérieur des enveloppes des caractéristiques de déplacement mécanique, depuis l'instant de séparation des contacts jusqu'à la fin du déplacement des contacts dans le cas d’une manœuvre d'ouverture, et depuis le début du déplacement des contacts jusqu’à l’instant d'entrée en contact dans le cas d’une manœuvre de fermeture d’essais triphasés, alors les essais en monophasé représentant les conditions triphasées sont valables.

Les enveloppes peuvent être déplacées verticalement jusqu'à ce qu'une des courbes couvre la courbe de référence. Ceci donne des tolérances maximales respectives sur la courbe de référence de déplacement des contacts de –0 %, +10 % et de +0 %, –10 % (voir Figures 23c et 23d). Le déplacement de l'enveloppe ne peut être fait qu'une seule fois pour la procédure complète de façon à obtenir une déviation totale maximale de 10 % de la courbe de référence.

NOTE Pour obtenir des caractéristiques adéquates de déplacement des contacts des pôles individuels, selon la conception (manœuvre monopolaire ou tripolaire), il peut être nécessaire de faire des ajustements par exemple, en utilisant des fonctions de transfert.

Il convient de porter une attention particulière aux émissions de produits causées par l'arc. Si on considère que de telles émissions sont, par exemple, susceptibles d'affaiblir la distance d'isolement avec les pôles adjacents, cela doit alors être vérifié en utilisant des écrans métalliques reliés à la terre (voir 6.102.8).

6.102.4.2 Essais sur éléments séparés

Certains disjoncteurs sont construits par montage en série d'éléments identiques de coupure ou de fermeture, la répartition de tension entre les éléments de chaque pôle étant souvent améliorée par l'utilisation d'impédances parallèles.

Ce type de construction permet de vérifier les caractéristiques de coupure ou de fermeture d'un disjoncteur en effectuant les essais sur un ou plusieurs éléments.

Les exigences de 6.101.1.1, 6.102.3 et 6.102.4.1 s'appliquent aussi aux essais sur éléments séparés. Étant donné que l'on doit fournir au moins un pôle complet pour les essais de vérification sur un ou plusieurs éléments, les résultats des essais se rapportent seulement au type de pôle spécifique considéré.

Les situations suivantes peuvent être rencontrées :

a) Le pôle du disjoncteur est composé d'éléments (ou d'assemblage d'éléments) qui sont actionnés séparément et n'ont pas de liens communs en ce qui concerne le fluide extincteur de l'arc.

   Dans ce cas, les essais par éléments séparés sont acceptables. Cependant, il convient que l'influence mutuelle des forces électrodynamiques du courant sur les éléments et sur l'arc à l'intérieur de ceux-ci soit considérée (voir Figure 24). Cela peut être effectué en remplaçant la deuxième chambre de coupure par un conducteur de forme équivalente.

b) Le pôle du disjoncteur est composé d'éléments (ou d'assemblage d'éléments) qui sont actionnés séparément mais ont un lien commun en ce qui concerne le fluide extincteur de l'arc.

   Dans ce cas, les essais par éléments séparés sont acceptables seulement si les éléments qui ne sont pas essayés sont soumis à l'arc durant l'essai (par exemple utilisé comme disjoncteur auxiliaire lors d'essais synthétiques).

c) Le pôle du disjoncteur est composé d'éléments (ou d'assemblage d'éléments) qui ne sont pas opérés séparément.

   ~~Dans ce cas, les essais par éléments séparés sont acceptables seulement si les caractéristiques de déplacement mécanique pour l'essai sur élément séparé et pour l'essai sur le pôle complet sont les mêmes. La procédure donnée en 6.102.4.1 pour les essais en monophasé de disjoncteurs tripolaires doit être appliquée en conséquence. De plus, l'influence des forces électrodynamiques (voir aussi le point a) ci-dessus) doit être considérée.~~

   ~~Cependant, si les éléments qui ne sont pas essayés sont soumis à l'arc durant l'essai (par exemple, utilisé comme disjoncteur auxiliaire lors d'essais synthétiques), les exigences relatives aux caractéristiques de déplacement mécanique sont considérées comme étant rencontrées. Dans ce cas, l'exigence pour les disjoncteurs dont les éléments ont un lien commun en ce qui concerne le fluide extincteur de l'arc (voir aussi le point b) ci-dessus) est rencontrée en même temps.~~

   Dans ce cas, les essais par éléments séparés sont acceptables seulement si les caractéristiques mécaniques pour l'essai sur élément séparé et pour l'essai sur le pôle complet sont les mêmes. La procédure donnée en 6.102.4.1 pour les essais en monophasé de disjoncteurs tripolaires doit être appliquée en conséquence. De plus, l'influence des forces électrodynamiques (voir aussi le point a) ci-dessus) doit être considérée.

   Cependant, si les éléments qui ne sont pas essayés sont soumis à l'arc durant l'essai (par exemple, utilisé comme disjoncteur auxiliaire lors d'essais synthétiques), les exigences relatives aux caractéristiques mécaniques sont considérées comme étant satisfaites. Dans ce cas, l'exigence pour les disjoncteurs dont les éléments ont un lien commun en ce qui concerne le fluide extincteur de l'arc (voir aussi le point b) ci-dessus) est satisfaite en même temps.

d) Pour les courants d'essais égaux ou inférieurs à 60 % du pouvoir assigné de court-circuit, les essais par éléments séparés sont acceptables si le volume du fluide extincteur de l'arc de l'élément en essai est proportionnel à la partie applicable d'un ensemble d'éléments ayant le même fluide extincteur de l'arc.

~~Les caractéristiques de déplacement mécanique pour les essais sur l'élément séparé et pour les essais sur le pôle complet doivent être les mêmes. La procédure donnée en 6.102.4.1 pour les essais en monophasé de disjoncteurs tripolaires doit être appliquée en conséquence.~~

Les caractéristiques mécaniques à vide pour les essais sur l'élément séparé et pour les essais sur le pôle complet doivent être les mêmes. La procédure de comparaison des caractéristiques mécaniques donnée en 6.102.4.1 pour les essais en monophasé de disjoncteurs tripolaires doit être appliquée en conséquence. L'influence mutuelle des forces électrodynamiques du courant et de l'arc sur les éléments est considérée comme négligeable pour des courants d'essai inférieurs ou égaux à 60 % du courant assigné de court-circuit.

Quand on effectue des essais sur éléments séparés, il est essentiel que ceux-ci soient identiques et que la répartition statique de tension pour le type d'essai (par exemple défauts aux bornes, défauts proches en ligne, en discordance de phases, etc.) soit connue.

Pour les essais par éléments séparés de disjoncteurs de GIS et de disjoncteurs à cuve mise à la terre, voir l'Annexe O.

6.102.4.2.1 Similitude des éléments

Les éléments du disjoncteur doivent être identiques dans leur forme, leurs dimensions et leurs conditions de fonctionnement; seuls les dispositifs de répartition de tension peuvent différer d'un élément à l'autre. En particulier, les conditions suivantes doivent être remplies.

a) *Fonctionnement des contacts*

L'ouverture des contacts d'un pôle pour les essais de coupure, ou la fermeture des contacts d'un pôle pour les essais d'établissement, doivent être telles que l'intervalle de temps entre l'instant de l'ouverture ou de la fermeture des contacts de l'élément qui manœuvre le premier et de ceux de l'élément qui manœuvre le dernier ne soit pas supérieur à un huitième de période de la fréquence assignée. On doit utiliser les pressions et tensions de commande assignées pour déterminer cet intervalle de temps.

b) *Alimentation en fluide d'extinction*

Dans le cas de disjoncteurs utilisant un fluide d'extinction provenant d'une source extérieure, l'alimentation de chaque élément doit être pratiquement indépendante de l'alimentation des autres éléments et le positionnement des canalisations d'alimentation doit être tel que tous les éléments soient pratiquement alimentés ensemble et de manière identique.

6.102.4.2.2 Répartition de la tension

La tension d'essai est déterminée en analysant la répartition de tension entre les éléments du pôle.

La répartition de la tension entre les éléments d'un pôle, qui dépend de l'influence de la terre, doit être déterminée pour les conditions particulières d'essais utilisées pour des essais unipolaires:

– pour les conditions correspondant au défaut aux bornes, voir les points c) et d) de 6.103.3 et les Figures 27a, 27b, 28a et 28b;

NOTE 1 Le circuit d'essai présenté aux Figures 27b et 28b n'est pas applicable pour les disjoncteurs dont l'isolation entre phases et/ou à la terre est critique (par exemple, disjoncteurs de GIS ou disjoncteurs à cuve mise à la terre). Des méthodes d'essais appropriées pour ces disjoncteurs sont présentées à l'Annexe O de la présente norme et dans la CEI 62271-101.

– pour les conditions correspondant au défaut proche en ligne voir 6.109.3;
– pour les conditions en discordance de phases voir 6.110.1 et les Figures 51, 52 et 53;
– pour les conditions correspondant à la manœuvre de courants capacitifs voir 6.111.3, 6.111.4 et 6.111.5.

Lorsque les éléments ne sont pas disposés de façon symétrique, la répartition de la tension doit être également déterminée en inversant les connexions.

La répartition de la tension est déterminée soit par des mesures ou par des calculs. Les valeurs utilisées dans les calculs doivent résulter de la mesure des capacités parasites du disjoncteur. Ces calculs et mesures vérifiant les hypothèses utilisées dans les calculs incombent au constructeur.

Si le disjoncteur est muni de résistances en parallèle, la répartition de la tension doit être calculée ou mesurée statiquement à une fréquence équivalente à celle de la TTR.

NOTE 2 On considère que la fréquence équivalente est égale à $1/(2t_1)$ dans le cas d'une TTR à quatre paramètres et à $1/(2t_3)$ dans le cas d'une TTR à deux paramètres (voir Figures 39 et 40).

Pour les essais de défaut proche en ligne sur éléments séparés, la répartition de la tension doit être calculée ou mesurée statiquement en considérant une tension du côté ligne à la fréquence fondamentale d'oscillation de la ligne et une tension du côté source à la fréquence équivalente de la TTR du défaut aux bornes, le point commun aux deux tensions étant au potentiel de la terre.

Si la répartition de la tension est réalisée à l'aide de condensateurs uniquement, elle peut être calculée ou mesurée à la fréquence industrielle.

On doit tenir compte des tolérances de fabrication des résistances et des condensateurs. Le constructeur doit indiquer la valeur de ces tolérances.

NOTE 3 On peut tenir compte du fait que la répartition de la tension est plus favorable lors des essais de coupure dans des conditions de discordance de phases et de courants capacitifs que lors des essais de coupure de défauts aux bornes ou proches en ligne. C'est également le cas lorsque, exceptionnellement, il y a lieu que des essais soient effectués dans des conditions de défauts isolés de la terre dans des réseaux à neutre relié effectivement à la terre.

NOTE 4 On n'a pas tenu compte de l'influence de la pollution dans la détermination de la répartition de la tension. Dans certains cas, la pollution peut modifier cette répartition de la tension.

6.102.4.2.3 Conditions à remplir pour les essais sur éléments séparés

Lors d'essais sur un seul élément, la tension d'essai doit être la tension de l'élément le plus sollicité du pôle complet du disjoncteur, déterminée conformément à 6.102.4.2.2. Dans les conditions de défaut proche en ligne, l'élément de référence est celui qui est le plus sollicité à l'instant de la première crête de la tension transitoire du côté ligne.

Lors des essais d'un groupe d'éléments, la tension apparaissant aux bornes de l'élément le plus sollicité du groupe doit être égale à celle de l'élément le plus sollicité du pôle, les deux étant déterminées conformément à 6.102.4.2.2.

Au cours des essais sur éléments séparés, l'isolation à la terre n'est pas contrainte à la pleine tension qui apparaît pendant un essai de coupure effectué sur le disjoncteur complet. Pour certains types de disjoncteurs, tels les disjoncteurs dont les pôles sont contenus dans des enveloppes métalliques, il est par conséquent nécessaire de prouver que l'isolation à la terre est capable de supporter cette pleine tension après l'interruption du courant de court-circuit assigné avec le temps d'arc maximal pour tous les éléments. Il convient de tenir compte aussi de l'influence des gaz d'échappement.

Des lignes directrices supplémentaires sont données à l'Annexe O de la présente norme. La CEI 62271-101 doit être prise en compte.

6.102.4.3 Essais en plusieurs parties

S'il n'est pas possible de répondre simultanément à toutes les exigences de la TTR pour une séquence d'essais donnée, l'essai peut être effectué en deux parties successives, tel que présenté à la Figure 43.

Dans la première partie, la partie initiale de la TTR doit ne pas traverser le segment de droite définissant le temps de retard et doit être conforme au tracé de référence spécifié jusqu'au point défini par la tension u_1 et le temps t_1.

Dans la seconde partie, le point défini par la tension u_c et le temps t_2 doit être atteint.

Le nombre d'essais pour chacune des parties doit être le même que celui requis pour la séquence d'essais et les durées d'arc pour chacune des parties doivent être conformes aux exigences de 6.102.10. Les durées d'arc des essais formant une partie de l'essai en plusieurs parties doivent être les mêmes avec une tolérance de ±1 ms. De plus, si la durée d'arc minimale dans une des parties diffère de celle établie dans l'autre partie de plus de 1 ms alors la durée d'arc maximale associée à la plus longue des durées d'arc minimales doit être utilisée pour les deux parties.

Le disjoncteur peut être remis en état entre la première partie et la deuxième partie selon les exigences de 6.102.9.5.

Dans des cas exceptionnels, il peut être nécessaire d'effectuer l'essai avec plus de deux parties. Dans ces cas, les principes évoqués ci-dessus doivent être appliqués.

6.102.5 Essais synthétiques

Les méthodes d'essais synthétiques peuvent être appliquées aux essais d'établissement de coupure et de manœuvre demandés de 6.106 à 6.111. Les méthodes et techniques d'essais synthétiques sont décrites dans la CEI 62271-101.

6.102.6 Manœuvres à vide avant les essais

Avant d'entreprendre les essais d'établissement et de coupure, des manœuvres et séquences de manœuvres à vide (O, CO et O – t – CO) doivent être effectuées et les caractéristiques de fonctionnement du disjoncteur doivent être enregistrées. Les caractéristiques telles que les durées de fermeture et d'ouverture doivent être enregistrées.

De plus, il doit être démontré que le comportement mécanique du disjoncteur, ou du spécimen en essai, est conforme aux caractéristiques de déplacement mécanique de référence demandées en 6.101.1.1. Pour cet essai, les conditions fonctionnelles données en 6.101.1.1 s'appliquent. Après un changement de contacts ou n'importe quel type de remise en état, ces caractéristiques de déplacement mécanique doivent être confirmées à nouveau en répétant ces essais à vide.

Dans le cas d'un disjoncteur muni d'un déclencheur sous courant de fermeture, on doit montrer que celui-ci ne fonctionne pas au cours des essais à vide.

La pression du fluide servant à l'interruption doit être réglée à sa valeur minimale telle que définie en 3.7.158.

Dans le cas de disjoncteurs à commande électrique ou à ressorts, les manœuvres doivent être faites en alimentant le solénoïde de fermeture ou les déclencheurs shunt de fermeture à 100 % et 85 % de la tension d'alimentation assignée du dispositif de fermeture, et les déclencheurs shunt d'ouverture à 100 % et 85 % de la tension d'alimentation assignée dans le cas de courant alternatif ou à 100 % et 70 % de la tension d'alimentation assignée dans le cas de courant continu.

Dans le cas des dispositifs de fermeture et d'ouverture à commande pneumatique ou oléopneumatique, les manœuvres doivent être faites dans les conditions suivantes:

a*)* à la pression du fluide pour la manœuvre ajustée à sa valeur minimale telle que définie en 3.7.157 avec les déclencheurs shunt d'ouverture alimentés à 85 % en courant alternatif ou à 70 % en courant continu, et avec les déclencheurs shunt de fermeture alimentés à 85 % de la tension d'alimentation assignée;

b) à la pression du fluide pour la manœuvre ajustée à sa valeur de pression nominale telle que définie en 4.10 avec les déclencheurs shunt alimentés à la tension d'alimentation assignée.

6.102.7 Mécanismes d'entraînement différents

Pour un disjoncteur équipé d'un mécanisme d'entraînement alternatif, il n'est pas nécessaire de répéter les essais de type dans les conditions de court-circuit et de discordance de phases et les essais de type d'établissement et de coupure de courants capacitifs.

NOTE 1 Dans ce paragraphe, il est considéré qu'une version du disjoncteur utilisant un certain mécanisme d'entraînement est entièrement soumise aux essais de type, conformément à la présente norme; cette version est désignée par le disjoncteur entièrement soumis aux essais. Les autres versions, différant uniquement dans les mécanismes d'entraînement (voir définition en 3.5.124), sont désignées par des disjoncteurs avec des mécanismes d'entraînement alternatifs.

Les essais à réaliser sont limités aux suivants:

a) Sur chacun des disjoncteurs (disjoncteur entièrement soumis aux essais et disjoncteurs avec des mécanismes d'entraînement alternatifs), les caractéristiques mécaniques doivent être enregistrées et comparées conformément à 6.101.1.1 (L'utilisation de caractéristiques mécaniques et les exigences qui y sont liées sont décrites à l'Annexe N).

b) Sur chacun des disjoncteurs (disjoncteur entièrement soumis aux essais et disjoncteurs avec des mécanismes d'entraînement alternatifs), la séquence d'essais T100s doit être réalisée. De plus, les caractéristiques mécaniques au cours des manœuvres de coupure avec la durée d'arc la plus longue doivent être évaluées conformément à la méthode exigée en 6.101.1.1. (L'utilisation des caractéristiques mécaniques et les exigences qui y sont liées sont décrites à l'Annexe N).

c) Dans le cas particulier où les variations dans les durées d'ouverture du mécanisme d'entraînement alternatif entraînent le passage du disjoncteur dans une catégorie différente de durée minimale de coupure (voir 3.7.159), la séquence d'essais T100a doit être réalisée sur le disjoncteur avec un mécanisme d'entraînement alternatif.

Si les exigences a), b) et c) sont satisfaites, les caractéristiques mécaniques de référence du disjoncteur entièrement soumis aux essais doivent aussi s'appliquer aux disjoncteurs qui ont des mécanismes d'entraînement alternatifs.

6.102.8 Comportement du disjoncteur pendant les essais

Pendant les essais d'établissement et de coupure, le disjoncteur ne doit pas

– présenter de signes de fatigue;

– montrer d'interaction nuisible entres les pôles et la terre;

– nuire aux équipements adjacents du laboratoire;

– montrer un comportement qui pourrait mettre en danger un opérateur.

Pour les disjoncteurs conçus pour laisser échapper le milieu extincteur dans l'atmosphère durant les essais d'établissement et de coupure, les exigences décrites ci-dessus sont considérées comme remplies à condition que

– pour les disjoncteurs à huile, il n'y ait pas d'émission extérieure de flammes et que les gaz produits, ainsi que l'huile entraînée par ces gaz, soient canalisés et dirigés loin des conducteurs sous tension et des emplacements où des personnes peuvent se trouver;
– pour les autres types de disjoncteurs, tels qu'à air comprimé ou à isolation dans l'air, il y ait des émissions extérieures de flammes, de gaz et/ou de particules métalliques. Si ces émissions sont appréciables, on peut demander que les essais soient effectués avec des écrans métalliques placés au voisinage des parties sous tension et séparées de ces dernières par une distance de sécurité spécifiée par le constructeur. Les écrans doivent être isolés de la terre, mais y sont reliés par un dispositif convenable permettant de déceler tout passage d'un courant de fuite significatif à la terre. Il ne doit pas avoir de courant de fuite significatif dans la structure métallique du disjoncteur ou dans les écrans si l'appareil en est muni lors des essais.

NOTE 1 S'il n'y a pas d'autres dispositifs disponibles, il convient que les parties mises à la terre, etc., soient raccordées à la terre au travers d'un fusible consistant en un fil de cuivre de 0,1 mm de diamètre et d'une longueur de 5 cm. Il n'y a pas eu de courant de fuite significatif si le fil fusible est intact après les essais.

Si des échecs surviennent, ni persistants ni causés par un défaut de conception mais plutôt par des erreurs d'assemblage ou d'entretien, les déficiences peuvent être corrigées et la séquence d'essais concernée peut être répétée sur le même disjoncteur. Dans ces cas, le rapport d'essais doit mentionner les essais non valables.

Les décharges disruptives non maintenues (NSDD; en anglais *non-sustained disruptive discharges*) peuvent apparaître pendant la période de tension de rétablissement à la suite d'une coupure. Cependant, leur apparition n'est pas un signe de dommage de l'appareil de connexion en essai. Par conséquent, leur nombre n'a pas de signification dans l'interprétation de la performance du dispositif en essai. Elles doivent être mentionnées dans le rapport d'essais, afin de les différencier des réamorçages.

NOTE 2 L'objectif n'est pas d'exiger l'installation de circuits de mesure particuliers afin de détecter les décharges disruptives non maintenues. Il convient uniquement de les mentionner lorsqu'elles sont vues sur un oscillogramme.

6.102.9 Etat du disjoncteur après les essais

6.102.9.1 Généralités

Le disjoncteur peut être examiné après chaque séquence d'essais. Ses parties mécaniques et ses isolateurs doivent être pratiquement dans le même état qu'avant la séquence d'essais. Un contrôle visuel suffit en général à la vérification des propriétés d'isolation. En cas de doute, l'essai de contrôle de l'état conformément à 6.2.11 suffit à démonter les propriétés d'isolation.

Pour les disjoncteurs comportant des sous-ensembles interrupteurs scellés à vie, l'essai de contrôle de l'état est obligatoire sauf dans les conditions indiquées en 6.102.9.4.

6.102.9.2 Etat après une séquence d'essais de court-circuit

Après chaque série d'essais de court-circuit, le disjoncteur doit être capable d'établir et de couper son courant assigné en service continu sous sa tension assignée, alors que ses possibilités de fermeture et de coupure en court-circuit peuvent être réduites. Après la séquence d'essais L_{90}, un essai de contrôle d'état selon 6.2.11 doit être effectué. Si l'essai L_{90} n'est pas effectué, l'essai de contrôle d'état doit être effectué après l'essai T100s.

Si les éléments de coupure sont placés dans un fluide isolant avec des caractéristiques différentes, ceci peut également soutenir les tensions d'essai lors du remplacement du fluide d'extinction de l'arc original (par exemple élément de coupure à vide dans une enveloppe remplie de SF_6), l'essai de contrôle de l'état comme exigé en 6.2.11 peut ne pas être adéquat pour vérifier l'intégrité du dispositif. Dans de tels cas, un essai de coupure de court-circuit doit être réalisé en plus. Si plus d'une séquence d'essais est effectuée sans remise en état, cet essai supplémentaire doit être réalisé avant ou après les essais à vide postérieurs aux séquences d'essais de court-circuit, comme suit:

– lorsqu'il est effectué en triphasé, un circuit qui fournit au moins 10 % du pouvoir de coupure assigné en court-circuit et au moins 50 % de la tension assignée doit être utilisé avec, à la fois, le point neutre du côté alimentation et le point de court-circuit mis à la terre;
– lorsqu'il est effectué en monophasé, la même procédure s'applique et l'essai doit être répété sur chaque pôle.

Les exigences mentionnées ci-dessus s'appliquent également aux essais synthétiques.

Une coupure réussie dans chaque pôle prouve que l'intégrité de l'interrupteur est maintenue.

Pour les sous-ensembles interrupteurs autres que ceux scellés à vie, un contrôle visuel est généralement suffisant pour vérifier la capacité du disjoncteur à transporter le courant assigné en service continu et à établir et couper son courant assigné en service continu sous la tension assignée.

Les contacts principaux doivent être, en particulier en ce qui concerne l'usure due à l'arc, la surface de contact, la pression et la liberté de mouvement, dans un état tel qu'ils puissent supporter le courant assigné en service continu du disjoncteur sans que leur échauffement dépasse de plus de 10 K les valeurs spécifiées pour ces contacts dans le Tableau 3 de la CEI 62271-1.

NOTE L'expérience montre qu'une augmentation seule de la chute de tension aux bornes du disjoncteur ne peut être considérée comme une preuve certaine d'un accroissement de l'échauffement.

On ne doit considérer les contacts comme "recouverts d'argent" que si une couche d'argent subsiste aux points de contact après l'une quelconque des séquences d'essais de court-circuit; dans le cas contraire, les contacts sont considérés comme "non recouverts d'argent" (voir 4.4.3, point 6, de la CEI 62271-1).

Pour contrôler le fonctionnement du disjoncteur après essais, des manœuvres à vide doivent être effectuées s'il est prévu de faire un changement de contacts ou toute autre maintenance après les séquences d'essais. Ces essais doivent être comparés avec les manoeuvres correspondantes effectuées suivant 6.102.6 et ne doivent pas montrer de changements significatifs.

6.102.9.3 Etat après une série d'essais de court-circuit

Pour vérifier le fonctionnement du disjoncteur après essais, des manœuvres de fermeture et d'ouverture à vide doivent être effectuées à la suite d'une série complète d'essais de court-circuit. Ces manœuvres doivent être effectuées dans les mêmes conditions que l'une des manœuvres correspondantes avant les essais. Les manœuvres à vide après la série d'essais doivent être comparées aux manœuvres correspondantes réalisées conformément à 6.102.6 et ne doivent présenter aucun changement significatif. Les exigences de 6.101.1.1 et de l'Annexe N doivent être satisfaites. La fermeture et l'accrochage mécanique du disjoncteur doivent se faire d'une manière satisfaisante.

Il est admis que les pouvoirs de fermeture, de coupure et de tenue de courte durée du courant de court-circuit assigné soient modifiés, mais la dégradation des composants du circuit principal du courant ne doit pas réduire l'intégrité des composants isolants ou des composants de support mécanique du disjoncteur. Pour les contacts principaux, 6.102.9.2 s'applique.

Aucun critère ne peut être donné quant au niveau de dégradation acceptable de l'isolation par fluide (gaz, huile, air, etc.) car leur rigidité exigée est liée aux critères de conception de chaque type de disjoncteur différent.

6.102.9.4 Etat après une série d'essais d'établissement et de coupure de courants capacitifs

Le disjoncteur doit, après avoir subi la série d'essais de commutation de courant de charge de la ligne, de charge du câble et de la batterie de condensateurs spécifiée en 6.111.9 et avant remise en état, pouvoir fonctionner de manière satisfaisante à tout courant d'établissement et de coupure jusqu'à son courant d'établissement et de coupure assigné en service continu sous la tension assignée.

En outre, le disjoncteur doit être capable de conduire son courant normal assigné avec un échauffement ne dépassant pas l'échauffement autorisé au Tableau 3 de la CEI 62271-1. Pour les disjoncteurs de classe C2, l'échauffement ne doit pas dépasser les valeurs permises par le Tableau 3 de CEI 62271-1 de plus de 10 K.

Pour les sous-ensembles interrupteurs autres que ceux scellés à vie, un contrôle visuel est généralement suffisant pour vérifier la capacité du disjoncteur à conduire le courant assigné en service continu et à établir et couper tout courant jusqu'à son pouvoir de fermeture et de coupure assigné en court-circuit sous la tension assignée.

Aucune trace de perforation, de contournement ou de cheminement ne doit être observée sur les matériaux isolants internes. Seule une usure modérée des pièces des dispositifs de contrôle d'arc exposées aux arcs est autorisée.

La dégradation des composants du circuit principal de courant ne doit pas réduire l'intégrité dudit circuit.

Si, au cours des essais d'établissement et de coupure de courants capacitifs, un ou plusieurs réamorçages se sont produits, l'essai de contrôle de l'état diélectrique conformément à 6.2.11 doit être effectué avant le contrôle visuel, à condition que la tension de rétablissement crête soumise aux essais pendant les essais d'établissement et de coupure de courants capacitifs soit inférieure à la tension crête de l'essai de contrôle de l'état diélectrique spécifié. Le contrôle visuel ultérieur doit ensuite démontrer que le réamorçage s'est produit uniquement sur les contacts d'arc. Aucune trace de perforation, de contournement ou de cheminement permanent ne doit être observée sur les matériaux isolants internes. L'usure des parties des dispositifs de contrôle d'arc exposées à l'arc est permise si elle n'affecte pas l'intégrité de la capacité de coupure. En outre, l'examen de l'intervalle isolant entre les contacts principaux, s'ils sont différents des contacts d'arc, ne doit révéler aucune trace de réamorçage.

Si aucun réamorçage ne s'est produit pendant les essais de commutation de courant capacitif, le contrôle visuel suffit. L'essai de contrôle de l'état diélectrique conformément à 6.2.11 ne doit pas être effectué.

Si d'autres essais sont effectués sur le même pôle, l'essai de contrôle de l'état diélectrique doit être effectué après les essais capacitifs. Si aucun amorçage ne s'est produit pendant les essais d'établissement et de coupure de courants capacitifs, il n'est pas nécessaire d'effectuer cet essai de contrôle de l'état diélectrique, ce dernier peut être effectué après des essais additionnels.

NOTE Si le disjoncteur échoue pendant ces essais additionnels, la procédure peut rendre invalide la série d'essais d'établissement et de coupure de courants capacitifs.

Pour les disjoncteurs à unités d'interruption scellées à vie, l'essai de contrôle de l'état diélectrique conformément à 6.2.11 doit être effectué, qu'un réamorçage se soit produit ou non au cours de l'essai, à condition que la tension crête de rétablissement appliquée pendant les essais d'établissement et de coupure de courants capacitifs soit inférieure à la tension crête de l'essai de contrôle de l'état diélectrique.

6.102.9.5 Remise en état après une séquence d'essais de court-circuit et d'autres séries d'essais

Il est admis qu'à la suite d'une séquence d'essais de court-circuit ou d'autres séries d'essais, il peut être nécessaire de procéder à la maintenance du disjoncteur en vue de le remettre dans l'état initial spécifié par le constructeur. Par exemple, il est admis qu'il soit nécessaire de

a) réparer ou de remplacer les contacts d'arc ainsi que toute autre pièce interchangeable recommandée par le constructeur;

b) filtrer ou de remplacer l'huile ou tout autre fluide d'extinction et d'y ajouter la quantité nécessaire pour rétablir son niveau normal ou sa densité;

c) nettoyer l'isolation interne pour la débarrasser des dépôts provenant de la décomposition du fluide d'extinction.

Le disjoncteur de classe E2 ne doit pas être remis en état pendant les séquences d'essais de court-circuit standard, décrites en 6.106.

6.102.10 Démonstration des durées d'arc

La séquence d'exécution des trois manœuvres de coupure valables doit être telle que la dernière manœuvre de coupure produise une durée d'arc moyenne. Les procédures décrites ci-après servent à l'ajustement des durées d'arc présumées. Les durées d'arc réelles peuvent être différentes des durées d'arc présumées. Les essais sont valables si les durées d'arc sont en accord avec les tolérances indiquées dans l'Annexe B.

Pour les disjoncteurs ayant une séquence de manœuvres CO – *t*'' – CO, un CO doit démontrer la durée d'arc minimale et le second doit démontrer la durée d'arc maximale.

Les essais de défaut T100a en 6.102.10.1.2, 6.102.10.2.1.2 et 6.102.10.2.2.2 se composent de trois manœuvres valables indépendantes de la séquence de fonctionnement assignée. Après le nombre de manœuvres prévu, conformément à la séquence de fonctionnement assignée, le disjoncteur peut être remis en état conformément à 6.102.9.5.

NOTE Les durées d'arc exigées par le présent paragraphe couvrent de manière adéquate l'effet de la non-simultanéité non intentionnelle des pôles du disjoncteur.

6.102.10.1 Essais triphasés

Les procédures sont données ci-après pour des essais directs. Lorsque des essais synthétiques sont effectués, il est nécessaire de démontrer la durée d'arc minimale du premier pôle qui coupe avant de débuter la séquence. La méthode de détermination de la durée d'arc minimale est donnée en 6.102.10.2.

6.102.10.1.1 Séquence d'essais T10, T30, T60, T100s, T100s(b), OP1 et OP2

Pour ces séquences d'essais, l'ordre d'ouverture doit être avancé d'environ 40 degrés électriques (40°) entre chaque manœuvre d'ouverture. Pour la séquence T100s(b), voir la note de 6.106.

~~Une représentation graphique des trois manœuvres valables de coupure pour un facteur de premier pôle égal à 1,5 est donné par la Figure 29 et pour un facteur de premier pôle égal à 1,3 par la Figure 30.~~

Des exemples de représentation graphique des trois manœuvres valables de coupure pour un facteur de premier pôle qui coupe égal à 1,5 sont données à la Figure 29 et pour un facteur de premier pôle qui coupe égal à 1,3 à la Figure 30.

6.102.10.1.2 Séquence d'essais T100a

Etant donné que la sévérité des essais de cette séquence d’essais peut varier beaucoup en fonction de l'instant de séparation des contacts, une procédure a été mise au point pour aboutir à une contrainte correcte du disjoncteur en essai. L'instant d'établissement du court-circuit est modifié de 60° entre chaque essai afin de transférer successivement sur chaque phase les critères d'asymétrie requis.

L'intention est d'obtenir une série de trois essais valables et la séquence est considérée satisfaisante si les conditions suivantes sont réunies:

a) Une opération où l'extinction de l'arc du premier pôle qui coupe se produit à la fin d'une grande alternance de courant avec une durée d'arc la plus grande possible et avec les critères d'asymétrie demandés tels qu’ils sont indiqués en 6.106.6, de façon à être conforme aux exigences de la TTR.

NOTE Certains disjoncteurs ne couperont pas à la fin d'une grande alternance. L'arc se prolongera durant la petite alternance suivante de courant et ce pôle sera le dernier qui coupe. Toutefois, cet essai est considéré valable si, durant un essai ultérieur, il est démontré que la durée d'arc la plus grande possible a été obtenue.

b) Une opération où l'extinction de l'arc dans un des derniers pôles qui coupent se produit à la fin d'une grande alternance allongée de courant avec une durée d'arc la plus grande possible et avec les critères d'asymétrie demandés tels que donnés en 6.106.6.

   Un essai où le disjoncteur interrompt à la fin d'une grande alternance réduite de courant ou à la fin d'une petite alternance dans la phase qui rencontre les critères d'asymétrie n’est pas valable (sauf pour la situation décrite dans la note du point a) ci-dessus).

c) Une opération avec les critères d'asymétrie demandés, tels que donnés en 6.106.6, pour démontrer la validité des conditions d'essais décrites aux points a) et b) ci-dessus.

L'ordre des essais n'a pas de conséquence pour autant que la série d'essais soit conforme aux conditions d'essais mentionnées en a), b) et c).

Si, à cause des caractéristiques du disjoncteur, il n'est pas possible de respecter les exigences citées précédemment, il convient d'augmenter le nombre d'opérations pour démontrer, dans ce cas particulier, que les conditions d'essais les plus sévères ont été obtenues. Il convient de ne pas faire subir plus de six manœuvres d’ouverture au disjoncteur pour l’obtention des exigences ci-dessus.

Le disjoncteur peut être remis en état avec des pièces interchangeables avant les opérations additionnelles (voir 6.102.9.5). Un spécimen d'essai complémentaire peut aussi être utilisé pour les opérations additionnelles.

Le mode opératoire recommandé est celui qui suit.

Pour la première manœuvre valable, l'établissement du court-circuit et le réglage de l'ordre d'ouverture doivent être tels que

– les critères d'asymétrie requis sont obtenus dans une phase;
– l'extinction de l'arc se produit dans la phase rencontrant les critères d'asymétrie requis à l'issue d'une grande alternance (ou la plus grande partie possible de cette alternance) dans le cas de la première phase qui coupe ou à l'issue d'une grande alternance allongée (ou de la plus grande partie possible de cette alternance) dans le cas de l'une des dernières phases qui coupent.

Pour la deuxième manœuvre valable, il convient d'avancer l'instant d'établissement du court-circuit de 60° et le réglage de l'ordre d'ouverture doit être tel que:

– si la première manœuvre était valable parce que l’extinction de l’arc s’est produite sur la phase avec les critères d'asymétrie requis après une grande alternance, le réglage de l'ordre d'ouverture doit être avancé approximativement de 130° par rapport à la première manœuvre valable;

– si la première manœuvre était valable parce que l'extinction de l'arc s'est produite sur la phase avec les critères d'asymétrie requis après une grande alternance allongée, le réglage de l'ordre d'ouverture doit être avancé approximativement de 25° par rapport à la première manœuvre valable.

Pour la troisième manœuvre, la procédure de la deuxième manœuvre peut être répétée. L'instant d'établissement du court-circuit doit être avancé de 60° par rapport à la deuxième manœuvre et l'ordre d'ouverture doit être réglé comme suit:

– si la deuxième manœuvre était valable parce que l'extinction de l'arc s'est produite sur la phase avec les critères d'asymétrie requis après une grande alternance, le réglage de l'ordre d'ouverture doit être avancé approximativement de 130° par rapport à la deuxième manœuvre valable ;
– si la deuxième manœuvre était valable parce que l'extinction de l'arc s'est produite sur la phase avec les critères d'asymétrie requis après une grande alternance allongée, le réglage de l'ordre d'ouverture doit être avancé approximativement de 25° par rapport à la deuxième manœuvre valable.

Si les caractéristiques du disjoncteur ne sont pas constantes, il peut être nécessaire d'utiliser d'autres procédures pour réaliser les trois opérations valables décrites ci-dessus.

Cette procédure d'essai est applicable aux réseaux à neutre relié non effectivement à la terre (facteur de premier pôle 1,5) et aux réseaux à neutre relié effectivement à la terre (facteur de premier pôle 1,3).

Les Figures 31 et 32 donnent des exemples graphiques des trois opérations de coupure valables.

6.102.10.2 Essais monophasés en substitution des essais triphasés

Les procédures données ci-après sont partiellement dérivées des méthodes d'essais synthétiques. Lorsque des essais directs sont effectués la procédure utilisée pour démontrer la durée d'arc minimale peut conduire à un essai valable avec la durée d'arc maximale ou avec une durée d'arc plus longue que la durée d'arc maximale.

L'objet des essais monophasés suivants est de satisfaire aux conditions du premier pôle qui coupe et du dernier pôle qui coupe avec un circuit d'essai et pour chaque séquence d'essais.

Les procédures suivantes sont applicables si toutes les manœuvres de la séquence de manœuvres assignée satisfont aux exigences de 5.101. Dans le cas contraire, les Tableaux 15 à 22 doivent être utilisés avec prudence.

6.102.10.2.1 Systèmes à neutre non effectivement mis à la terre

6.102.10.2.1.1 Séquence d'essais T10, T30, T60, T100s et T100s(b), OP1 et OP2

La première manœuvre de coupure valable doit démontrer la coupure avec une durée d'arc la plus courte possible. La durée d'arc résultante est définie comme la durée d'arc minimale ($t_{\text{arc min}}$). Elle est obtenue lorsqu'un retard supplémentaire à la séparation des contacts par rapport à une alternance de courant conduit à une coupure au zéro suivant du courant. Cette durée d'arc minimale est obtenue en changeant le réglage de l'ordre d'ouverture par pas de 18° environ (dα).

La deuxième manœuvre de coupure valable doit démontrer la coupure avec la durée d'arc maximale. La durée d'arc maximale requise est désignée par $t_{\text{arc max}}$, elle est définie par

$$t_{\text{arc max}} \geq t_{\text{arc min}} + T\,\frac{150° - \mathrm{d}\alpha}{360°}$$

où

$t_{\text{arc min}}$ est la durée d'arc minimale obtenue à partir de la première manœuvre valable;

dα = 18°;

T est une période de la fréquence du courant.

Elle est normalement obtenue en avançant l'ordre d'ouverture d'au moins (150° – dα) par rapport à la première manœuvre de coupure valable.

La troisième manœuvre de coupure valable doit démontrer la coupure avec une durée d'arc approximativement égale à la valeur moyenne de celles des première et deuxième manœuvres de coupure. La durée d'arc est définie comme étant la durée d'arc moyenne ($t_{\text{arc med}}$), elle est donnée par:

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

L'ordre d'ouverture de la troisième manœuvre de coupure valable doit être retardé de 75° (±18°) par rapport à celle de la deuxième manœuvre de coupure valable.

La Figure 33 donne une représentation graphique des trois manœuvres de coupure valables.

6.102.10.2.1.2 Séquence d'essais T100a

a) Durées d'arc

La première manœuvre de coupure valable doit démontrer l'interruption à la fin de la petite alternance avec une durée d'arc aussi petite que possible. La durée d'arc résultante est définie dans cette norme comme la durée d'arc minimale ($t_{\text{arc min}}$). Elle est obtenue lorsqu'un retard de séparation supplémentaire des contacts par rapport au passage à zéro du courant entraîne la coupure au passage à zéro suivant après une grande alternance du courant. Cette durée d'arc minimale est trouvée en modifiant le réglage de l'ordre d'ouverture par pas d'environ 18° (dα).

NOTE 1 Avec certains disjoncteurs, la durée d'arc minimale pour la petite alternance peut être si longue que le disjoncteur sera capable d'interrompre la grande alternance précédente au même instant de séparation des contacts. Pour de tels cas, la durée d'arc minimale est démontrée à la fin d'une grande alternance, et aucun essai sur la petite alternance n'est requis.

La durée d'arc minimale obtenue ($t_{\text{arc min major loop}}$) est utilisée pour calculer la durée minimale d'interruption et pour déterminer les paramètres de la grande alternance pour toutes les manœuvres (paramètres des Tableaux 15 à 22). Pour la deuxième manœuvre de coupure valable avec la durée d'arc maximale, la durée d'arc minimale ($t_{\text{arc min}}$), à utiliser dans la formule est $t_{\text{arc min}} = t_{\text{arc min major loop}} + \Delta t_2$.

Si des essais supplémentaires sont nécessaires, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 est autorisée.

La deuxième manœuvre de coupure valable doit démontrer la coupure avec la durée d'arc maximale. La durée d'arc maximale requise dans cette norme est identifiée comme $t_{\text{arc max}}$ et est déterminée par

$$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times \frac{30^{\text{o}} + \mathrm{d}\alpha}{360^{\text{o}}}$$

où l'intervalle de temps Δt_1 est la durée de la grande alternance donnée aux Tableaux 15 à 22.

L'intervalle de temps Δt_1 est fonction de la constante de temps de la composante apériodique (τ), de la fréquence assignée du système, de la durée d'ouverture et de la durée d'arc minimale du disjoncteur. L'intervalle de temps Δt_1 est égal à la durée (valeur arrondie) de la grande alternance suivante (sur la forme d'onde du courant asymétrique requise) qui se produira après la durée minimale d'interruption. L'interruption doit survenir après une grande alternance ou après la petite alternance ultérieure si le disjoncteur n'interrompt pas le courant après la grande alternance requise. Ceci est obtenu en retardant l'ordre d'ouverture par rapport à la première manœuvre d'interruption valable.

Les Tableaux 15 à 22 prennent en compte un temps relais de 0,5 cycle de la fréquence assignée (10 ms à 50 Hz et 8,3 ms à 60 Hz). Si le disjoncteur n'a pas coupé après la grande alternance requise et coupe après la petite alternance suivante, la durée d'arc maximale requise est prolongée par la durée de la petite alternance appropriée (Δt_2), donnée aux Tableaux 15 à 22.

NOTE 2 Dans un circuit d'essais directs, tout retard de l'ordre d'ouverture après l'essai à $t_{\text{arc min}}$ entraînera une durée d'arc sur la grande alternance suivante de:

$$t_{\text{arc max}} = t_{\text{arc min}} + \Delta t_1 - T \times \frac{\mathrm{d}\alpha}{360^{\circ}}$$

Cela implique que seulement une fenêtre d'arc de 180° peut être démontrée dans un circuit d'essai monophasé. Cette condition peut conduire à des contraintes excessives sur le disjoncteur. Si tel est le cas, seulement pour des applications à neutre relié non effectivement à la terre, il est permis de retarder davantage l'ordre d'ouverture, de façon à obtenir la durée d'arc maximale demandée.

La troisième manœuvre de coupure valable doit être effectuée avec une durée d'arc comprise approximativement entre celles des première et deuxième manœuvres de coupure valables. Cette durée d'arc a été définie dans cette norme comme la durée d'arc moyenne ($t_{\text{arc med}}$) et est déterminée par:

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

Cette coupure doit également se produire après une grande alternance ou après la petite alternance suivante si le disjoncteur n'a pas coupé après la grande alternance requise.

NOTE 3 Dans les cas spécifiques où un disjoncteur interrompt après une petite alternance de courant lors de l'essai avec la durée d'arc maximale, il convient que la durée d'arc moyenne soit déterminée en utilisant la durée d'arc maximale présumée avec interruption suivant une grande alternance de courant.

L'ordre d'ouverture de la troisième manœuvre de coupure valable doit être retardé par rapport à celui de la deuxième manœuvre de coupure valable afin d'obtenir cette durée d'arc.

La Figure 34 donne un exemple graphique des trois manœuvres de coupure valables.

b) Courant de court-circuit pendant la période d'arc

Les manœuvres de coupure sont valables si les conditions suivantes sont remplies:

– le courant de court-circuit crête au cours de la dernière alternance précédant la coupure est compris entre 90 % et 110 % de la valeur requise et

– la durée de l'alternance du courant de court-circuit précédant la coupure est comprise entre 90 % et 110 % de la valeur requise.

ou si les tolérances ci-dessus ne peuvent pas être satisfaites:

– le produit "$I \times t$", "I" étant la valeur crête requise de la dernière alternance du courant de court-circuit et "t" étant la durée requise de la dernière alternance du courant de court-circuit, est compris entre 81 % et 121 % des valeurs demandées.

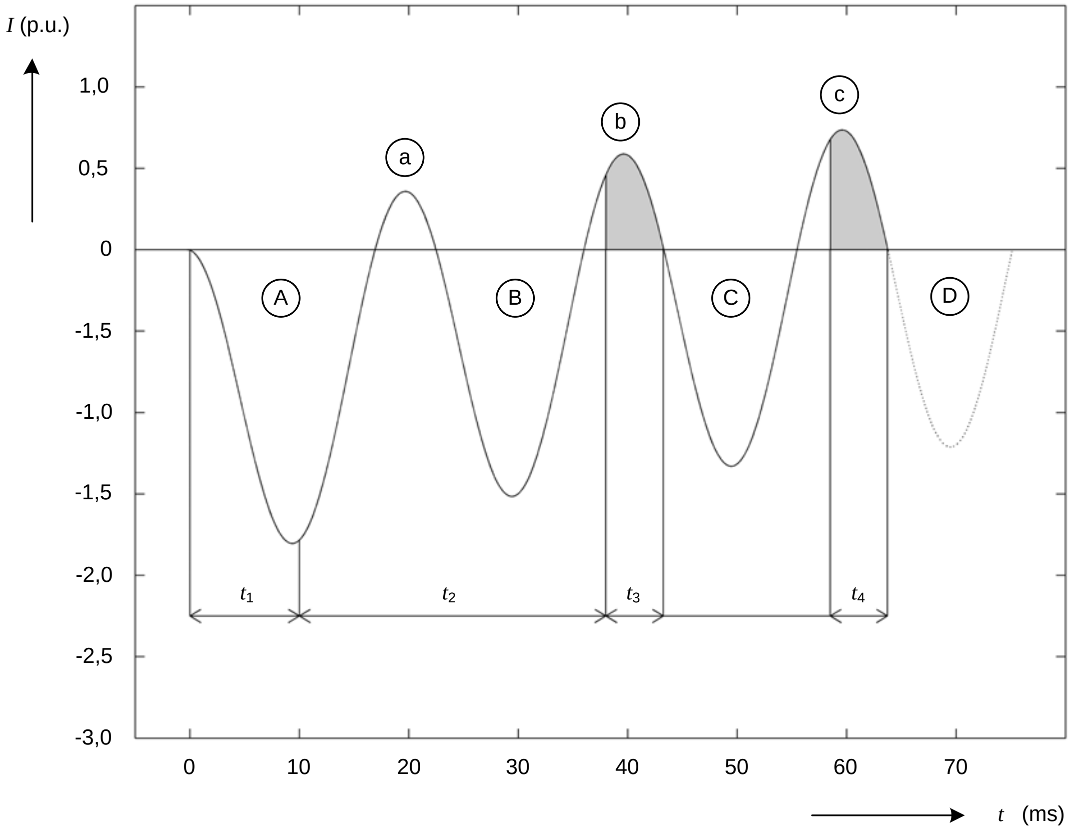
Les Tableaux 15 à 22 donnent les valeurs requises du courant de court-circuit crête et des durées d'alternance qu'il convient que la dernière alternance précédant la coupure atteigne. Le produit "$I \times t$" requis peut aussi être déterminé à partir de ces tableaux.

NOTE 4 Pour les essais directs, ces conditions s'appliquent au courant de court-circuit présumé seulement si l'instant d'initiation du courant est compris entre ±10° de celui obtenu durant l'essai d'étalonnage du courant présumé.

NOTE 5 Pour les disjoncteurs ayant des tensions d'arc relativement élevées, la procédure pour obtenir l'amplitude et la durée de l'alternance de courant demandées durant les essais synthétiques est expliquée dans la CEI 62271-101.

NOTE 6 Les valeurs de di/dt correspondantes données aux Tableaux 15 à 22 sont seulement applicables au premier pôle qui coupe. Pour les deuxième et troisième pôles qui coupent, le di/dt peut être considéré similaire au di/dt des deuxième et troisième pôles qui interrompent un courant de défaut symétrique. Voir le Tableau 6 pour les valeurs de la TTR correspondantes.

Si au cours des essais, la durée d'arc minimale est telle que le disjoncteur ne peut pas couper à la petite alternance prévue (b sur la Figure 57) sans dépasser la fenêtre de durée minimale d'interruption, la procédure monophasée doit être répétée à la petite alternance suivante (c sur la Figure 57). Si au cours de ces essais, la durée d'arc minimale est telle que la durée minimale de coupure se trouve de nouveau dans la fenêtre de durée de coupure d'origine, la grande alternance située entre les deux petites alternances (C sur la Figure 57) doit être retenue pour l'essai. Les durées d'arc moyenne et maximale de la troisième grande alternance doivent être basées sur la durée d'arc minimale de la troisième petite alternance.



Légende

A	**Première grande alternance**	t_1	t_{relay}
B	**Deuxième grande alternance**	t_2	$t_{open\ min}$
C	**Troisième grande alternance**	t_3	$t_{arc\ 1}$
D	**Quatrième grande alternance**	t_4	$t_{arc\ 2}$
a	**Première petite alternance**		
b	**Deuxième petite alternance**		
c	**Troisième petite alternance**		

$t_{arc\ 1} = t_{arc\ min\ minor\ loop\ b} - 18°$

$t_{arc\ 2} = t_{arc\ min\ minor\ loop\ c}$

Si $t_{arc\ 2} \leq t_{arc\ 1}$ → essai de la grande alternance C

Si $t_{arc\ 2} > t_{arc\ 1}$ → essai de la grande alternance D

Figure 57 – Détermination de la grande alternance à considérer en essai

Tableau 15 – Paramètres de la dernière alternance de courant applicables lors d'une séquence d'essais de court-circuit T100a à 50 Hz τ = 45 ms

τ = 45 ms	Grande alternance				Petite alternance			
Durée minimale de coupure ms	$\hat{I}$ p.u.	Δt_1 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %	$\hat{I}$ p.u.	Δt_2 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %
10,0 < t ≤ 22,5	1,52	13,5	44,6	92,7	0,36	5,5	60,2	75,6
22,5 < t ≤ 43,5	1,33	12,0	28,9	97,8	0,59	7,5	37,9	89,9
43,5 < t ≤ 64,0	1,21	11,5	18,7	99,6	0,74	8,5	24,1	95,3
64,0 < t ≤ 84,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
84,5 < t ≤ 104,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

$\hat{I}$: valeur unitaire (p.u.) du courant de crête par rapport à la valeur de crête du courant de court-circuit symétrique

Δt_1: durée de la grande alternance (arrondie à 0,5 ms)

Δt_2: durée de la petite alternance (arrondie à 0,5 ms)

τ: constante de temps du réseau

[a] La séquence d'essais T100a n'est pas applicable, composante apériodique inférieure à 20 % pour les deux alternances de courant.

Toutes les valeurs de ce tableau ont été calculées avec une durée de la protection par relais de 10 ms.

~~NOTE 1 La constante de temps du réseau τ = 45 ms est la valeur normalisée; τ = 60 ms, 75 ms et 120 ms sont des valeurs spéciales selon 4.101.2.~~

NOTE ~~2~~ Si la durée d'arc minimale obtenue au cours de l'essai est différente de la valeur spécifiée par le constructeur et si la durée réelle d'arc minimale conduit à une autre classe de durée minimale de coupure (coupure à une autre alternance de courant), il pourrait alors être nécessaire de répéter l'essai avec les valeurs d'alternance de courant appropriées. Si une répétition est nécessaire, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 sont autorisées.

Tableau 16 – Paramètres de la dernière alternance de courant applicables lors d'une séquence d'essais de court-circuit T100a à 50 Hz τ = 60 ms

τ = 60 ms	Grande alternance				Petite alternance			
Durée minimale de coupure ms	$\hat{I}$ p.u.	Δt_1 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**di/dt correspondant au zéro de courant (pourcentage par rapport au di/dt du courant symétrique assigné)** %	$\hat{I}$ p.u.	Δt_2 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**di/dt correspondant au zéro de courant (pourcentage par rapport au di/dt du courant symétrique assigné)** %
10,0 < t ≤ 22,5	1,61	14,0	54,2	86,9	0,28	5,0	68,7	69,0
22,5 < t ≤ 43,0	1,44	13,0	39,2	94,1	0,49	6,5	48,6	84,8
43,0 < t ≤ 63,5	1,31	12,0	28,3	97,4	0,63	7,5	34,5	92,0
63,5 < t ≤ 84,0	1,22	11,5	20,3	99,0	0,74	8,5	24,6	95,6
84,0 < t ≤ 104,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

$\hat{I}$: valeur unitaire (p.u.) du courant de crête par rapport à la valeur de crête du courant de court-circuit symétrique

Δt_1: durée de la grande alternance (arrondie à 0,5 ms)

Δt_2: durée de la petite alternance (arrondie à 0,5 ms)

τ: constante de temps du réseau

[a] La séquence d'essais T100a n'est pas applicable, composante apériodique inférieure à 20 % pour les deux alternances de courant.

Toutes les valeurs de ce tableau ont été calculées avec une durée de la protection par relais de 10 ms.

~~NOTE 1 La constante de temps du réseau τ = 45 ms est la valeur normalisée; τ = 60 ms, 75 ms et 120 ms sont des valeurs spéciales selon 4.101.2.~~

NOTE ~~2~~ Si la durée d'arc minimale obtenue au cours de l'essai est différente de la valeur spécifiée par le constructeur et si la durée réelle d'arc minimale conduit à une autre classe de durée minimale de coupure (coupure à une autre alternance de courant), il pourrait alors être nécessaire de répéter l'essai avec les valeurs d'alternance de courant appropriées. Si une répétition est nécessaire, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 sont autorisées.

Tableau 17 – Paramètres de la dernière alternance de courant applicables lors d'une séquence d'essais de court-circuit T100a à 50 Hz τ = 75 ms

τ = 75 ms	Grande alternance				Petite alternance			
Durée minimale de coupure ms	$\hat{I}$ p.u.	Δt_1 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %	$\hat{I}$ p.u.	Δt_2 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %
$10,0 < t \leq 22,0$	1,67	15,0	61,0	81,8	0,23	4,5	74,3	63,8
$22,0 < t \leq 43,0$	1,51	13,5	47,1	90,2	0,41	6,0	56,4	80,2
$43,0 < t \leq 63,5$	1,39	12,5	36,3	94,7	0,55	7,0	42,9	88,5
$63,5 < t \leq 84,0$	1,30	12,0	27,9	97,2	0,66	8,0	32,7	93,1
$84,0 < t \leq 104,0$	1,23	11,5	21,4	98,6	0,74	8,5	25,0	95,8

$\hat{I}$: valeur unitaire (p.u.) du courant de crête par rapport à la valeur de crête du courant de court-circuit symétrique
Δt_1: durée de la grande alternance (arrondie à 0,5 ms)
$\Delta t2$: durée de la petite alternance (arrondie à 0,5 ms)
τ: constante de temps du réseau

Toutes les valeurs de ce tableau ont été calculées avec une durée de la protection par relais de 10 ms.

~~NOTE 1 La constante de temps du réseau τ = 45 ms est la valeur normalisée; τ = 60 ms, 75 ms et 120 ms sont des valeurs spéciales selon 4.101.2.~~

NOTE ~~2~~ Si la durée d'arc minimale obtenue au cours de l'essai est différente de la valeur spécifiée par le constructeur et si la durée réelle d'arc minimale conduit à une autre classe de durée minimale de coupure (coupure à une autre alternance de courant), il pourrait alors être nécessaire de répéter l'essai avec les valeurs d'alternance de courant appropriées. Si une répétition est nécessaire, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 sont autorisées.

Tableau 18 – Paramètres de la dernière alternance de courant applicables lors d'une séquence d'essais de court-circuit T100a à 50 Hz τ = 120 ms

τ = 120 ms	**Grande alternance**				**Petite alternance**			
Durée minimale de coupure ms	**$\hat{I}$** p.u.	**Δt_1** ms	**Pourcentage de la composante apériodique au zéro de courant** %	**di/dt correspondant au zéro de courant (pourcentage par rapport au di/dt du courant symétrique assigné)** %	**$\hat{I}$** p.u.	**Δt_2** ms	**Pourcentage de la composante apériodique au zéro de courant** %	**di/dt correspondant au zéro de courant (pourcentage par rapport au di/dt du courant symétrique assigné)** %
10,0 < t ≤ 22,0	1,78	15,5	73,1	70,2	0,15	3,5	83,4	53,0
22,0 < t ≤ 42,5	1,66	14,5	62,1	80,0	0,28	5,0	70,2	69,4
42,5 < t ≤ 63,5	1,56	14,0	52,8	86,3	0,39	6,0	59,2	79,0
63,5 < t ≤ 83,5	1,47	13,0	44,8	90,6	0,49	6,5	50,0	85,3
83,5 < t ≤ 103,5	1,40	12,5	38,0	93,5	0,57	7,0	42,2	89,5

$\hat{I}$: valeur unitaire (p.u.) du courant de crête par rapport à la valeur de crête du courant de court-circuit symétrique
Δt_1: durée de la grande alternance (arrondie à 0,5 ms)
Δt_2: durée de la petite alternance (arrondie à 0,5 ms)
τ: constante de temps du réseau

Toutes les valeurs de ce tableau ont été calculées avec une durée de la protection par relais de 10 ms.

~~NOTE 1 La constante de temps du réseau τ = 45 ms est la valeur normalisée; τ = 60 ms, 75 ms et 120 ms sont des valeurs spéciales selon 4.101.2.~~

NOTE ~~2~~ Si la durée d'arc minimale obtenue au cours de l'essai est différente de la valeur spécifiée par le constructeur et si la durée réelle d'arc minimale conduit à une autre classe de durée minimale de coupure (coupure à une autre alternance de courant), il pourrait alors être nécessaire de répéter l'essai avec les valeurs d'alternance de courant appropriées. Si une répétition est nécessaire, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 sont autorisées.

Tableau 19 – Paramètres de la dernière alternance de courant applicables lors d'une séquence d'essais de court-circuit T100a à 60 Hz τ = 45 ms

τ = 45 ms	Grande alternance				Petite alternance			
Durée minimale de coupure ms	$\hat{I}$ p.u.	Δt_1 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %	$\hat{I}$ p.u.	Δt_2 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %
8,5 < t ≤ 19	1,58	11,5	50,8	89,1	0,31	4,5	65,8	71,4
19,0 < t ≤ 36,0	1,40	10,5	35,4	95,6	0,52	5,5	44,8	86,6
36,0 < t ≤ 53,0	1,27	10,0	24,6	98,4	0,67	6,5	30,6	93,4
53,0 < t ≤ 70,0	1,19	9,5	17,1	99,5	0,77	7,0	21,0	96,5
70,0 < t ≤ 87,0	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
87,0 < t ≤ 103,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

$\hat{I}$: valeur unitaire (p.u.) du courant de crête par rapport à la valeur de crête du courant de court-circuit symétrique

Δt_1: durée de la grande alternance (arrondie à 0,5 ms)

Δt_2: durée de la petite alternance (arrondie à 0,5 ms)

τ: constante de temps du réseau

[a] La séquence d'essais T100a n'est pas applicable, composante apériodique inférieure à 20 % pour les deux alternances de courant.

Toutes les valeurs de ce tableau ont été calculées avec une durée de la protection par relais de 8,3 ms.

~~NOTE 1 La constante de temps du réseau τ = 45 ms est la valeur normalisée; τ = 60 ms, 75 ms et 120 ms sont des valeurs spéciales selon 4.101.2.~~

NOTE ~~2~~ Si la durée d'arc minimale obtenue au cours de l'essai est différente de la valeur spécifiée par le constructeur et si la durée réelle d'arc minimale conduit à une autre classe de durée minimale de coupure (coupure à une autre alternance de courant), il pourrait alors être nécessaire de répéter l'essai avec les valeurs d'alternance de courant appropriées. Si une répétition est nécessaire, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 sont autorisées.

Tableau 20 – Paramètres de la dernière alternance de courant applicables lors d'une séquence d'essais de court-circuit T100a à 60 Hz τ = 60 ms

τ = 60 ms	Grande alternance				Petite alternance			
Durée minimale de coupure ms	$\hat{I}$ p.u.	Δt_1 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %	$\hat{I}$ p.u.	Δt_2 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %
8,5 < t ≤ 18,5	1,66	12,0	59,8	82,8	0,24	4,0	73,3	64,8
18,5 < t ≤ 36,0	1,50	11,0	45,7	91,0	0,43	5,0	55,0	81,1
36,0 < t ≤ 53,0	1,38	10,5	34,8	95,3	0,57	6,0	41,4	89,2
53,0 < t ≤ 70,0	1,29	10,0	26,4	97,6	0,67	6,5	31,2	93,6
70,0 < t ≤ 87,0	1,22	9,5	20,1	98,8	0,75	7,0	23,5	96,2
87,0 < t ≤ 103,5	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

$\hat{I}$: valeur unitaire (p.u.) du courant de crête par rapport à la valeur de crête du courant de court-circuit symétrique
Δt_1: durée de la grande alternance (arrondie à 0,5 ms)
Δt_2: durée de la petite alternance (arrondie à 0,5 ms)
τ: constante de temps du réseau

[a] La séquence d'essais T100a n'est pas applicable, composante apériodique inférieure à 20 % pour les deux alternances de courant.

Toutes les valeurs de ce tableau ont été calculées avec une durée de la protection par relais de 8,3 ms.

~~NOTE 1 La constante de temps du réseau τ = 45 ms est la valeur normalisée; τ = 60 ms, 75 ms et 120 ms sont des valeurs spéciales selon 4.101.2.~~

NOTE ~~2~~ Si la durée d'arc minimale obtenue au cours de l'essai est différente de la valeur spécifiée par le constructeur et si la durée réelle d'arc minimale conduit à une autre classe de durée minimale de coupure (coupure à une autre alternance de courant), il pourrait alors être nécessaire de répéter l'essai avec les valeurs d'alternance de courant appropriées. Si une répétition est nécessaire, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 sont autorisées.

Tableau 21 – Paramètres de la dernière alternance de courant applicables lors d'une séquence d'essais de court-circuit T100a à 60 Hz τ = 75 ms

τ = 75 ms	Grande alternance				Petite alternance			
Durée minimale de coupure ms	$\hat{I}$ p.u.	Δt_1 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**di/dt correspondant au zéro de courant (pourcentage par rapport au di/dt du courant symétrique assigné)** %	$\hat{I}$ p.u.	Δt_2 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**di/dt correspondant au zéro de courant (pourcentage par rapport au di/dt du courant symétrique assigné)** %
8,5 < t ≤ 18,5	1,72	12,5	66,1	77,4	0,20	3,5	78,2	59,6
18,5 < t ≤ 35,5	1,57	11,5	53,2	86,6	0,36	4,5	62,1	76,2
35,5 < t ≤ 52,5	1,46	11,0	42,8	91,9	0,49	6,0	49,5	85,1
52,5 < t ≤ 69,5	1,37	10,5	34,4	95,1	0,59	6,0	39,5	90,5
69,5 < t ≤ 86,5	1,30	10,0	27,6	97,1	0,67	6,5	31,5	93,8
86,5 < t ≤ 103,5	1,24	9,5	22,2	98,3	0,74	7,0	25,2	95,9

$\hat{I}$: valeur unitaire (p.u.) du courant de crête par rapport à la valeur de crête du courant de court-circuit symétrique
Δt_1: durée de la grande alternance (arrondie à 0,5 ms)
Δt_2: durée de la petite alternance (arrondie à 0,5 ms)
τ: constante de temps du réseau

Toutes les valeurs de ce tableau ont été calculées avec une durée de la protection par relais de 8,3 ms.

~~NOTE 1 La constante de temps du réseau τ = 45 ms est la valeur normalisée; τ = 60 ms, 75 ms et 120 ms sont des valeurs spéciales selon 4.101.2.~~

NOTE ~~2~~ Si la durée d'arc minimale obtenue au cours de l'essai est différente de la valeur spécifiée par le constructeur et si la durée réelle d'arc minimale conduit à une autre classe de durée minimale de coupure (coupure à une autre alternance de courant), il pourrait alors être nécessaire de répéter l'essai avec les valeurs d'alternance de courant appropriées. Si une répétition est nécessaire, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 sont autorisées.

Tableau 22 – Paramètres de la dernière alternance de courant applicables lors d'une séquence d'essais de court-circuit T100a à 60 Hz τ = 120 ms

τ = 120 ms	Grande alternance				Petite alternance			
Durée minimale de coupure ms	$\hat{I}$ p.u.	Δt_1 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %	$\hat{I}$ p.u.	Δt_2 ms	**Pourcentage de la composante apériodique au zéro de courant** %	**d*i*/d*t* correspondant au zéro de courant (pourcentage par rapport au d*i*/d*t* du courant symétrique assigné)** %
8,5 < t ≤ 18,0	1,81	13,5	77,0	65,5	0,13	2,5	86,0	49,1
18,0 < t ≤ 35,0	1,71	12,5	67,2	75,5	0,24	4,0	74,6	64,9
35,0 < t ≤ 52,0	1,62	12,0	58,6	82,3	0,34	4,5	64,7	74,8
52,0 < t ≤ 69,0	1,54	11,5	51,1	87,1	0,43	5,0	56,2	81,5
69,0 < t ≤ 86,0	1,47	11,0	44,6	90,5	0,50	5,5	48,8	86,2
86,0 < t ≤ 103,0	1,41	10,5	38,8	93,0	0,57	6,0	42,4	89,6

$\hat{I}$: valeur unitaire (p.u.) du courant de crête par rapport à la valeur de crête du courant de court-circuit symétrique

Δt_1: durée de la grande alternance (arrondie à 0,5 ms)

Δt_2: durée de la petite alternance (arrondie à 0,5 ms)

τ: constante de temps du réseau

Toutes les valeurs de ce tableau ont été calculées avec une durée de la protection par relais de 8,3 ms.

~~NOTE 1 La constante de temps du réseau τ = 45 ms est la valeur normalisée; τ = 60 ms, 75 ms et 120 ms sont des valeurs spéciales selon 4.101.2.~~

NOTE ~~2~~ Si la durée d'arc minimale obtenue au cours de l'essai est différente de la valeur spécifiée par le constructeur et si la durée réelle d'arc minimale conduit à une autre classe de durée minimale de coupure (coupure à une autre alternance de courant), il pourrait alors être nécessaire de répéter l'essai avec les valeurs d'alternance de courant appropriées. Si une répétition est nécessaire, la remise en état du disjoncteur conformément à 6.102.9.5 ou l'utilisation d'un spécimen d'essai supplémentaire conformément à 6.102.2 sont autorisées.

6.102.10.2.2 Systèmes avec neutre effectivement à la terre, y compris essais de défaut proche en ligne

6.102.10.2.2.1 Séquence d'essais T10, T30, T60, T100s et T100s(b), OP1 et OP2, L_{90}, L_{75} et L_{60}

La procédure permettant d'obtenir les trois manœuvres de coupure valables est la même que celle décrite pour les systèmes à neutre non effectivement à la terre, avec les modifications suivantes:

La durée d'arc maximale requise doit être

$$t_{\text{arc max}} \geq t_{\text{arc min}} + T\frac{180^{\text{o}} - \text{d}\alpha}{360^{\text{o}}}$$

On procède normalement en avançant l'ordre d'ouverture d'au moins (180° – dα) par rapport à celui de la première manœuvre de coupure valable.

La troisième manœuvre de coupure valable doit démontrer la coupure avec une durée d'arc approximativement égale à la valeur moyenne de celles des première et deuxième manœuvres de coupure. La durée d'arc est définie est donnée par

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

La troisième manœuvre de coupure valable est obtenue en retardant l'ordre d'ouverture de 90° (±18°) par rapport à celui de la deuxième manœuvre de coupure valable.

La Figure 35 donne la représentation graphique des trois manœuvres de coupure valables.

6.102.10.2.2.2 Séquence d'essais T100a

La procédure permettant d'obtenir les trois manœuvres de coupure valables est la même que celle décrite pour les réseaux à neutre relié non effectivement à la terre, avec les modifications suivantes:

La durée d'arc maximale requise doit être:

$$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times \frac{\text{d}\alpha}{360^{\text{o}}}$$

où Δt_1 est donnée aux Tableaux 15 à 22.

La Figure 36 donne un exemple graphique des trois manœuvres de coupure valables.

6.102.10.2.3 Procédure modifiée dans les cas où le disjoncteur n'a pas coupé au cours d'un essai à durée d'arc moyenne

6.102.10.2.3.1 Essais de coupure avec courant symétrique

Si le disjoncteur n'a pas coupé au zéro de courant prévu pendant l'essai de coupure avec courant symétrique et durée d'arc moyenne, deux essais supplémentaires sont nécessaires.

a) Essais directs

Deux cas doivent être considérés:

– Pour k_{pp} = 1,3 (systèmes à neutre effectivement à la terre)

Si le disjoncteur n’a pas coupé avec la durée d’arc présumée mais au passage par zéro suivant du courant, la durée d'arc obtenue est appelée durée d'arc maximale «ultime» $t_{\text{arc ult max}}$. Cet essai est valable si le disjoncteur est capable de couper pendant un essai supplémentaire avec une nouvelle durée d’arc minimale qui est 18° plus longue que la durée d’arc moyenne présumée. Dans ce cas, cet essai supplémentaire suffit avec une synchronisation de l’ordre d’ouverture avancé de 18°.

– Pour k_{pp} = 1,5 (systèmes à neutre non effectivement à la terre)

Si le disjoncteur n'a pas coupé avec la durée d'arc présumée et au passage par zéro suivant du courant, deux essais supplémentaires sont nécessaires:

i) un essai avec la «nouvelle durée d'arc minimale» $t_{arc\ new\ min}$, qui doit être 18° plus longue que la durée d'arc moyenne présumée;

ii) un autre essai avec la «nouvelle durée d'arc maximale», qui doit être 150° plus longue que la «nouvelle durée d'arc minimale». Cet essai peut nécessiter l'utilisation d'un circuit de réallumage forcé au passage par zéro précédent du courant.

b) Essais synthétiques

Le premier essai supplémentaire valable doit démontrer la coupure avec la «nouvelle durée d'arc minimale» $t_{arc\ new\ min}$. C'est le cas lorsque une avance supplémentaire de l'instant de séparation des contacts par rapport à celui de l'essai à durée d'arc moyenne, donne lieu à une coupure réussie. La «nouvelle durée d'arc minimale» est trouvée en changeant la synchronisation de l'ordre d'ouverture par pas d'environ 18° (dα).

La deuxième manœuvre de coupure valable doit démontrer l'ouverture avec la durée d'arc maximale «ultime» $t_{arc\ ult\ max}$ définie comme:

$$t_{\text{arc ult max}} \geq t_{\text{arc new min}} + T\,\frac{150^\circ - \mathrm{d}\alpha}{360^\circ} \quad \text{si } k_{pp} = 1{,}5$$

$$t_{\text{arc ult max}} \geq t_{\text{arc new min}} + T\,\frac{180^\circ - \mathrm{d}\alpha}{360^\circ} \quad \text{si } k_{pp} = 1{,}3,\ 1{,}2 \text{ ou } 1{,}0$$

où

$t_{arc\ new\ min}$ est la «nouvelle durée d'arc minimale»;

$t_{arc\ ult\ max}$ est la durée d'arc maximale «ultime»;

dα = 18°.

Si le disjoncteur n'interrompt par le courant lors du deuxième essai supplémentaire, il est permis d'effectuer des travaux de maintenance sur le disjoncteur conformément à 6.102.9.5 et de reprendre la séquence d'essais en commençant par une durée d'arc minimale supérieure à la durée d'arc moyenne à laquelle la défaillance s'est produite.

6.102.10.2.3.2 Essais de coupure avec courant asymétrique

Si au cours des essais de coupure avec courants asymétriques (séquence d'essais T100a), le disjoncteur ne coupe pas au passage par zéro du courant après une grande alternance et avec la durée d'arc moyenne, il doit couper après la petite alternance suivante.

6.102.10.2.4 Essais combinant les conditions des systèmes à neutre effectivement à la terre et non effectivement à la terre

Les deux états, à savoir celui des systèmes à neutre non effectivement à la terre (6.102.10.2.1) et celui des systèmes à neutre effectivement à la terre (6.102.10.2.2) peuvent être combinés en une seule série d'essais. La tension transitoire et la tension à fréquence industrielle à utiliser doivent être celles applicables à un système à neutre non effectivement à la terre et les durées d'arc doivent être celles applicables à un système à neutre effectivement à la terre.

6.102.10.2.5 Séparation des séquences d'essais en séries d'essai en tenant compte de la TTR exacte de chaque pôle qui s'ouvre

Il est admis que les essais en monophasé effectués en lieu et place de conditions triphasées sont plus sévères que les essais en triphasé du fait que la durée d'arc du dernier pôle qui coupe est utilisée avec la TTR du premier pôle qui coupe. Le constructeur peut également décider de diviser chaque séquence d'essais en deux ou trois séries d'essais séparées, chaque série d'essais démontrant une coupure réussie avec les durées d'arc minimale, maximale et moyenne pour chaque pôle qui s'ouvre avec sa TTR associée. Les multiplicateurs standards pour les valeurs de TTR pour les deuxièmes et troisièmes pôles qui coupent pour les tensions assignées au-dessus de 72,5 kV sont donnés au Tableau 6.

La remise en état du disjoncteur après chaque série d'essais est autorisée et doit être conforme aux exigences de 6.102.9.5.

En supposant que la simultanéité des pôles pendant toutes les manœuvres de la séquence de manœuvres assignée est dans la tolérance de 5.101, pour les essais avec courant symétrique la fenêtre de coupure pour chaque phase est comprise dans l'intervalle donné dans le Tableau 23 où l'instant de coupure du premier pôle qui coupe avec une durée d'arc minimale est prise comme référence. Une représentation graphique de la fenêtre de coupure et du facteur de tension k_p, qui détermine la TTR de chaque pôle, est donnée par la Figure 37 et la Figure 58 pour les systèmes avec facteur de premier pôle égal à 1,2 et 1,3, et par la Figure 38 pour les systèmes avec facteur de premier pôle égal à 1,5.

Tableau 23 – Fenêtre de coupure pour les essais avec courant symétrique

Facteur de premier pôle qui coupe	Premier pôle qui coupe °	Deuxième pôle qui coupe °	Troisième pôle qui coupe °
1,5	0 – 42	90 – 132	90 – 132
1,3	0 – 42	77 – 119	120 – 162
1,2	0 – 42	71 – 113	120 – 162

6.103 Circuits d'essais pour les essais d'établissement et de coupure en court-circuit

6.103.1 Facteur de puissance

Le facteur de puissance de chaque phase est déterminé suivant l'une des méthodes indiquées dans l'Annexe D.

Le facteur de puissance d'un circuit triphasé est considéré comme étant la moyenne des facteurs de puissance de chaque phase.

Lors des essais, cette valeur ne doit pas être supérieure à 0,15.

Le facteur de puissance d'une phase quelconque ne doit pas s'écarter de la moyenne de plus de 25 % de celle-ci.

6.103.2 Fréquence

Les disjoncteurs doivent être essayés à la fréquence assignée, avec une tolérance de ±8 %.

Toutefois, pour des raisons de commodité d'essai, des écarts sur la tolérance ci-dessus sont permis; par exemple, lorsque les disjoncteurs dont la fréquence assignée est de 50 Hz sont essayés à 60 Hz et vice versa, il convient d'interpréter les résultats avec précaution et de tenir compte de toutes les données significatives telles que le type du disjoncteur et le type d'essai effectué.

6.103.3 Mise à la terre du circuit d'essai

Les connexions à la terre du circuit d'essai pour les essais d'établissement et de coupure en court-circuit doivent être conformes aux prescriptions suivantes et doivent, dans tous les cas, figurer sur le schéma du circuit d'essai faisant partie du rapport d'essai (voir le point g) de C.2.4).

a) Essais en triphasé d'un disjoncteur tripolaire, facteur de premier pôle 1,5:

Le disjoncteur (avec son bâti mis à la terre comme en service) doit être branché dans un circuit ayant le point neutre de l'alimentation isolé et le point de court-circuit mis à la terre comme indiqué à la Figure 25a, ou vice versa comme indiqué à la Figure 25b, si l'essai ne peut être effectué que de cette dernière façon.

Ces circuits d'essai donnent un facteur de premier pôle de 1,5.

Conformément à la Figure 25a, le neutre du circuit d'alimentation peut être mis à la terre par l'intermédiaire d'une résistance. La valeur de cette résistance est aussi élevée que possible et, exprimée en ohms, n'est en aucun cas inférieure à $U/10$, ou U est la valeur numérique, exprimée en volts, de la tension entre phases du circuit d'essai.

Quand un circuit d'essai conforme à la Figure 25b est utilisé, il est reconnu que dans le cas d'un défaut à la terre sur une borne du disjoncteur en essai, le courant de terre résultant peut être dangereux. En conséquence, il est permis de relier le neutre du circuit d'alimentation à la terre par l'intermédiaire d'une impédance appropriée.

b) Essais en triphasé d'un disjoncteur tripolaire, facteur de premier pôle 1,3:

Le disjoncteur (avec son bâti mis à la terre comme en service) doit être branché dans un circuit d'essai ayant le point neutre de l'alimentation mis à la terre par une impédance appropriée et le point de court-circuit mis à la terre comme indiqué à la Figure 26a, ou vice versa comme indiqué à la Figure 26b, si l'essai ne peut être effectué que de cette dernière façon.

On doit choisir l'impédance reliée au point neutre en accord avec un facteur de premier pôle de 1,3. En supposant Z_0 = 3,25 × Z_1 la valeur correcte de l'impédance entre le point neutre et la terre est 0,75 fois l'impédance de phase.

NOTE 1 Pour les disjoncteurs destinés à être utilisés dans des systèmes à facteur de premier pôle inférieur à 1,3, il peut être nécessaire d'abaisser la valeur de l'impédance entre le neutre et la terre pour remplir les conditions de courant de coupure dans les deuxième et troisième pôles. Pour les trois pôles, il convient que la TTR fasse l'objet du plus grand soin.

NOTE 2 Le circuit d'essai représenté à la Figure 26b n'est pas applicable aux disjoncteurs où l'isolement entre phases et/ou à la terre est critique (par exemple disjoncteurs de GIS ou disjoncteurs à cuve mise à la terre). Des méthodes d'essais appropriées pour ces disjoncteurs sont présentées à l'Annexe O de la présente norme et dans la CEI 62271-101.

c) Essais en monophasé d'un pôle séparé d'un disjoncteur tripolaire, facteur de premier pôle 1,5 :

Le circuit d'essai et le bâti du disjoncteur doivent être connectés comme cela est indiqué à la Figure 27a, de façon que la différence de tension entre les pièces sous tension et le bâti soit, après la coupure, la même que celle qui existerait sur le pôle du disjoncteur tripolaire qui coupe le premier, s'il avait été essayé complet sur le circuit d'essai indiqué à la Figure 25a.

Le circuit d'essai recommandé est donné à la Figure 27a. Dans le cas où les équipements d'essai sont limités, le circuit de la Figure 27b peut être utilisé.

NOTE 3 Le circuit d'essai représenté à la Figure 27b n'est pas applicable aux disjoncteurs où l'isolement entre phases et/ou à la terre est critique (par exemple disjoncteurs de GIS ou disjoncteurs à cuve mise à la terre). Des méthodes d'essais appropriées pour ces disjoncteurs sont présentées à l'Annexe O de la présente norme et dans la CEI 62271-101.

d) Essais en monophasé d'un pôle séparé d'un disjoncteur tripolaire, facteur de premier pôle 1,3 :

Le circuit d'essai et le bâti du disjoncteur doivent être connectés comme indiqué à la Figure 28a, de façon que la différence de tension entre les pièces sous tension et le bâti soit, après la coupure, approximativement la même que celle qui existerait sur le pôle du disjoncteur tripolaire qui coupe le premier, s'il avait été essayé complet sur le circuit d'essai indiqué sur la Figure 26a.

Le circuit d'essai recommandé est donné à la Figure 28a. Dans le cas où les équipements d'essai sont limités, le circuit de la Figure 28b peut être utilisé.

NOTE 4 Le circuit d'essai représenté à la Figure 28b n'est pas applicable aux disjoncteurs où l'isolement entre phases et/ou à la terre est critique (par exemple disjoncteurs de GIS ou disjoncteurs à cuve mise à la terre). Des méthodes d'essais appropriées pour ces disjoncteurs sont présentées à l'Annexe O de la présente norme et dans la CEI 62271-101.

e) Essais en monophasé d'un disjoncteur unipolaire:

Le circuit d'essai et le bâti du disjoncteur doivent être connectés de façon que la différence de tension entre les pièces sous tension et la terre dans le disjoncteur soit la même, après la coupure, que dans les conditions de service normales. Le rapport d'essai doit faire mention des connexions adoptées.

6.103.4 Raccordement du circuit d'essai au disjoncteur

Dans le cas où les dispositions matérielles d'un côté du disjoncteur ne sont pas semblables à celles qui existent de l'autre côté, le côté sous tension du circuit d'essai doit être relié, lors de l'essai, au côté du disjoncteur dont le raccordement conduit aux conditions les plus sévères, en ce qui concerne la tension par rapport à la terre, sauf dans le cas où l'alimentation du disjoncteur s'effectue par construction toujours du même côté.

Lorsque le type de raccordement conduisant aux conditions les plus sévères ne peut pas être démontré de manière satisfaisante, les séquences d'essais T10 et T30 (6.106.1 et 6.106.2) doivent être effectuées en alimentant sur des connexions différentes, de même que pour les séquences d'essais T100s et T100a. Si la séquence d'essais T100a n'est pas effectuée, la séquence d'essais T100s doit être effectuée avec l'alimentation sur chacune des deux connexions.

6.104 Caractéristiques pour les essais de court-circuit

6.104.1 Tension appliquée avant les essais d'établissement en court-circuit

Pour les essais d'établissement en court-circuit de 6.106, la tension appliquée doit être la suivante.

a) Pour les essais en triphasé d'un disjoncteur tripolaire, la valeur moyenne des tensions appliquées entre phases doit être au moins égale à la tension assignée U_r et ne doit pas excéder cette valeur de plus de 10 % sans l'accord du constructeur.

   Les différences entre la valeur moyenne des tensions appliquées et les tensions appliquées sur chacun des pôles ne doivent pas dépasser 5 %.

b) Pour les essais en monophasé d'un disjoncteur tripolaire, la tension appliquée doit être au moins égale à la valeur de tension entre phase et terre $U_r/\sqrt{3}$ et ne doit pas excéder cette valeur de plus de 10 % sans l'accord du constructeur.

NOTE Avec l'accord du constructeur et pour des raisons de commodité d'essais, il est permis d'appliquer une tension égale à la tension entre phase et terre multipliée par le facteur de premier pôle (1,3 ou 1,5) du disjoncteur.

   Lorsque le disjoncteur peut avoir la possibilité d'un cycle de refermeture unipolaire et que l'écart de temps maximal entre les temps de contact des pôles lors de la manœuvre de fermeture tripolaire dépasse un quart de période de la fréquence assignée (voir la note de 5.101), la tension appliquée doit être égale à la tension entre phase et terre multipliée par le facteur de premier pôle (1,3 ou 1,5) du disjoncteur.

c) Pour un disjoncteur unipolaire, la tension appliquée doit être au moins égale à la tension assignée et ne doit pas excéder cette valeur de plus de 10 % sans l'accord du constructeur.

   Lorsque des essais synthétiques sont effectués, la CEI 62271-101 s'applique, voir aussi 6.106.4.1 a), 6.106.4.2 a) et 6.106.4.3.

6.104.2 Courant établi en court-circuit

6.104.2.1 Généralités

La capacité d'un disjoncteur à établir le courant de court-circuit assigné est démontrée par la séquence d'essais T100s (voir 6.106.4).

Le disjoncteur doit être capable d'établir le courant avec préamorçage de l'arc en tout point de l'onde de tension. Deux cas extrêmes sont spécifiés ci-dessous (voir Figure 1):

– établissement à la crête de l'onde de tension, produisant un courant de court-circuit symétrique et l'arc de préamorçage le plus long;
– établissement au zéro de l'onde de tension, sans préamorçage, produisant un courant de court-circuit asymétrique.

La procédure d'essai décrite ci-dessous démontre la capacité du disjoncteur à remplir les deux conditions suivantes:

a) le disjoncteur peut établir un courant symétrique résultant d'un préamorçage initié à la crête de la tension appliquée. Ce courant doit être égal à la composante symétrique du courant assigné de coupure de court-circuit (voir 4.101);
b) le disjoncteur peut établir un courant pleinement asymétrique. Ce courant sera le courant assigné de fermeture de court-circuit (voir 4.103);

   Un disjoncteur doit être capable de fonctionner à des tensions inférieures à sa tension assignée (voir le point a) de 4.101) à laquelle il établit réellement le plein courant asymétrique. La valeur limite inférieure, si applicable, doit être indiquée par le constructeur.

NOTE 1 Le courant de court-circuit est considéré comme symétrique, si l'initiation du courant se situe à ± 15 ° de la valeur crête de la tension appliquée.

NOTE 2 Pour des disjoncteurs ayant un préamorçage supérieur à 10 ms, plus de deux fermetures peuvent être nécessaires pour démontrer les conditions les plus difficiles.

NOTE 3 En raison d'une non-simultanéité non intentionnelle entre les pôles, les instants de contacts durant la fermeture peuvent être différents et provoquer des courants d'établissement plus importants dans un pôle (voir aussi 5.101). C'est particulièrement le cas si dans un pôle, le courant commence à circuler environ un quart de cycle après les deux autres pôles, prouvant qu'il n'y a pas de préamorçage. Un essai non réussi pour un disjoncteur durant un tel événement est considéré comme une séquence d'essais non satisfaisante.

6.104.2.2 Procédure d'essai

6.104.2.2.1 Essais triphasés

Pour les essais triphasés d'un disjoncteur tripolaire, il est admis que les exigences mentionnées en a) et b) ci-dessus sont couvertes de façon adéquate par la séquence d'essais T100s.

Le contrôle du temps doit être tel que le courant de fermeture assigné en court-circuit est obtenu dans au moins un des deux cycles de fermeture-ouverture (CO) de la séquence d'essais T100s.

Quand un disjoncteur présente un préarc tel que le courant de fermeture assigné en court-circuit n'est pas atteint pendant le premier cycle de manœuvres CO de la séquence d'essais T100s et, même après avoir ajusté les temps, il n'est pas atteint pendant le second cycle de manœuvres CO, un troisième cycle de manœuvres CO doit être effectué à une tension réduite. Avant ce cycle de manœuvres, le disjoncteur peut être remis en état.

6.104.2.2.2 Essais monophasés

Pour les essais monophasés, les séquences d'essai T100s ou T100s(a) doivent être réalisées de manière telle que l'exigence du point a) de 6.104.2.1 soit obtenue lors d'une manœuvre de fermeture, et celle de b) de 6.104.2.1 dans l'autre manœuvre. L'ordre de ces manœuvres n'est pas spécifié. Si pendant les séquences T100s ou T100s (a) (voir la note en 6.106) une des exigences des points a) et b) n'a pas été vérifiée de façon adéquate, un cycle de manœuvres CO additionnel est nécessaire. Avant ce cycle de manœuvres, le disjoncteur peut être reconditionné.

Suivant les résultats obtenus pendant les séquences T100s ou T100s(a) normales, le cycle de manœuvres CO additionnel doit

– vérifier les exigences du point a) ou b) de 6.104.2.1, ou
– démontrer l'évidence que les courants de fermeture en court-circuit obtenus sont représentatifs des conditions rencontrées en service avec les caractéristiques de préarc du disjoncteur.

Si pendant les séquences T100s ou T100s(a) le courant de fermeture assigné en court-circuit n'a pas été atteint à cause des caractéristiques du disjoncteur, l'essai CO additionnel peut être effectué à une tension appliquée plus faible.

Si pendant les séquences T100s ou T100s(a) on n'obtient pas de courant symétrique, comme spécifié au point a) ci-dessus, l'essai CO additionnel peut être réalisé à une tension appliquée avec les tolérances établies en 6.104.1.

6.104.3 Courant coupé en court-circuit

Le courant en court-circuit que doit couper un disjoncteur doit être déterminé à l'instant de la séparation des contacts, conformément aux indications de la Figure 8, et doit être exprimé par les deux valeurs suivantes:

– la moyenne des valeurs efficaces des composantes périodiques sur tous les pôles;
– la valeur en pourcentage de la composante apériodique du courant la plus élevée obtenue sur l'un quelconque des pôles.

La différence entre la moyenne des valeurs efficaces des composantes périodiques et les valeurs obtenues sur chaque pôle ne doit pas dépasser 10 % de la valeur moyenne.

Alors que le courant coupé en court-circuit est mesuré à l'instant de la séparation des contacts, l'aptitude du disjoncteur à la coupure est déterminée entre autres facteurs par le courant qui est finalement interrompu dans la dernière alternance de l'arc. Le décrément de la composante périodique du courant de court-circuit peut par conséquent être très important, en particulier pour les disjoncteurs dont la durée d'arc s'étend sur plusieurs alternances de courant. Pour éviter une réduction des contraintes, il est recommandé d'utiliser un décrément de la composante périodique du courant de court-circuit tel qu'à l'instant correspondant à l'extinction finale de l'arc principal sur le dernier pôle qui coupe, la composante périodique du courant présumé soit au moins à 90 % de la valeur correspondant à la séquence d'essais. Ceci doit être prouvé par un enregistrement du courant présumé avant le début des essais.

Si les caractéristiques du disjoncteur sont telles que le courant de court-circuit est réduit à une valeur inférieure à celle du courant présumé coupé, ou si l'oscillogramme ne permet pas de tracer correctement l'enveloppe des ondes de courant, la valeur moyenne du courant présumé coupé en court-circuit sur tous les pôles, mesurée sur l'oscillogramme du courant présumé à l'instant correspondant à la séparation des contacts, doit être utilisée comme étant le courant coupé en court-circuit.

On peut déterminer l'instant de la séparation des contacts selon l'expérience de la station d'essais et le type de l'appareil en essai par diverses méthodes, par exemple par l'enregistrement de la course des contacts pendant l'essai, par l'enregistrement de la tension d'arc ou par un essai à vide sur le disjoncteur.

6.104.4 Composante apériodique du courant coupé en court-circuit

Pour les disjoncteurs dont la durée d'ouverture est telle que la composante apériodique ne peut être contrôlée, par exemple les disjoncteurs à déclenchement autonome préparés pour l'essai comme indiqué en 6.102.3, la composante apériodique peut être supérieure à celle spécifiée pour les séquences d'essais T10, T30, T60 et T100s de 6.106.

Les disjoncteurs doivent être considérés comme ayant satisfait à la séquence d'essais T100a, même si le pourcentage de la composante apériodique au cours d'une manoeuvre d'ouverture est inférieur à la valeur spécifiée, à condition que la moyenne des pourcentages des composantes apériodiques au cours des manoeuvres d'ouverture de la séquence d'essais dépasse le pourcentage spécifié de la composante apériodique. Dans tous les essais de la séquence, le pourcentage de la composante apériodique doit être supérieur à 90 % de la valeur spécifiée.

Si l'oscillogramme d'une quelconque coupure ne permet pas de dessiner l'enveloppe de courant de façon satisfaisante, on doit prendre comme valeur de composante apériodique à la séparation des contacts pendant l'essai sa valeur présumée dans la mesure où les instants d'initiation des courts-circuits sont comparables. Le pourcentage de composante apériodique doit être mesuré à partir de l'oscillogramme du courant présumé, à l'instant correspondant à la séparation des contacts.

6.104.5 Tension transitoire de rétablissement (TTR) pour les essais de coupure de court-circuit

6.104.5.1 Généralités

~~La TTR présumée du circuit d'essai doit être déterminée par des méthodes telles que les appareils servant à générer et mesurer l'onde de la TTR soient sans influence pratique sur celle-ci. Elle doit être mesurée aux bornes auxquelles le disjoncteur sera relié avec tous les dispositifs de mesure nécessaires, tels que les diviseurs de tension, etc. Des méthodes appropriées sont décrites dans l'Annexe F (voir aussi 6.104.6). Dans les cas où la mesure n'est pas possible, par exemple dans certains laboratoires synthétiques, on admet un calcul de la TTR présumée. Des lignes directrices figurent à l'Annexe F.~~

~~Pour les circuits triphasés, la TTR présumée se réfère au pôle qui coupe le premier, c'est-à-dire à la tension aux bornes d'un pôle ouvert, les deux autres pôles étant fermés, suivant le circuit d'essai correspondant, comme spécifié en 6.103.3.~~

~~La courbe de la TTR présumée pour les essais est représentée par son enveloppe tracée comme l'indique l'Annexe E, et par sa partie initiale.~~

~~La TTR spécifiée pour les essais est représentée par un tracé de référence, un segment définissant le retard et une enveloppe de tension transitoire de rétablissement initial (TTRI) de la même façon que la TTR relative au courant de court-circuit assigné, conformément à 4.102.2 et aux Figures 10, 11 et 12.~~

~~Les paramètres de la TTR sont définis ci-dessous en fonction de la tension assignée (U_r), du facteur de premier pôle (k_{pp}) et du facteur d'amplitude (k_{af}). Les valeurs réelles de k_{pp} et de k_{af} sont indiquées dans les Tableaux 1, 2, 3, 4, 5, 24, 25, 26 et 27. Pour les disjoncteurs de tension assignée supérieure ou égale à 100 kV, correspondant à des réseaux dont le neutre est habituellement relié effectivement à la terre, le facteur de premier pôle k_{pp} est égal à 1,3, comme indiqué dans le Tableau 26. Dans le cas de réseaux de 100 kV à 170 kV, dont le neutre est relié non effectivement à la terre, le facteur de premier pôle k_{pp} est égal à 1,5, comme indiqué dans le Tableau 27.~~

~~a) *Pour les tensions assignées inférieures à 100 kV*~~

- ~~On utilise un tracé de référence de la TTR présumée à deux paramètres pour toutes les séquences d'essais.~~
- ~~Dans le Tableau 24, pour les disjoncteurs de réseaux par câbles.~~

  ~~La valeur de crête de la TTR est~~ $u_c = k_{pp} \times k_{af} \sqrt{(2/3)} \times U_r$ ~~où~~ k_{af} ~~est égal à 1,4 pour la séquence d'essais T100, 1,5 pour la séquence T60, 1,6 pour la séquence T30, 1,7 pour la séquence T10 et 1,25 pour la coupure en discordance de phase.~~

  ~~Le temps~~ t_3 ~~pour la séquence T100 est déduit du Tableau 24. Le temps~~ t_3 ~~pour les séquences T60, T30 et T10 est obtenu en multipliant le temps~~ t_3 ~~pour la séquence T100 par 0,44 (pour T60), 0,22 (pour T30) et 0,22 (pour T10).~~
- ~~Dans le Tableau 25, pour les disjoncteurs de réseaux aériens.~~

  ~~La valeur de crête de la TTR est~~ $u_c = k_{pp} \times k_{af} \sqrt{(2/3)} \times U_r$ ~~où~~ k_{af} ~~est égal à 1,54 pour la séquence d'essais T100, 1,65 pour la séquence T60, 1,74 pour la séquence T30, 1,8 pour la séquence T10 et 1,25 pour la coupure en discordance de phase.~~

  ~~Le temps~~ t_3 ~~pour la séquence T100 est déduit du Tableau 25. Le temps~~ t_3 ~~pour les séquences T60, T30 et T10 est obtenu en multipliant le temps~~ t_3 ~~pour la séquence T100 par 0,67 (pour T60), 0,40 (pour T30) et 0,40 (pour T10).~~
- ~~Le temps de retard~~ t_d ~~pour la séquence T100 est 0,15 ×~~ t_3 ~~pour les réseaux par câbles, 0,05 ×~~ t_3 ~~pour les réseaux aériens, 0,05 ×~~ t_3 ~~pour le circuit d'alimentation du défaut proche en ligne.~~
- ~~Le temps de retard~~ t_d ~~est 0,15 ×~~ t_3 ~~pour les séquences T60, T30 et T10 et pour la coupure en discordance de phases.~~
- ~~La tension~~ $u' = u_c/3$.
- ~~Le temps~~ t' ~~est déterminé à partir de~~ u', t_3 ~~et~~ t_d ~~selon la Figure 11,~~ $t' = t_d + t_3/3$.

~~b) *Pour les tensions assignées de 100 kV à 800 kV*~~

- ~~On utilise un tracé de référence de la TTR présumée à quatre paramètres pour les séquences T100 et T60, pour le circuit d'alimentation du défaut proche en ligne~~ L_{90} ~~et~~ L_{75} ~~et pour les séquences d'essais en discordance de phases OP1 et OP2, et à deux paramètres pour les séquences T30 et T10.~~
  - ~~La première tension de référence:~~ $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$
  - ~~Le temps~~ t_1 ~~est déterminé à partir de~~ u_1 ~~et de la valeur spécifiée de la vitesse d'accroissement~~ u_1/t_1.
  - ~~La valeur de crête de la TTR:~~ $u_c = k_{pp} \times k_{af} \times U_r \sqrt{\frac{2}{3}}$
  - ~~où~~ k_{af} ~~est égal à 1,4 pour la séquence T100 et pour le circuit d'alimentation du défaut proche en ligne, 1,5 pour la séquence T60, 1,54 pour la séquence T30, 0,9 × 1,7 pour la séquence T10 et 1,25 pour la coupure en discordance de phases.~~
  - ~~Le temps~~ t_2 ~~est égal à~~ $4t_1$ ~~pour la séquence T100 et pour le circuit d'alimentation du défaut proche en ligne et entre~~ t_2 ~~(pour T100) et~~ $2t_2$ ~~(pour T100) pour la coupure en discordance de phases. Le temps~~ t_2 ~~est égal à~~ $6t_1$ ~~pour la séquence T60.~~
  - ~~Pour les séquences T30 et T10, le temps~~ t_3 ~~est déduit de~~ u_c ~~et de la valeur spécifiée de la vitesse d'accroissement~~ u_c/t_3.
  - ~~Le retard~~ t_d ~~est entre 2 µs et~~ $0{,}28t_1$ ~~pour la séquence T100, entre 2 µs et~~ $0{,}3t_1$ ~~pour la séquence T60, entre 2 µs et~~ $0{,}1t_1$ ~~pour OP1 et OP2. Le retard est~~ $0{,}15t_3$ ~~pour les séquences T30 et T10. Pour le circuit d'alimentation du défaut proche en ligne, le retard est de 2 µs. Les valeurs de~~ t_d ~~à utiliser pour les essais sont données de 6.104.5.2 à 6.104.5.5.~~

- ~~La tension $u' = u_1/2$ pour les séquences T100 et T60, pour le circuit d'alimentation du défaut proche en ligne et pour la coupure en discordance de phases, et $u_c/3$ pour les séquences T30 et T10.~~
- ~~Le temps t' est déduit de u', u_1/t_1 et t_d pour les séquences T100, T60, pour le circuit d'alimentation du défaut proche en ligne et pour la coupure en discordance de phases, selon la Figure 10; et de u', u_c/t_3 et t_d pour les séquences T30 et T10 selon la Figure 11.~~

~~L'onde de la TTR présumée du circuit d'essai doit être conforme aux deux exigences suivantes:~~

~~– Exigence a)~~

~~Son enveloppe ne doit jamais être située en dessous du tracé de référence spécifié.~~

~~NOTE 1 Il est précisé que l'accord du constructeur est nécessaire pour fixer de combien l'enveloppe peut dépasser le tracé de référence spécifié (voir 6.104); ce point est particulièrement important lorsqu'on utilise des enveloppes à deux paramètres alors que des tracés de référence à quatre paramètres ont été spécifiés, et lorsqu'on utilise des enveloppes à quatre paramètres alors que des tracés de référence à deux paramètres ont été spécifiés.~~

~~NOTE 2 Pour la commodité des essais, il est permis de réaliser avec une TTR à deux paramètres les séquences d'essais pour lesquelles une TTR à quatre paramètres est spécifiée, sous réserve que la vitesse d'accroissement de la tension de rétablissement corresponde à la valeur normale u_1/t_1 et la valeur de crête de tension à la valeur normale u_c. Cette procédure requiert le consentement du constructeur.~~

~~– Exigence b)~~

~~Sa partie initiale doit satisfaire aux exigences de la TTRI spécifiée. La TTRI doit être considérée comme un défaut proche en ligne. Par conséquent, il est nécessaire de mesurer le circuit de TTRI indépendamment du circuit d'alimentation, d'une manière inhérente. La TTRI est définie par la valeur de crête u_i et par le temps correspondant t_i (Figure 12b). La forme d'onde présumée doit suivre un segment de ligne droite de référence du point de démarrage de la TTRI au point défini par u_i et t_i. La forme d'onde de TTRI inhérente doit suivre le tracé de référence de 20 % à 80 % de la valeur crête de TTRI. Des écarts par rapport au tracé de référence sont permis lorsque l'amplitude de la TTRI est soit inférieure à 20 %, soit supérieure à 80 % de la valeur de crête de la TTRI spécifiée. Elle ne doit pas être significativement plus grande que le tracé de référence mentionné ci-dessus. Si 80 % de la valeur ne peut être atteinte sans augmenter de manière significative la vitesse d'accroissement de la TTRI, il est préférable d'accroître la valeur de crête u_i au-dessus de la valeur spécifiée pour atteindre le point 80 %. La vitesse d'accroissement de la TTRI ne doit pas augmenter car cela correspondrait à un changement d'impédance et donc à un changement important de la sévérité de l'essai.~~

~~Il est nécessaire de réaliser les essais pour les séquences T100a, T100s et L_{90} avec les conditions de TTRI (tension transitoire de rétablissement initiale). Dans les cas où le disjoncteur a une caractéristique assignée de défaut proche en ligne, les exigences de TTRI sont considérées comme étant satisfaites si les essais de défaut proche en ligne sont réalisés avec une ligne introduisant un retard insignifiant (voir 6.104.5.2).~~

~~Puisque la TTRI est proportionnelle à l'impédance d'onde du jeu de barres et au courant, l'exigence de TTRI peut être négligée dans le cas des disjoncteurs installés dans des appareillages sous enveloppe métallique isolés au gaz parce que l'impédance d'onde est faible et pour tous les disjoncteurs de pouvoir de coupure assigné en court-circuit inférieur à 25 kA. Il en est de même, pour les disjoncteurs de tension assignée inférieure à 100 kV à cause des faibles dimensions des jeux de barres.~~

La TTR présumée des circuits d'essai doit être déterminée par des méthodes telles que les appareils servant à générer et mesurer l'onde de la TTR soient sans influence pratique sur celle-ci. Elle doit être mesurée aux bornes auxquelles le disjoncteur sera relié avec tous les dispositifs de mesure nécessaires, tels que les diviseurs de tension, etc. Des méthodes appropriées sont décrites dans l'Annexe F (voir aussi 6.104.6). Dans les cas où la mesure n'est pas possible, par exemple dans certains circuits synthétiques, on admet un calcul de la TTR présumée. Des lignes directrices figurent à l'Annexe F.

Pour les circuits triphasés, la TTR présumée se réfère au pôle qui coupe le premier, c'est-à-dire à la tension aux bornes d'un pôle ouvert, les deux autres pôles étant fermés, suivant le circuit d'essai correspondant, comme spécifié en 6.103.3.

La courbe de la TTR présumée pour les essais est représentée par son enveloppe tracée comme l'indique l'Annexe E, et par sa partie initiale.

La TTR spécifiée pour les essais est représentée par un tracé de référence, un segment définissant le retard et une enveloppe de tension transitoire de rétablissement initial (TTRI) de la même façon que la TTR relative au courant de court-circuit assigné, conformément à 4.102.2 et aux Figures 10, 11 et 12.

Les paramètres de la TTR sont définis ci-dessous en fonction de la tension assignée (U_r), du facteur de premier pôle (k_{pp}) et du facteur d'amplitude (k_{af}). Les valeurs réelles de k_{pp} et de k_{af} sont indiquées dans les Tableaux 1, 2, 3, 4, 5, 24, 25, 26 et 27. Pour les disjoncteurs de tension assignée comprise entre 100 kV et 800 kV, correspondant à des réseaux dont le neutre est habituellement relié effectivement à la terre, le facteur de premier pôle k_{pp} est égal à 1,3, comme indiqué dans le Tableau 26. Pour les disjoncteurs de tension assignée supérieure à 800 kV, le facteur de premier pôle k_{pp} est égal à 1,2, comme indiqué dans le Tableau 26. Pour les disjoncteurs dans des réseaux de 100 kV à 170 kV, dont le neutre est relié non effectivement à la terre, k_{pp} est égal à 1,5, comme indiqué dans le Tableau 27.

a) *Pour les tensions assignées inférieures à 100 kV*

On utilise un tracé de référence de la TTR présumée à deux paramètres pour toutes les séquences d'essais.

– Dans le Tableau 24, pour les disjoncteurs de réseaux par câbles.

La valeur de crête de la TTR est $u_c = k_{pp} \times k_{af} \times \sqrt{\left(2/3\right)} \times U_r$ où k_{af} est égal à 1,4 pour la séquence d'essais T100, 1,5 pour la séquence T60, 1,6 pour la séquence T30, 1,7 pour la séquence T10 et 1,25 pour la coupure en discordance de phase.

Le temps t_3 pour la séquence T100 est déduit du Tableau 24. Le temps t_3 pour les séquences T60, T30 et T10 est obtenu en multipliant le temps t_3 pour la séquence T100 par 0,44 (pour T60), 0,22 (pour T30) et 0,22 (pour T10).

– Dans le Tableau 25, pour les disjoncteurs de réseaux aériens.

La valeur de crête de la TTR est $u_c = k_{pp} \times k_{af} \times \sqrt{\left(2/3\right)} \times U_r$ où k_{af} est égal à 1,54 pour la séquence d'essais T100 et pour le circuit d'alimentation du défaut proche en ligne, 1,65 pour la séquence T60, 1,74 pour la séquence T30, 1,8 pour la séquence T10 et 1,25 pour la coupure en discordance de phase.

Le temps t_3 pour la séquence T100 est déduit du Tableau 25. Le temps t_3 pour les séquences T60, T30 et T10 est obtenu en multipliant le temps t_3 pour la séquence T100 par 0,67 (pour T60), 0,40 (pour T30) et 0,40 (pour T10).

– Le temps de retard t_d pour la séquence T100 est 0,15 × t_3 pour les réseaux par câbles, 0,05 × t_3 pour les réseaux aériens, 0,05 × t_3 pour le circuit d'alimentation du défaut proche en ligne. Pour les réseaux aériens, le temps de retard t_d pour la séquence d'essais T100 peut être prolongé jusqu'à 0,15 × t_3 si des essais de défaut proche en ligne sont effectués.

– Le temps de retard t_d est 0,15 × t_3 pour les séquences T60, T30 et T10 et pour la coupure en discordance de phases.

– Tension $u' = u_c/3$.

– Le temps t' est déterminé à partir de u', t_3 et t_d selon la Figure 11, $t' = t_d + t_3/3$.

b) *Pour les tensions assignées de 100 kV à 800 kV*

On utilise un tracé de référence de la TTR présumée à quatre paramètres pour les séquences T100 et T60, pour le circuit d'alimentation du défaut proche en ligne L_{90} et L_{75}

et pour les séquences d’essais en discordance de phases OP1 et OP2, et à deux paramètres pour les séquences d'essais T30 et T10.

– Première tension de référence $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\left(\frac{2}{3}\right)}$

– Pour les séquences d'essais de défaut aux bornes, le temps t_1 est déduit de u_1 et de la valeur spécifiée de la vitesse d’accroissement u_1/t_1. Pour les séquences d'essais OP1 et OP2, t_1 est égal à deux fois t_1 pour la séquence d'essais T100 et la vitesse d'accroissement est déduite de u_1 et t_1.

– Valeur de crête de TTR $u_c = k_{pp} \times k_{af} \times U_r \times \sqrt{\frac{2}{3}}$

où k_{af} est égal à 1,4 pour la séquence T100 et pour le circuit d’alimentation du défaut proche en ligne, 1,5 pour la séquence T60, 1,54 pour la séquence T30, 0,9 × 1,7 pour la séquence T10 et 1,25 pour la coupure en discordance de phases.

– Le temps t_2 est égal à $4t_1$ pour la séquence T100 et pour le circuit d’alimentation du défaut proche en ligne et entre t_2 (pour T100) et $2t_2$ (pour T100) pour la coupure en discordance de phases. Le temps t_2 est égal à $6t_1$ pour la séquence T60.

– Pour les séquences T30 et T10, le temps t_3 est déduit de u_c et de la valeur spécifiée de la vitesse d’accroissement u_c/t_3.

– Le retard t_d est de 2 µs pour la séquence T100, entre 2 µs et 0,3 t_1 pour la séquence T60, entre 2 µs et $0{,}1t_1$ pour les séquences OP1 et OP2. Le retard est 0,15 t_3 pour les séquences T30 et T10. Pour le circuit d’alimentation du défaut proche en ligne, le retard est de 2 µs. Lorsque des essais de défaut proche en ligne sont effectués, le retard t_d pour la séquence d'essais T100 peut être prolongé jusqu'à 0,28 t_1. Les valeurs de t_d à utiliser pour les essais sont données de 6.104.5.2 à 6.104.5.5.

– La tension $u' = u_1/2$ pour les séquences T100 et T60, pour le circuit d’alimentation du défaut proche en ligne et pour la coupure en discordance de phases, et $u_c/3$ pour les séquences T30 et T10.

– Le temps t' est déduit de u', u_1/t_1 et t_d pour les séquences T100, T60, pour le circuit d’alimentation du défaut proche en ligne et pour la coupure en discordance de phases, selon la Figure 10; et de u', u_c/t_3 et t_d pour les séquences T30 et T10 selon la Figure 11.

c) *Pour les tensions assignées supérieures à 800 kV*

On utilise un tracé de référence de la TTR présumée à quatre paramètres pour les séquences T100 et T60, pour le circuit d’alimentation du défaut proche en ligne L_{90} et L_{75} et à deux paramètres pour les séquences T30 et T10 et pour les séquences d’essais en discordance de phases OP1 et OP2.

– Première tension de référence $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$

– Pour les séquences d'essais de défaut aux bornes, le temps t_1 est déduit de u_1 et de la valeur spécifiée de la vitesse d’accroissement u_1/t_1.

– Pour les séquences d'essais en discordance de phases OP1 et OP2, le temps t_3 est déduit de u_c et de la valeur spécifiée de la vitesse d’accroissement.

– Valeur de crête de TTR $u_c = k_{pp} \times k_{af} \times U_r \sqrt{\frac{2}{3}}$

où k_{af} est égal à 1,5 pour la séquence T100 et pour le circuit d’alimentation du défaut proche en ligne, 1,5 pour la séquence T60, 1,54 pour la séquence T30, 1,76 pour la séquence T10 et 1,25 pour la coupure en discordance de phases.

– Le temps t_2 est égal à 3 t_1 pour la séquence d'essais T100 et pour le circuit côté alimentation pour le défaut proche en ligne. Le temps t_2 est égal à 4,5 t_1 pour la séquence T60.

- Pour les séquences T30 et T10, le temps t_3 est déduit de u_c et de la valeur spécifiée de la vitesse d'accroissement u_c/t_3.
- Le temps de retard t_d est 2 µs pour la séquence T100, entre 2 µs et 0,3 t_1 pour la séquence T60. Le retard est de 0,15 t_3 pour les séquences d'essais T30 et T10, 0,05 t_3 pour les séquences d'essais OP1 et OP2. Pour le circuit d'alimentation du défaut proche en ligne, le temps de retard est de 2 µs. Lorsque des essais de défaut proche en ligne sont effectués, le temps de retard t_d pour la séquence d'essais T100 peut être prolongé jusqu'à 0,28 t_1. Les valeurs de t_d à utiliser pour les essais sont données de 6.104.5.2 à 6.104.5.5.
- La tension $u' = u_1/2$ pour les séquences T100 et T60, pour le circuit d'alimentation du défaut proche en ligne et pour la coupure en discordance de phases, et $u_c/3$ pour les séquences T30, T10 et pour les séquences d'essais en discordance de phases.
- Le temps t' est déduit de u', u_1/t_1 et t_d pour les séquences T100, T60, pour le circuit d'alimentation du défaut proche en ligne selon la Figure 10; et de u', u_c/t_3 et t_d pour les séquences T30, T10 et pour les séquences d'essais en discordance de phases selon la Figure 11.

L'onde de la TTR présumée du circuit d'essai doit être conforme aux deux exigences suivantes:

- Exigence a)

  Son enveloppe ne doit jamais être située en dessous du tracé de référence spécifié.

NOTE 1 Il est précisé que l'accord du constructeur est nécessaire pour fixer de combien l'enveloppe peut dépasser le tracé de référence spécifié (voir 6.104); ce point est particulièrement important lorsqu'on utilise des enveloppes à deux paramètres alors que des tracés de référence à quatre paramètres ont été spécifiés, et lorsqu'on utilise des enveloppes à quatre paramètres alors que des tracés de référence à deux paramètres ont été spécifiés.

NOTE 2 Pour la commodité des essais, il est permis de réaliser avec une TTR à deux paramètres les séquences d'essais pour lesquelles une TTR à quatre paramètres est spécifiée, sous réserve que la vitesse d'accroissement de la tension de rétablissement corresponde à la valeur normale u_1/t_1 et la valeur de crête de tension à la valeur normale u_c. Cette procédure requiert le consentement du constructeur.

- Exigence b)

  Sa partie initiale doit satisfaire aux exigences de la TTRI spécifiée. La TTRI doit être considérée comme un défaut proche en ligne. Par conséquent, il est nécessaire de mesurer le circuit de TTRI indépendamment du circuit d'alimentation, d'une manière inhérente. La TTRI est définie par la valeur de crête u_i et par le temps correspondant t_i (Figure 12b). La forme d'onde présumée doit suivre un segment de ligne droite de référence du point de démarrage de la TTRI au point défini par u_i et t_i. La forme d'onde de TTRI inhérente doit suivre le tracé de référence de 20 % à 80 % de la valeur crête de TTRI. Des écarts par rapport au tracé de référence sont permis lorsque l'amplitude de la TTRI est inférieure à 20 % et supérieure à 80 % de la valeur de crête de la TTRI spécifiée. Elle ne doit pas être significativement plus grande que le tracé de référence mentionné ci-dessus. Si 80 % de la valeur ne peut être atteinte sans augmenter de manière significative la vitesse d'accroissement de la TTRI, il est préférable d'accroître la valeur de crête u_i au-dessus de la valeur spécifiée pour atteindre le point 80 %. La vitesse d'accroissement de la TTRI ne doit pas augmenter car cela correspondrait à un changement d'impédance et donc à un changement important de la sévérité de l'essai.

  Il est nécessaire de réaliser les essais pour les séquences T100a, T100s et L_{90} avec les conditions de tension transitoire de rétablissement initiale (TTRI). Si toutefois un disjoncteur de tension assignée inférieure ou égale à 800 kV a une caractéristique assignée de défaut proche en ligne, les exigences de TTRI sont considérées comme étant satisfaites si les essais de défaut proche en ligne sont réalisés avec une ligne introduisant un retard inférieur à 100 ns (voir aussi 6.104.5.2).

  Si un disjoncteur de tension assignée supérieure à 800 kV a une caractéristique assignée de défaut proche en ligne, les exigences de TTRI sont considérées comme étant satisfaites si les essais de défaut proche en ligne sont réalisés avec une ligne introduisant un retard inférieur à 100 ns et une impédance d'onde de 450 Ω (voir aussi 6.104.5.2 et 6.109.3).

Puisque la TTRI est proportionnelle à l'impédance d'onde du jeu de barres et au courant, les exigences de TTRI peuvent être négligées dans le cas des disjoncteurs installés dans des appareillages sous enveloppe métallique isolés au gaz parce que l'impédance d'onde est faible et pour tous les disjoncteurs de pouvoir de coupure assigné en court-circuit inférieur à 25 kA. Il en est de même, pour les disjoncteurs de tension assignée inférieure à 100 kV à cause des faibles dimensions des jeux de barres.

6.104.5.2 Séquences d'essais T100s et T100a

Pour les tensions assignées inférieures à 100 kV, les valeurs normales spécifiées sont indiquées dans

– le Tableau 24, pour les disjoncteurs pour réseaux par câbles,

– le Tableau 25, pour les disjoncteurs pour réseaux aériens.

Pour les tensions assignées supérieures ou égales à 100 kV, les valeurs normales spécifiées sont indiquées dans les Tableaux 26 et 27.

Les tracés de référence, segments définissant le retard et TTRI spécifiés sont les valeurs normales indiquées dans les Tableaux 1, 2, 3, 4, 5, 6 et 7.

En ce qui concerne la TTRI, si un essai est effectué avec une TTR suivant le contour du tracé de référence spécifié en 6.104.5.1, point b), et indiqué à la Figure 12b, il est admis que le disjoncteur est contraint de la même façon qu'avec une TTRI définie selon 6.104.5.1, point b), et Figure 12b.

Par suite de limitations du laboratoire d'essai, il peut être impossible de répondre complètement à l'exigence du point b) de 6.104.5.1 en ce qui concerne le retard t_d spécifié dans les Tableaux 3, 4 ou 5. Lorsque des essais de défaut proche en ligne sont également effectués, toute déficience de ce genre de la TTR du circuit d'alimentation doit être compensée par une augmentation de la première crête de la tension, côté ligne (voir 6.109.3). Le retard du circuit d'alimentation doit être aussi faible que possible, mais ne doit en aucun cas dépasser les valeurs indiquées entre parenthèses dans les Tableaux 25 ou 26 ou 27.

~~Lorsque des essais de défaut proche en ligne sont également effectués, il peut être commode de combiner les exigences de TTRI et les exigences du défaut proche en ligne, du côté ligne. Si la TTRI est combinée avec la tension transitoire d'une ligne courte introduisant le retard~~ $\cancel{t_{dL}}$ ~~spécifié dans le Tableau 8, la contrainte totale est pratiquement égale à la contrainte due à une ligne courte n'introduisant qu'un retard insignifiant. Par conséquent, les exigences de la TTRI des séquences d'essais T100s et T100a sont considérées comme satisfaites si les séquences d'essais de défaut proche en ligne sont effectuées avec une ligne courte n'introduisant qu'un retard insignifiant~~ $\cancel{t_{dL}}$ ~~(voir 6.109.3) à moins que les deux bornes ne soient pas identiques du point de vue électrique (comme c'est le cas par exemple, quand une capacité additionnelle est utilisée comme il est indiqué dans la Note 4 de 6.109.3).~~

Lorsque des essais de défaut proche en ligne doivent également être effectués, il peut être commode de combiner les exigences de TTRI et les exigences du défaut proche en ligne, du côté ligne. Si la TTRI est combinée avec la tension transitoire d'une ligne courte introduisant le retard t_{dL} spécifié dans le Tableau 8, la contrainte totale est pratiquement égale à la contrainte due à une ligne courte introduisant un retard inférieur à 100 ns et une impédance d'onde de 450 Ω. Par conséquent, les exigences de la TTRI des séquences d'essais T100s et T100a sont considérées comme satisfaites si les séquences d'essais de défaut proche en ligne sont effectuées avec une ligne courte introduisant un retard inférieur à 100 ns et une impédance d'onde de 450 Ω (voir 6.109.3) à moins que les deux bornes ne soient pas identiques du point de vue électrique (comme c'est le cas par exemple, quand une capacité additionnelle est utilisée comme il est indiqué dans la Note 4 du 6.109.3).

Lorsque des séquences d'essai de défaut proche en ligne avec un retard inférieur à 100 ns sont utilisées pour satisfaire aux exigences de TTRI, la partie initiale de la tension transitoire côté ligne allant jusqu'à 0,2 u_L*ne doit pas être inférieure au tracé de référence de défaut proche en ligne (SLF) de 20 % à 80 % sauf si le temps de retard défini sur la Figure 16b est inférieur à 100 ns.

6.104.5.3 Séquence d'essais T60

Pour les tensions assignées inférieures à 100 kV, les valeurs normales spécifiées sont indiquées dans

– le Tableau 24, pour les disjoncteurs pour réseaux par câbles,

– le Tableau 25 pour les disjoncteurs pour réseaux aériens.

Pour les tensions assignées supérieures ou égales à 100 kV, les valeurs normales spécifiées sont indiquées dans les Tableaux 26 et 27.

6.104.5.4 Séquence d'essais T30

a) Pour les tensions assignées inférieures à 100 kV, les valeurs normales spécifiées sont indiquées dans

– le Tableau 24, pour les disjoncteurs ~~pour~~ de réseaux par câblés,

– le Tableau 25 pour les disjoncteurs ~~pour~~ de réseaux aériens.

~~En essais directs ou synthétiques, il peut être difficile d'obtenir les faibles valeurs de t_3. Il convient d'utiliser le plus petit temps que l'on puisse atteindre sans être inférieur aux valeurs spécifiées. Les valeurs utilisées doivent être consignées dans le rapport d'essai.~~

Si de petites valeurs du temps t_3 ne peuvent pas être satisfaites, la durée la plus courte pouvant être satisfaite doit être utilisée. Les valeurs utilisées doivent être consignées dans le rapport d'essai.

b) Pour les tensions assignées supérieures ou égales à 100 kV, les valeurs normales spécifiées sont indiquées dans les Tableaux 26 et 27.

~~NOTE L'apport des transformateurs au courant de court-circuit est relativement plus important pour les faibles valeurs de courant de court-circuit comme dans T30 et T10. Cependant, la plupart des réseaux ont un neutre effectivement à la terre pour les tensions assignées supérieures ou égales à 100 kV. Pour des réseaux et transformateurs à neutre effectivement à la terre, le facteur de premier pôle de 1,3 est applicable pour toutes les séquences d'essais sauf pour T10 pour laquelle un facteur de premier pôle de 1,5 est requis afin de prendre aussi en compte les défauts alimentés par un transformateur. Dans des réseaux de tension assignée de 100 kV à 170 kV inclus, des transformateurs à neutre non effectivement à la terre sont en service, même si le reste du réseau peut avoir un neutre effectivement à la terre. Ces réseaux sont considérés comme étant des cas particuliers est sont couverts dans les Tableaux 4 et 27 où les TTR spécifiées pour toutes les séquences d'essais sont basées sur un facteur de premier pôle égal à 1,5. Pour les tensions assignées supérieures à 170 kV, tous les réseaux et leurs transformateurs sont considérés comme ayant des neutres effectivement à la terre.~~

NOTE L'apport des transformateurs au courant de court-circuit est relativement plus important pour les faibles valeurs de courant de court-circuit comme dans T30 et T10. Cependant, la plupart des réseaux ont un neutre effectivement à la terre pour les tensions assignées de 100 kV jusqu'à 800 kV. Pour des réseaux et transformateurs à neutre effectivement à la terre, le facteur de premier pôle qui coupe de 1,3 est applicable pour toutes les séquences d'essais sauf pour T10 pour laquelle un facteur de premier pôle qui coupe de 1,5 est utilisé afin de prendre aussi en compte les défauts alimentés par un transformateur. Pour des tensions assignées supérieures à 800 kV, le facteur de premier pôle qui coupe de 1,2 est applicable à toutes les séquences d'essais.

Dans des réseaux de tension assignée de 100 kV à 170 kV inclus, des transformateurs à neutre non effectivement à la terre sont en service, même si le reste du réseau peut avoir un neutre effectivement à la terre. Ces réseaux sont considérés comme étant des cas particuliers et sont couverts dans les Tableaux 4 et 27 où les TTR spécifiées pour toutes les séquences d'essais sont basées sur un facteur de premier pôle égal à 1,5. Pour les tensions assignées supérieures à 170 kV, tous les réseaux et leurs transformateurs sont considérés comme ayant des neutres effectivement à la terre.

6.104.5.5 Séquence d'essais T10

a) Pour les tensions assignées inférieures à 100 kV, les valeurs normales spécifiées sont indiquées dans

– le Tableau 24, pour les disjoncteurs ~~pour~~ de réseaux par câbles,

– le Tableau 25 pour les disjoncteurs ~~pour~~ de réseaux aériens.

b) Pour les tensions assignées supérieures ou égales à 100 kV, les valeurs normales spécifiées sont indiquées dans les Tableaux 26 et 27. Le temps t_3 est fonction de la fréquence naturelle des transformateurs.

~~En essais directs ou synthétiques, il peut être difficile d'obtenir les faibles valeurs de t_3. Il convient d'utiliser le plus petit temps que l'on puisse atteindre sans être inférieur aux valeurs spécifiées. Les valeurs utilisées doivent être consignées dans le rapport d'essai.~~

Si de petites valeurs du temps t_3 ne peuvent pas être satisfaites, la durée la plus courte pouvant être satisfaite doit être utilisée. Les valeurs utilisées doivent être consignées dans le rapport d'essai.

6.104.5.6 Séquences d'essais OP1 et OP2

Pour les tensions assignées inférieures ou égales à 72,5 kV, les valeurs normales spécifiées sont indiquées dans les Tableaux 1 et 2.

Pour les tensions assignées supérieures ou égales à 100 kV, les valeurs normales spécifiées sont indiquées dans les Tableaux 3, 4 et 5. Deux valeurs des temps t_d et t' sont données. Elles indiquent les limites inférieures et supérieures des valeurs ~~qui peuvent être~~ qu'il convient ~~utilisées~~ d'utiliser pour les essais.

6.104.6 Mesurage de la TTR pendant l'essai

Au cours d'un essai en court-circuit, les caractéristiques du disjoncteur telles que la tension d'arc, la conductivité post-arc et la présence éventuelle de résistances de coupure affecteront la tension transitoire de rétablissement. En conséquence, la tension transitoire de rétablissement d'essai différera plus ou moins, selon les caractéristiques du disjoncteur, de l'onde de TTR présumée du circuit d'essai sur lequel sont fondées les conditions de fonctionnement.

A moins que l'influence propre du disjoncteur soit sans importance et que le courant coupé comprenne une composante apériodique insignifiante, il est recommandé que les enregistrements relevés au cours des essais ne soient pas utilisés pour évaluer les caractéristiques de la tension transitoire de rétablissement présumée du circuit; il convient d'effectuer ceci plutôt par d'autres moyens tels que ceux décrits dans l'Annexe F.

La TTR pendant l'essai doit être enregistrée.

Tableau 24 – Valeurs normales de la TTR présumée pour les disjoncteurs de classe S1 – Tensions assignées supérieures à 1 kV et inférieures à 100 kV – Représentation par deux paramètres

Tension assignée U_r kV	Séquence d'essais	Facteur de 1er pôle k_{pp} p.u.	Facteur d'ampli -tude k_{af} p.u.	Valeur de crête de la TTR u_c kV	Temps t_3 µs	Temps de retard t_d µs	Tension u' kV	Temps t' µs	VATR[a] u_c/t_3 kV/µs
3,6	T100	1,5	1,4	6,2	41	6	2,1	20	0,15
	T60	1,5	1,5	6,6	18	3	2,2	9	0,37
	T30	1,5	1,6	7,1	9	1,4	2,4	4,4	0,79
	T10	1,5	1,7	7,5	9	1,4	2,5	4,4	0,83
4,76 [b]	T100	1,5	1,4	8,2	44	7	2,7	21	0,19
	T60	1,5	1,5	8,7	19	3	2,9	9	0,46
	T30	1,5	1,6	9,3	10	1,5	3,1	5	0,93
	T10	1,5	1,7	9,9	10	1,5	3,3	5	0,99
7,2	T100	1,5	1,4	12,3	51	8	4,1	25	0,24
	T60	1,5	1,5	13,2	22	3	4,4	11	0,60
	T30	1,5	1,6	14,1	11	2	4,7	5	1,28
	T10	1,5	1,7	15,0	11	2	5,0	5	1,36
8,25 [b]	T100	1,5	1,4	14,1	52	8	4,7	25	0,27
	T60	1,5	1,5	15,2	23	3	5,1	11	0,66
	T30	1,5	1,6	16,2	11	2	5,4	6	1,47
	T10	1,5	1,7	17,2	11	2	5,7	6	1,56
12	T100	1,5	1,4	20,6	61	9	6,9	29	0,34
	T60	1,5	1,5	22,0	27	4	7,3	13	0,81
	T30	1,5	1,6	23,5	13	2	7,8	6	1,81
	T10	1,5	1,7	25,0	13	2	8,3	6	1,92
15 [b]	T100	1,5	1,4	25,7	66	10	8,6	32	0,39
	T60	1,5	1,5	27,6	29	4	9,2	14	0,95
	T30	1,5	1,6	29,4	15	2	9,8	7	1,96
	T10	1,5	1,7	31,2	15	2	10,4	7	2,08
17,5	T100	1,5	1,4	30,0	71	11	10,0	34	0,42
	T60	1,5	1,5	32,1	31	5	10,7	15	1,04
	T30	1,5	1,6	34,3	16	2	11,4	8	2,14
	T10	1,5	1,7	36,4	16	2	12,1	8	2,28

Tableau 24 *(suite)*

Tension assignée U_r kV	**Séquence d'essais**	**Facteur de 1er pôle** k_{pp} p.u.	**Facteur d'ampli -tude** k_{af} p.u.	**Valeur de crête de la TTR** u_c kV	**Temps** t_3 µs	**Temps de retard** t_d µs	**Tension** u' kV	**Temps** t' µs	**VATR** [a] u_c/t_3 kV/µs
24	T100	1,5	1,4	41	87	13	13,7	42	0,47
	T60	1,5	1,5	44,1	38	6	14,7	19	1,16
	T30	1,5	1,6	47,0	19	3	15,7	9	2,47
	T10	1,5	1,7	50	19	3	16,7	9	2,63
25,8 [b]	T100	1,5	1,4	44,2	91	14	14,7	44	0,49
	T60	1,5	1,5	47,4	40	6	15,8	18	1,19
	T30	1,5	1,6	50,6	20	3	16,9	10	2,53
	T10	1,5	1,7	53,7	20	3	17,9	10	2,69
36	T100	1,5	1,4	61,7	109	16	20,6	53	0,57
	T60	1,5	1,5	66,1	48	7	22	23	1,38
	T30	1,5	1,6	70,5	24	3,6	23,5	12	2,94
	T10	1,5	1,7	75,0	24	3,6	25	12	3,13
38 [b]	T100	1,5	1,4	65,2	109	16	21,7	53	0,60
	T60	1,5	1,5	69,8	48	7	23,3	23	1,45
	T30	1,5	1,6	74,5	24	3,6	24,8	12	3,1
	T10	1,5	1,7	79,1	24	3,6	26,4	12	3,3
48,3 [b]	T100	1,5	1,4	82,8	125	19	27,6	60	0,66
	T60	1,5	1,5	88,7	55	8	29,6	27	1,61
	T30	1,5	1,6	94,6	28	4	31,5	13	3,38
	T10	1,5	1,7	101	28	4	33,5	13	3,61
52	T100	1,5	1,4	89,2	131	20	29,7	63	0,68
	T60	1,5	1,5	95,5	58	9	31,8	28	1,65
	T30	1,5	1,6	102	29	4	34	14	3,52
	T10	1,5	1,7	108	29	4	36,1	14	3,72
72,5	T100	1,5	1,4	124	165	25	41,4	80	0,75
	T60	1,5	1,5	133	73	11	44,4	35	1,82
	T30	1,5	1,6	142	36	5	47,4	18	3,94
	T10	1,5	1,7	151	36	5	50,3	18	4,19

[a] VATR = vitesse d'accroissement de rétablissement de tension.

[b] Utilisée en Amérique du Nord.

Tableau 25 – Valeurs normales de la TTR [c] présumée pour les disjoncteurs de classe S2 – Tensions assignées égales ou supérieures à 15 kV et inférieures à 100 kV – Représentation par deux paramètres

Tension assignée	Séquence d'essais	Facteur de 1er pôle	Facteur d'amplitude	Valeur de crête de la TTR	Temps	Temps de retard	Tension	Temps	VATR [a]
U_r		k_{pp}	k_{af}	u_c	t_3	t_d	u'	t'	u_c/t_3
kV		p.u.	p.u.	kV	µs	µs	kV	µs	kV/µs
15 [b]	T100	1,5	1,54	28,3	31	2 (5)	9,4	12 (15)	0,91
	T60	1,5	1,65	30,3	21	3	10,1	10	1,44
	T30	1,5	1,74	32,0	12,5	2	10,7	6	2,56
	T10	1,5	1,80	33,1	12,5	2	11,0	6	2,67
17,5	T100	1,5	1,54	33,0	34	2 (5)	11,0	13 (17)	0,97
	T60	1,5	1,65	35,3	23	3	11,8	11	1,53
	T30	1,5	1,74	37,3	14	2	12,4	7	2,66
	T10	1,5	1,8	38,6	14	2	12,9	7	2,76
24	T100	1,5	1,54	45,3	43	2 (6)	15,1	16 (21)	1,05
	T60	1,5	1,65	48,4	29	4	16,1	14	1,67
	T30	1,5	1,74	51,2	17	3	17,0	8	3,01
	T10	1,5	1,8	52,9	17	3	17,6	8	3,11
25,8 [b]	T100	1,5	1,54	48,7	45	2 (7)	16,2	17 (22)	1,08
	T60	1,5	1,65	52,1	30	5	17,4	15	1,74
	T30	1,5	1,74	55,0	18	3	18,3	9	3,06
	T10	1,5	1,8	56,9	18	3	19,0	9	3,16
36	T100	1,5	1,54	67,9	57	3 (9)	22,6	22 (28)	1,19
	T60	1,5	1,65	72,7	38	6	24,2	18	1,91
	T30	1,5	1,74	76,7	23	3	25,6	11	3,33
	T10	1,5	1,8	79,4	23	3	26,5	11	3,45
38 [b]	T100	1,5	1,54	71,7	59	3 (9)	23,9	23 (29)	1,22
	T60	1,5	1,65	76,8	40	6	25,6	19	1,92
	T30	1,5	1,74	81,0	24	4	27,0	11,9	3,38
	T10	1,5	1,8	83,8	24	4	28,0	11,9	3,49
48,3 [b]	T100	1,5	1,54	91,1	70	4 (11)	30,4	27 (34)	1,30
	T60	1,5	1,65	97,5	47	7	32,5	23	2,07
	T30	1,5	1,74	103	28	4	34,3	13,5	3,68
	T10	1,5	1,8	107	28	4	35,5	13,5	3,82
52	T100	1,5	1,54	98,1	74	4 (11)	32,7	28 (36)	1,33
	T60	1,5	1,65	105	50	7	35,0	24	2,10
	T30	1,5	1,74	111	30	4	36,9	14	3,70
	T10	1,5	1,8	115	30	4	38,3	14	3,83
72,5	T100	1,5	1,54	137	93	5 (14)	45,6	36 (45)	1,47
	T60	1,5	1,65	146	62	9	48,8	30	2,35
	T30	1,5	1,74	155	37	6	51,5	18	4,19
	T10	1,5	1,8	160	37	6	53,3	18	4,32

[a] VATR = vitesse d'accroissement de rétablissement de tension.

[b] Utilisé en Amérique du Nord.

[c] ~~Lorsque deux valeurs de temps t_d et t' sont données pour le défaut aux bornes (T100), les valeurs entre parenthèses peuvent être utilisées si des essais de défaut en ligne sont aussi effectués. Si cela n'est pas le cas, les valeurs les plus faibles de t_d et t' sont applicables.~~

Lorsque deux valeurs de temps t_d and t' sont données pour la séquence d'essais T100, séparées par des parenthèses, t_d entre parenthèses est la limite supérieure du retard t_d pouvant être utilisée pour la séquence d'essais T100 si des essais de défaut proche en ligne sont aussi effectués. Dans ce cas, le segment définissant le retard se termine à t' indiqué entre parenthèses. Si cela n'est pas le cas, les valeurs les plus faibles de t_d et t' sont applicables.

Tableau 26 – Valeurs normales de la ~~TTR présumée – Tensions assignées de 100 kV à 800 kV, cas des réseaux à neutre effectivement à la terre – Représentation par quatre paramètres (T100, T60, OP1 et OP2) ou deux paramètres (T30, T10)~~ tension transitoire de rétablissement présumée – Tensions assignées supérieures ou égales à 100 kV

Tension assignée	Séquence d'essais	Facteur de premier pôle	Facteur d'amplitude	Première tension de référence	Temps	Valeur de crête de la TTR	Temps	Retard	Tension	Temps	Vitesse d'accroissement
U_r		k_{pp}	k_{af}	u_1	t_1	u_C	t_2 ou t_3	t_d	u'	t'	u_1/t_1 u_c/t_3
kV		p.u.	p.u.	kV	µs	kV	µs	µs	kV	µs	kV/µs
100	T100	1,3	1,40	80	40	149	160	2 (11)	40	22 (31)	2
	T60	1,3	1,50	80	27	159	162	2-8	40	15-21	3
	T30	1,3	1,54	-	-	163	33	5	54	16	5
	T10	1,5	0,9 × 1,7	-	-	187	27	4	62	13	7
	OP1-OP2	2	1,25	122	80	204	160-320	2-8	61	42-48	1,54
123	T100	1,3	1,40	98	49	183	196	2 (14)	49	26 (38)	2
	T60	1,3	1,50	98	33	196	198	2-10	49	18-26	3
	T30	1,3	1,54	-	-	201	40	6	67	19	5
	T10	1,5	0,9 × 1,7	-	-	230	33	5	77	16	7
	OP1-OP2	2	1,25	151	98	251	196-392	2-10	75	51-59	1,54
145	T100	1,3	1,40	115	58	215	232	2 (16)	58	31 (45)	2
	T60	1,3	1,50	115	38	231	228	2-12	58	21-31	3
	T30	1,3	1,54	-	-	237	47	7	79	23	5
	T10	1,5	0,9 × 1,7	-	-	272	39	6	91	19	7
	OP1-OP2	2	1,25	178	116	296	232-464	2-12	89	60-70	1,54
170	T100	1,3	1,40	135	68	253	272	2 (19)	68	36 (53)	2
	T60	1,3	1,50	135	45	271	270	2-14	68	25-36	3
	T30	1,3	1,54	-	-	278	56	8	93	27	5
	T10	1,5	0,9 × 1,7	-	-	319	46	7	106	22	7
	OP1-OP2	2	1,25	208	136	347	272-544	2-14	104	70-82	1,54
245	T100	1,3	1,40	195	98	364	392	2 (27)	98	51 (76)	2
	T60	1,3	1,50	195	65	390	390	2-20	98	35-52	3
	T30	1,3	1,54	-	-	400	80	12	133	39	5
	T10	1,5	0,9 × 1,7	-	-	459	66	10	153	32	7
	OP1-OP2	2	1,25	300	196	500	392-784	2-20	150	99-117	1,54
300	T100	1,3	1,40	239	119	446	476	2 (33)	119	62 (93)	2
	T60	1,3	1,50	239	80	478	480	2-24	119	42-64	3
	T30	1,3	1,54	-	-	490	98	15	163	47	5
	T10	1,5	0,9 × 1,7	-	-	562	80	12	187	39	7
	OP1-OP2	2	1,25	367	238	612	476-952	2-24	184	121-143	1,54

Tableau 26 *(suite)*

Tension assignée	Séquence d'essais	Facteur de premier pôle	Facteur d'amplitude	Première tension de référence	Temps	Valeur de crête de la TTR	Temps	Retard	Tension	Temps	Vitesse d'accroissement
U_r		k_{pp}	k_{af}	u_1	t_1	u_C	t_2 ou t_3	t_d	u'	t'	u_1/t_1 u_c/t_3
kV		p.u.	p.u.	kV	µs	kV	µs	µs	kV	µs	kV/µs
362	T100	1,3	1,40	288	144	538	576	2 (40)	144	74 (112)	2
	T60	1,3	1,50	288	96	576	576	2-29	144	50-77	3
	T30	1,3	1,54	-	-	592	118	18	197	57	5
	T10	1,5	0,9 × 1,7	-	-	678	97	15	226	47	7
	OP1-OP2	2	1,25	443	288	739	576-1152	2-29	222	146-173	1,54
420	T100	1,3	1,40	334	167	624	668	2 (47)	167	86 (130)	2
	T60	1,3	1,50	334	111	669	666	2-33	167	58-89	3
	T30	1,3	1,54	-	-	687	137	21	229	66	5
	T10	1,5	0,9 × 1,7	-	-	787	112	17	262	54	7
	OP1-OP2	2	1,25	514	334	857	668-1336	2-33	257	169-200	1,54
550	T100	1,3	1,40	438	219	817	876	2 (61)	219	111 (171)	2
	T60	1,3	1,50	438	146	876	876	2-44	219	75-117	3
	T30	1,3	1,54	-	-	899	180	27	300	87	5
	T10	1,5	0,9 × 1,7	-	-	1031	147	22	344	71	7
	OP1-OP2	2	1,25	674	438	1123	876-1752	2-44	337	221-263	1,54
800	T100	1,3	1,40	637	318	1189	1272	2 (89)	318	161 (248)	2
	T60	1,3	1,50	637	212	1274	1272	2-64	318	108-170	3
	T30	1,3	1,54	-	-	1308	262	39	436	126	5
	T10	1,5	0,9 × 1,7	-	-	1499	214	32	500	103	7
	OP1-OP2	2	1,25	980	636	1633	1272-2544	2-64	490	320-382	1,54
1 100	T100	1,2	1,50	808	404	1617	1212	2 (113)	404	204 (315)	2
	T60	1,2	1,50	808	269	1617	1212	2-81	404	137-216	3
	T30	1,2	1,54	-	-	1660	332	50	553	161	5
	T10	1,2	1,76	-	-	1897	271	41	632	131	7
	OP1-OP2	2	1,25	-	-	2245	1458	2-73	748	488-559	1,54
1 200	T100	1,2	1,50	882	441	1764	1323	2 (123)	441	222 (343)	2
	T60	1,2	1,50	882	294	1764	1323	2-88	441	149-235	3
	T30	1,2	1,54	-	-	1811	362	54	604	175	5
	T10	1,2	1,76	-	-	2069	296	44	690	143	7
	OP1-OP2	2	1,25	-	-	2449	1590	2-80	816	532-610	1,54

Tableau 26 *(suite)*

~~NOTE 1 Lorsque deux valeurs de temps t_d et t' sont données pour la séquence d'essais de défaut aux bornes T100, séparées par des parenthèses, la valeur entre parenthèses peut être utilisée si des essais de défaut proche en ligne sont aussi effectués. Dans le cas contraire, on utilise les valeurs avant les parenthèses.~~

~~Lorsque deux valeurs de temps t_d et t' sont données pour les séquences d'essais de défaut aux bornes T60 et les séquences d'essais en discordance de phases OP1 et OP2, elles indiquent les limites inférieures et supérieures qu'il convient d'utiliser pour l'essai. Il convient que les valeurs de retard t_d et de temps t' lors de l'essai ne soient ni plus faibles que les limites inférieures respectives, ni plus élevées que les limites supérieures respectives.~~

NOTE 1 Lorsque deux valeurs de temps t_d et t' sont données pour la séquence d'essais T100, séparées par des parenthèses, t_d entre parenthèses est la limite supérieure du retard t_d pouvant être utilisée pour la séquence d'essais T100 si des essais de défaut proche en ligne sont aussi effectués. Dans ce cas, le segment de retard se termine à t' indiqué entre parenthèses. Si cela n'est pas le cas, les valeurs les plus faibles de t_d et t' sont applicables.

Lorsque deux valeurs de temps t_d et t' sont données pour les séquences d'essais de défaut aux bornes T60 et les séquences d'essais en discordance de phases OP1 et OP2, elles indiquent les limites inférieures et supérieures qu'il convient d'utiliser pour l'essai. Il convient que les valeurs de retard t_d et de temps t' lors de l'essai ne soient ni plus faibles que les limites inférieures respectives, ni plus élevées que les limites supérieures respectives.

NOTE 2 Un facteur de premier pôle k_{pp} égal à 1,5 est spécifié pour couvrir les conditions de défaut limitées aux transformateurs avec X_0/X_1 supérieur à 3,2 (par exemple transformateurs reliés non effectivement à la terre dans les réseaux à neutre relié effectivement à la terre, ou cas de transformateurs avec un côté relié effectivement à la terre et l'autre côté connecté à des réseaux à neutre relié non effectivement à la terre). La TTR spécifiée couvre également les cas de défauts en ligne triphasés avec des réseaux à neutre relié effectivement à la terre (k_{pp}= 1,3), où le couplage entre phases peut entraîner un facteur d'amplitude de 1,76. Par conséquent, la fenêtre de durée d'arc pour les réseaux à neutre relié effectivement à la terre doit être démontrée pour T10 (voir 6.102.10.2.2.1).

Tableau 27 – Valeurs normales de la TTR présumée – Tensions assignées de 100 kV à 170 kV, cas des réseaux à neutre non effectivement à la terre – Représentation par quatre paramètres (T100, T60, OP1 et OP2) ou deux paramètres (T30 et T10)

Tension assignée	Séquence d'essais	Facteur de premier pôle	Facteur d'amplitude	Première tension de référence	Temps	Valeur de crête de la TTR	Temps	Retard	Tension	Temps	Vitesse d'accrois-sement
U_r		k_{pp}	k_{af}	u_1	t_1	u_C	t_2 ou t_3	t_d	u'	t'	u_1/t_1 u_c/t_3
kV		p.u.	p.u.	kV	µs	kV	µs	µs	kV	µs	kV/µs
100	T100	1,5	1,40	92	46	171	184	2 (13)	46	25 (36)	2
	T60	1,5	1,50	92	31	184	186	2-8	46	15-21	3
	T30	1,5	1,54	-	-	189	38	5	63	16	5
	T10	1,5	0,9 × 1,7	-	-	187	27	4	62	13	7
	OP1-OP2	2,5	1,25	153	92	255	184-368	2-8	77	42-48	1,67
123	T100	1,5	1,40	113	56	211	224	2 (16)	56	30 (44)	2
	T60	1,5	1,50	113	38	226	228	2-10	56	18-26	3
	T30	1,5	1,54	-	-	232	46	6	77	19	5
	T10	1,5	0,9 × 1,7	-	-	230	33	5	77	16	7
	OP1-OP2	2,5	1,25	188	112	314	224-448	2-10	94	51-59	1,67
145	T100	1,5	1,40	133	67	249	268	2 (19)	67	35 (52)	2
	T60	1,5	1,50	133	44	266	264	2-12	67	21-31	3
	T30	1,5	1,54	-	-	273	55	7	91	23	5
	T10	1,5	0,9 × 1,7	-	-	272	39	6	91	19	7
	OP1-OP2	2,5	1,25	222	134	370	268-536	2-12	111	60-70	1,67
170	T100	1,5	1,40	156	78	291	312	2 (22)	78	41 (61)	2
	T60	1,5	1,50	156	52	312	312	2-14	78	25-36	3
	T30	1,5	1,54	-	-	321	64	8	107	27	5
	T10	1,5	0,9 × 1,7	-	-	319	46	7	106	22	7
	OP1-OP2	2,5	1,25	260	156	434	312-624	2-14	130	70-82	1,67

~~NOTE 1 Lorsque deux valeurs de temps t_d et t' sont données pour la séquence d'essais de défaut aux bornes T100, séparées par des parenthèses, la valeur entre parenthèses peut être utilisée si des essais de défaut proche en ligne sont aussi effectués. Dans le cas contraire, on utilise les valeurs avant les parenthèses.~~

NOTE 1 Lorsque deux valeurs de temps t_d et t' sont données pour la séquence d'essais T100, séparées par des parenthèses, t_d entre parenthèses est la limite supérieure du retard t_d pouvant être utilisée pour la séquence d'essais T100 si des essais de défaut proche en ligne sont aussi effectués. Dans ce cas, le segment de retard se termine à t' indiqué entre parenthèses. Si cela n'est pas le cas, les valeurs les plus faibles de t_d et t sont applicables.

Lorsque deux valeurs de temps t_d et t' sont données pour les séquences d'essais de défaut aux bornes T60 et les séquences d'essais en discordance de phases OP1 et OP2, elles indiquent les limites inférieures et supérieures qu'il convient d'utiliser pour l'essai. Il convient que les valeurs de retard t_d et de temps t' lors de l'essai ne soient ni plus faibles que les limites inférieures respectives, ni plus élevées que les limites supérieures respectives.

NOTE 2 Un facteur de premier pôle k_{pp} égal à 1,5 est spécifié pour couvrir les conditions de défaut limitées aux transformateurs avec X_0/X_1 supérieur à 3,2 (par exemple transformateurs reliés non effectivement à la terre dans les réseaux à neutre relié effectivement à la terre, ou cas de transformateurs avec un côté relié effectivement à la terre et l'autre côté connecté à des réseaux à neutre relié non effectivement à la terre). La TTR spécifiée couvre également les cas de défauts en ligne triphasés avec des réseaux à neutre relié effectivement à la terre (k_{pp}= 1,3), où le couplage entre phases peut entraîner un facteur d'amplitude de 1,76. Par conséquent, il y a lieu que la fenêtre de durée d'arc pour les réseaux à neutre relié effectivement à la terre soit démontrée pour T10 (voir 6.102.10.2.2.1).

6.104.7 Tension de rétablissement à fréquence industrielle

La tension de rétablissement à fréquence industrielle du circuit d'essai peut être indiquée en pourcentage de la tension de rétablissement à fréquence industrielle spécifiée ci-après. Elle ne doit pas être inférieure à 95 % de la valeur spécifiée et doit être maintenue pendant au moins 0,3 s.

Pour les circuits d'essais synthétiques, les détails et les tolérances figurent dans la CEI 62271-101.

Pour les séquences d'essais de court-circuit fondamentales de 6.106, la tension de rétablissement à fréquence industrielle doit être fixée comme suit, compte tenu de la valeur minimale de 95 % indiquée ci-dessus:

a) Pour les essais en triphasé d'un disjoncteur tripolaire, la valeur moyenne de la tension de rétablissement à fréquence industrielle est égale à la tension assignée U_r du disjoncteur divisée par $\sqrt{3}$.

   Il convient que la tension de rétablissement à fréquence industrielle de l'un quelconque des pôles ne diffère pas de plus de 20 % de la valeur moyenne à la fin du temps durant lequel elle est maintenue.

   Pour les réseaux mis effectivement à la terre, il doit être vérifié qu'une régénération diélectrique insuffisante sur un pôle ne conduit pas à une durée d'arc plus longue et donc à une défaillance éventuelle. L'essai monophasé (6.108) doit être utilisé comme démonstration.

b) ~~Pour les essais en monophasé d'un disjoncteur tripolaire, la tension de rétablissement à fréquence industrielle est égale au produit de la valeur phase-terre $U_r/\sqrt{3}$ par le facteur de premier pôle (1,3 ou 1,5); la tension de rétablissement à fréquence industrielle peut être ramenée à $U_r/\sqrt{3}$ après une durée égale à une période de la fréquence assignée.~~

   Pour les essais en monophasé d'un disjoncteur tripolaire, la tension de rétablissement à fréquence industrielle doit être égale au produit de la valeur phase-terre $U_r/\sqrt{3}$ par le facteur de premier pôle qui coupe (1,2, 1,3 ou 1,5); la tension de rétablissement à fréquence industrielle peut être ramenée à $U_r/\sqrt{3}$ après une durée égale à une période de la fréquence assignée.

c) Pour un disjoncteur unipolaire, la tension de rétablissement à fréquence industrielle est égale à la tension assignée U_r du disjoncteur.

La tension de rétablissement à fréquence industrielle doit être mesurée entre les bornes du pôle, dans chaque phase du circuit d'essai. Sa valeur efficace est déterminée sur l'oscillogramme au cours de l'intervalle de temps compris entre une demi-période et une période de la fréquence d'essai après l'extinction finale de l'arc comme indiqué à la Figure 44. On doit mesurer la distance verticale (respectivement V_1, V_2 et V_3) entre la crête de la seconde demi-onde et une ligne droite tracée entre les crêtes des demi-ondes précédentes et suivantes et cette distance (divisée par $2\sqrt{2}$ et multipliée par le coefficient d'étalonnage convenable) donne la valeur efficace de la tension de rétablissement à fréquence industrielle enregistrée.

6.105 Procédure d'essai en court-circuit

6.105.1 Intervalle de temps entre les essais

Les essais fondamentaux en court-circuit et, s'il y a lieu, en défaut proche en ligne comprennent les séries de séquences d'essais spécifiés en 6.106 et 6.109.

Les intervalles de temps entre les manœuvres individuelles d'une séquence d'essais doivent être les intervalles de temps de la séquence de manœuvres assignée du disjoncteur, indiqués en 4.104, mais tenant compte du 6.105.3, sous réserve de la disposition suivante:

A cause de limitation du laboratoire d'essais, il peut ne pas être possible d'obtenir l'intervalle de temps de 15 s, 1 min ou 3 min de la séquence de manœuvres assignée. Dans de tels cas, l'intervalle peut être porté à 10 min, l'essai restant valable; il se peut même que des intervalles plus longs que 10 min soient nécessaires. Un intervalle de temps prolongé ne doit pas être dû à une manœuvre défectueuse du disjoncteur. L'intervalle de temps réel entre les manœuvres doit être noté dans le rapport d'essais. S'il est plus grand que 10 min, la raison d'un tel retard doit être enregistrée dans le rapport d'essais.

Dans le cas des disjoncteurs ayant une séquence de manœuvres assignée de O – t – CO – t' – CO où t' peut avoir différentes valeurs, l'essai peut être effectué avec l'intervalle de temps t' le plus court. L'essai est considéré couvrir toutes les séquences de manœuvres assignées avec des intervalles de temps t' supérieurs. Cela rend possible la combinaison des essais pour réaliser les séquences assignées de manœuvres 4.104 a) et b). L'intervalle de temps réel doit être enregistré.

6.105.2 Application d'une source d'énergie auxiliaire aux déclencheurs d'ouverture – Essais de coupure

La source d'énergie auxiliaire doit être appliquée aux déclencheurs d'ouverture après le début du court-circuit, mais si cela est impossible à cause des limites du laboratoire d'essais, elle peut être appliquée avant le début du court-circuit (sous réserve que les contacts ne commencent pas leur course avant le début du court-circuit).

6.105.3 Application d'une source d'énergie auxiliaire aux déclencheurs d'ouverture – Essais d'établissement-coupure

~~Au cours des essais d'établissement-coupure, la source d'énergie auxiliaire ne doit pas être appliquée aux déclencheurs d'ouverture avant que le disjoncteur n'ait atteint sa position de fermeture. Au cours des cycles de manœuvres de fermeture-ouverture de la séquence d'essais T100s (voir 6.106.4), la source d'énergie ne doit pas être appliquée avant qu'au moins une demi-période ne se soit écoulée depuis l'instant de fermeture des contacts. Il est admis de retarder l'ouverture du disjoncteur pour que la composante apériodique ne dépasse pas la valeur admissible, mais la durée de fermeture-ouverture doit demeurer le plus près possible de la durée de fermeture-ouverture telle que définie en 3.7.143.~~

Au cours des essais d'établissement-coupure, la source d'énergie auxiliaire ne doit pas être appliquée aux déclencheurs d'ouverture avant que le disjoncteur n'ait atteint sa position de fermeture. Au cours de manœuvres de fermeture-ouverture de la séquence d'essais en court-circuit, la source d'énergie ne doit pas être appliquée avant qu'au moins une demi-période ne se soit écoulée depuis l'instant où les contacts se touchent. La durée de fermeture-ouverture doit rester aussi proche que possible de la durée de fermeture-ouverture minimale (voir note de 3.7.143) mais il est permis de retarder l'ouverture du disjoncteur de telle façon que la composante apériodique à la séparation des contacts soit dans les limites autorisées.

6.105.4 Accrochage à la fermeture sur court-circuit

Un disjoncteur est accroché quand les contacts dans lesquels circule le courant principal ont atteint une position de fermeture stable et complète et que cette position est maintenue jusqu'à un déclenchement intentionnel, mécanique ou électrique. A moins que le disjoncteur ne soit équipé d'un déclencheur sous courant de fermeture, ou d'un dispositif équivalent, on doit vérifier qu'il s'accroche correctement, sans hésitation exagérée lorsqu'il y a une décroissance négligeable de la composante périodique du courant au cours de la fermeture.

La capacité du disjoncteur à s'accrocher en fermeture sur court-circuit peut être vérifiée dans la séquence d'essais T100s (voir 6.106.4) ou dans l'essai de vérification de fermeture (voir 6.102.4.1). Pendant cet essai, les exigences suivantes s'appliquent:

– pour les essais triphasés de disjoncteur tripolaire, il convient de choisir l'angle de fermeture pour que la crête du courant établi soit appliquée au pôle le plus éloigné du dispositif de commande;

– en cas d'essai monophasé, il convient de veiller à contraindre le pôle le plus éloigné du mécanisme, de la même manière que pour un essai triphasé, par rapport à la tension appliquée au pôle et au courant dans le pôle.

Si les caractéristiques du laboratoire d'essais sont telles qu'il est impossible de réaliser la séquence d'essais T100s dans les limites spécifiques de tension appliquée indiquées en 6.104.1, on doit répéter l'essai à une tension réduite en utilisant un circuit d'essai donnant le pouvoir de fermeture assigné en court-circuit, avec une décroissance négligeable de la composante périodique.

Plusieurs méthodes peuvent être utilisées pour déterminer qu'un disjoncteur a fermé avec accrochage, par exemple

– par un enregistrement adéquat du déplacement des contacts auxiliaires ou principaux;
– par vérification visuelle de la position accrochée après l'essai de fermeture;
– par l'enregistrement de l'action du dispositif de détection de l'accrochage (par exemple un microcontact installé sur le dispositif de commande de façon adéquate).

La méthode employée pour vérifier l'efficacité de l'accrochage doit être enregistrée dans le rapport d'essais.

6.106 Séquences d'essais de court-circuit fondamentales

Les séries d'essais en court-circuit fondamentales doivent comprendre les séquences d'essais T10, T30, T60, T100s et T100a, suivant ce qui est spécifié ci-après.

Les courants coupés ne peuvent pas s'écarter des valeurs spécifiées de plus de 20 % en ce qui concerne les valeurs spécifiées pour les séquences d'essais T10 et T30 et de 10 % pour la séquence d'essais T60.

La valeur de crête du courant de court-circuit au cours des essais de coupure des séquences d'essais T100s, T100s(b) et T100a ne doit pas dépasser 110 % du pouvoir de fermeture assigné en court-circuit du disjoncteur.

NOTE Pour les cas mentionnés en 6.106.4, il peut être nécessaire de séparer les essais d'établissement et de coupure de la séquence T100s. Dans ce cas, la partie limitée aux essais d'établissement est désignée T100s(a) et celle des essais de coupure T100s(b).

Pour faciliter les essais, il est permis de supprimer les manœuvres de fermeture avant toute manœuvre d'ouverture lors des séquences d'essais T10, T30, T60. Les intervalles de temps entre les manœuvres de coupure doivent être les intervalles de temps de la séquence de manœuvres assignée du disjoncteur (voir 6.105.1).

6.106.1 Séquence d'essais T10

La séquence d'essais T10 se compose de la séquence de manœuvres assignée à 10 % du pouvoir de coupure assigné en court-circuit avec une composante apériodique à la séparation des contacts inférieure à 20 % et d'une tension de rétablissement transitoire et à fréquence industrielle telles que spécifiées en 6.104.5.5 et 6.104.7 (voir également les Tableaux 24, 25, 26 et 27).

6.106.2 Séquence d'essais T30

La séquence d'essais T30 se compose de la séquence de manœuvres assignée à 30 % du pouvoir de coupure assigné en court-circuit avec une composante apériodique à la séparation des contacts inférieure à 20 % et d'une tension de rétablissement transitoire et à fréquence industrielle telles que spécifiées en 6.104.5.4 et 6.104.7 (voir également les Tableaux 24, 25, 26 et 27).

6.106.3 Séquence d'essais T60

La séquence d'essais T60 se compose de la séquence de manœuvres assignée à 60 % du pouvoir de coupure assigné en court-circuit avec une composante apériodique à la séparation des contacts inférieure à 20 % et d'une tension de rétablissement transitoire et à fréquence industrielle telles que spécifiées en 6.104.5.3 et 6.104.7 (voir également les Tableaux 24, 25, 26 et 27).

6.106.4 Séquence d'essais T100s

La séquence d'essais T100s se compose de la séquence de manœuvres assignée à 100 % du pouvoir de coupure assigné en court-circuit en tenant compte de 6.104.3, avec une tension de rétablissement transitoire et à fréquence industrielle telles que spécifiées en 6.104.7 (voir également les Tableaux 24, 25, 26 et 27) et 100 % du pouvoir de fermeture assigné en court-circuit en tenant compte de 6.104.2, et une tension appliquée telle que spécifiée en 6.104.1.

Pour cette séquence d'essais, le pourcentage de composante apériodique à la séparation des contacts ne doit pas dépasser 20 % de la composante périodique.

Lors de l'exécution des essais monophasés sur un pôle de disjoncteur tripolaire, ou lorsque les caractéristiques de la station d'essais sont telles qu'il est impossible de réaliser la séquence d'essais T100s en respectant les limites spécifiées de la tension appliquée en 6.104.1, du courant établi en 6.104.2, du courant coupé en 6.104.3 et de la tension de rétablissement transitoire et à fréquence industrielle en 6.104.5.2 et 6.104.7 en prenant également en considération 6.105.3 et 6.105.4, les essais d'établissement et de coupure de la séquence d'essais T100s peuvent être faits séparément. Le courant de court-circuit dans les manœuvres d'établissement séparées doit être maintenu pendant une période d'au moins 100 ms. Les procédures d'essai sont celles qui suivent.

6.106.4.1 Cas où la constante de temps de la composante apériodique du circuit d'essai est égale à la valeur spécifiée

Lorsque la constante de temps de la composante apériodique du circuit d'essai est égale à la valeur spécifiée en 4.101.2, la méthode alternative pour effectuer la séquence d'essais T100s décrite ci-dessus est la suivante:

a) essais d'établissement, séquence d'essais T100s(a)

   La séquence C – *t*' – C ou C – *t*'' – C doit être effectuée à la place de la séquence de manœuvre assignée, respectivement O – *t* – CO – *t*' – CO ou CO – *t*'' – CO, avec lors de la première manœuvre de fermeture, un courant symétrique égal au pouvoir de coupure assigné et lors de la seconde fermeture, le pouvoir de fermeture assigné selon 6.104.2. La première manœuvre de fermeture doit être effectuée à la tension appliquée définie en 6.104.1;

b) essais de coupure, séquence d'essais T100s(b)

   Ces manœuvres de fermeture, détaillées en a), doivent être suivies de O – *t* – CO – *t*' – CO ou de CO – *t*'' – CO pour les séquences de manœuvre assignées respectivement O – *t* -CO – *t*' – CO ou CO – *t*'' – CO, à 100 % du pouvoir de coupure assigné et avec une tension de rétablissement transitoire et à fréquence industrielle selon les exigences de 6.104.5.2 et 6.104.7.

Pendant cette séquence d'essais, on applique les exigences suivantes:

– la maintenance n'est pas admise entre a) et b);
– la seconde manœuvre de a) peut être omise si une des manœuvres de fermeture de b) est telle que le pouvoir de fermeture assigné est atteint;
– pour les essais synthétiques, la CEI 62271-101 s'applique.

6.106.4.2 Cas où la constante de temps de la composante apériodique du circuit d'essai est inférieure à la valeur spécifiée

Lorsque la constante de temps de la composante apériodique du circuit d’essai est inférieure à la valeur spécifiée en 4.101.2, la méthode alternative décrite ci-dessus pour effectuer la séquence d’essai T100s est la suivante:

a) essais d’établissement, séquences d’essais T100s(a)

   Une seule manœuvre de fermeture avec le pouvoir de fermeture assigné selon 6.104.2 doit être effectuée. Cette manœuvre de fermeture peut être effectuée à tension réduite avec les tolérances indiquées en 6.104.2;

b) essais de coupure, séquence d’essais T100s(b)

   Cette manœuvre de fermeture doit être suivie de O – *t* – CO – *t*' – CO ou de CO – *t*'' – CO pour les séquences de manœuvres assignées respectivement O – *t* – CO – *t*' – CO ou CO – *t*'' – CO, à 100 % du pouvoir de coupure assigné en court-circuit, à la tension appliquée spécifiée en 6.104.1 et avec une tension de rétablissement transitoire et à fréquence industrielle selon 6.104.5.2 et 6.104.7 Dans cette seconde partie, une des manœuvres de fermeture doit être telle que soit établi un courant symétrique égal au pouvoir de coupure assigné en court-circuit.

NOTE Du fait que la constante de temps de la composante apériodique du circuit d’essai est plus faible que la valeur spécifiée utilisée pour le pouvoir de coupure assigné en court-circuit, il sera nécessaire que la valeur symétrique du courant pendant a) soit plus grande que la valeur assignée. De même, pendant b), la crête de courant, déjà vérifiée pendant a), sera plus faible que le pouvoir de fermeture assigné en court-circuit.

Pendant cette séquence d’essais, on applique les exigences suivantes:

– la maintenance n’est pas admise entre a) et b);
– pour les essais synthétiques, la CEI 62271-101 s’applique.

6.106.4.3 Constante de temps de la composante apériodique du circuit d'essai supérieure à la valeur spécifiée

Lorsque la constante de temps de la composante apériodique du courant délivré par le circuit d'essai est supérieure à la valeur spécifiée définie en 4.101.2, la méthode alternative de réalisation de la séquence d'essais T100s, décrite précédemment, est définie comme suit:

a) La séquence O – *t* – CO – *t*' – CO ou CO – *t*'' – CO doit être effectuée, respectivement pour les séquences de manœuvres assignées O – *t* – CO – *t*' – CO ou CO – *t*'' – CO, avec 100 % du pouvoir de coupure assigné en court-circuit sous la tension appliquée spécifiée en 6.104.1 et avec la tension transitoire de rétablissement et la tension de rétablissement à fréquence industrielle spécifiées en 6.104.5.2 et 6.104.7. Pendant cette séquence, une des manœuvres de fermeture doit être telle que le disjoncteur établisse un courant symétrique égal au pouvoir de coupure assigné en court-circuit, et l'autre manœuvre de fermeture doit être faite avec la pleine valeur du courant asymétrique. Etant donné que la constante de temps de la composante apériodique du circuit d'essai est plus grande que la valeur spécifiée en 4.101.2, la valeur de crête du courant pendant la fermeture asymétrique sera plus grande que la valeur assignée du courant établi en court-circuit. Par suite, la manœuvre de fermeture peut être réalisée en synchronisant l'ordre par rapport à l'onde de tension de manière à obtenir la valeur de crête requise du courant établi en court-circuit. La performance de la procédure d'essai a) est cependant soumise à l’accord du constructeur.

NOTE 1 Etant donné que la valeur de crête du courant est supérieure pendant la fermeture avec courant asymétrique, il n'est pas exigé de manœuvre séparée de fermeture avec la valeur de crête du courant établi en court-circuit suivant 6.104.2.

b) En variante, la séquence a) peut être effectuée avec une première manœuvre de fermeture avec établissement d'un courant symétrique égal au pouvoir de coupure assigné en court-circuit et une seconde manœuvre de fermeture à vide, c’est-à-dire, O – *t* – CO – *t*' – O ou CO – *t*'' – O respectivement pour les séquences de manœuvres assignées O – *t* – CO – *t*' – CO ou CO – *t*'' – CO, avec 100 % du pouvoir de coupure assigné en court-circuit sous la tension appliquée spécifiée en 6.104.1 et avec la tension transitoire de rétablissement et la tension de rétablissement à fréquence industrielle spécifiées en 6.104.5.2 et 6.104.7.

Dans ce cas, la démonstration de la capacité du disjoncteur à effectuer la séquence de manœuvres assignée sera faite en répétant la séquence d’essais a) avec les exigences correspondantes, et avec un courant symétrique inférieur au pouvoir de coupure assigné en court-circuit, tel que la valeur de crête du courant établi en court-circuit soit obtenue pendant une des manœuvres de fermeture. Pendant cette séquence répétée, les manœuvres de fermeture peuvent être faites sous tension réduite, avec les limites définies en 6.104.2.

NOTE 2 Dans la mesure où la capacité d'un disjoncteur à fermer avec la valeur de crête du courant établi en court-circuit est démontrée pendant la séquence répétée, il n'est pas exigé de manœuvre séparée de fermeture avec la valeur de crête du courant établi assigné en court circuit suivant 6.104.2.

Pendant cette séquence d'essais, ce qui suit s'applique:

– lorsque la séquence b) est adoptée, il est permis d'effectuer une remise en état de l'appareil avant de répéter la séquence de manœuvres assignée;
  – dans le cas d'essais synthétiques la CEI 62271-101 s’applique.

6.106.4.4 Décroissance significative de la composante périodique du circuit d’essai

Lorsque la décroissance de la composante périodique du circuit d’essai est significative, il peut être impossible d’effectuer la séquence de manœuvre assignée sans appliquer des contraintes excessives au disjoncteur. Dans ce cas, il est permis d’effectuer séparément les essais d’établissement et de coupure de la séquence d’essais T100s comme suit, à condition que la constante de temps de la composante périodique du circuit d’essai, correspondant à la décroissance de la composante périodique, soit au moins trois fois plus longue que la constante de temps de la composante apériodique spécifiée du système pour lequel le disjoncteur en essai est destiné à être utilisé:

a) Essais d’établissement, séquence d’essais T100s(a)

   C – t' – C dans le cas d’une séquence de manœuvres assignée O – t – CO – t' – CO, C – t'' – C dans le cas d’une séquence de manœuvres assignée CO – t'' – CO avec le courant établi spécifié en 6.104.2 et la tension appliquée spécifiée en 6.104.1. Pour l’intervalle de temps entre les essais individuels, 6.105.1 s’applique.

b) Essais de coupure, séquence d’essais T100s(b)

   La procédure d’essai dépend de la séquence de manœuvres assignée.

   – Dans le cas d’une séquence de manœuvres assignée O – t – CO – t' – CO, les manœuvres de fermeture de la séquence d’essais T100s(a) doivent être suivies de la séquence d’essais O – t – CO – t' – CO à 100 % du pouvoir de coupure assigné en court-circuit spécifié en 6.104.3 et avec une tension transitoire de rétablissement et une tension de rétablissement à fréquence industrielle spécifiées en 6.104.5.2 et 6.104.7. Pour l’intervalle de temps entre les essais individuels, 6.105.1 s’applique.

     La séquence de manœuvres O – t – CO (partie initiale de la séquence de manœuvres assignée O – t – CO – t' – CO) peut être démontrée par deux essais. Dans ce cas, les considérations suivantes s’appliquent:

     Lors du premier essai, la première manœuvre d’ouverture doit être essayée à 100 % du pouvoir de coupure assigné en court-circuit spécifié en 6.104.3 et avec une tension transitoire de rétablissement et une tension de rétablissement à fréquence industrielle spécifiées en 6.104.5.2 et 6.104.7. Les manœuvres suivantes de fermeture et d’ouverture doivent être essayées avec un courant établi et une tension appliquée ou un courant coupé, une tension transitoire de rétablissement et une tension de rétablissement à fréquence industrielle aussi proches que possible des valeurs spécifiées pour la séquence d’essais T100s.

     Lors du second essai, un cycle de manœuvres CO supplémentaire doit être effectué avec la manœuvre d’ouverture à 100 % du courant assigné de court-circuit spécifié en 6.104.3 et avec une tension transitoire de rétablissement et une tension de rétablissement à fréquence industrielle spécifiées en 6.104.5.2 et 6.104.7. Ce cycle de manœuvres CO doit être précédé d'une manœuvre d'ouverture à vide pour compléter la séquence de manœuvres O – t – CO. Pour la manœuvre C, les dispositions de 6.104.1 et 6.104.2 peuvent être omises, cependant, le courant établi et la tension appliquée doivent être conformes autant que possible aux valeurs spécifiées.

Le cycle de manœuvres CO (dernière partie de la séquence de manœuvres assignée O – t – CO – t' – CO) est démontré par une autre manœuvre CO, où la manœuvre d'ouverture doit être effectuée à 100 % du courant assigné de court-circuit spécifié en 6.104.3 et avec une tension transitoire de rétablissement et une tension de rétablissement à fréquence industrielle spécifiées en 6.104.5.2 et 6.104.7. Pour la manœuvre C, les dispositions de 6.104.1 et 6.104.2 peuvent être omises, cependant, le courant établi et la tension appliquée doivent être conformes autant que possible aux valeurs spécifiées.

– Dans le cas d'une séquence de manœuvres assignée CO – t'' – CO, les manœuvres de fermeture de la séquence d'essais T100s(a) doivent être suivies de la séquence d'essais CO – t'' – CO à 100 % du pouvoir de coupure assigné en court-circuit spécifié en 6.104.3 et avec une tension transitoire de rétablissement et une tension de rétablissement à fréquence industrielle spécifiées en 6.104.5.2 et 6.104.7. Pour l'intervalle de temps entre les essais individuels, 6.105.1 s'applique. Pour les deux manœuvres C, les dispositions de 6.104.1 et 6.104.2 peuvent être omises, cependant, le courant établi et la tension appliquée doivent être conformes autant que possible aux valeurs spécifiées.

  – Lorsqu'une manœuvre de fermeture de la séquence d'essais T100s(b) satisfait aux exigences de a) ci-dessus, les manœuvres de fermeture de la séquence d'essais T100s(a) peuvent être omises. Pour la séquence d'essais T100s(b), il peut être nécessaire d'effectuer une synchronisation de la fermeture, afin de ne pas dépasser les contraintes à appliquer au disjoncteur. Si nécessaire, il est possible d'utiliser un disjoncteur auxiliaire. Si, en raison de l'incohérence de la durée d'ouverture ou de fermeture, les valeurs d'essais spécifiées ne peuvent pas être satisfaites, il est permis d'alimenter les déclencheurs à leur tension maximale pour la manœuvre; dans ce cas, les dispositions de 6.102.3.1 relatives à la tension d'alimentation des dispositifs d'ouverture et de fermeture sont omises.

Aucune remise en état n'est permise entre les séquences d'essais T100s(a) et T100s(b). L'accord du constructeur est nécessaire lorsque cette procédure d'essai conduit à des contraintes qui, en pratique, dépassent les limites spécifiées dans le Tableau B.1.

6.106.5 Séquence d'essais T100a

La séquence d'essais T100a ne s'applique qu'aux disjoncteurs pour lesquels l'intervalle de temps qui est égal à la durée d'ouverture minimale T_{op} du disjoncteur, déclarée par le constructeur, plus la durée du relais de protection, est tel que la composante apériodique à l'instant de séparation des contacts est supérieure à 20 %. La composante apériodique à la séparation des contacts est déterminée par l'équation suivante:

$$\%\,\mathrm{dc} = 100 \times \mathrm{e}^{\frac{-(T_{\mathrm{op}}+T_{\mathrm{r}})}{\tau}}$$

où

% dc:	pourcentage de la composante apériodique à la séparation des contacts;
T_{op}:	durée d'ouverture minimale déclarée par le constructeur;
T_{r}:	durée du relais de protection (0,5 cycle; 10 ms pour 50 Hz et 8,3 ms pour 60 Hz);
τ	constante de temps de la composante apériodique du courant assigné en court-circuit (45 ms, 60 ms, 75 ms ou 120 ms; voir 4.101.2).

La séquence d'essais T100a se compose de trois manœuvres d'ouverture à des intervalles t' conformément à 6.105.1 à 100 % du pouvoir de coupure assigné en court-circuit avec les critères d'asymétrie requis donnés en 6.106.6 et la tension transitoire de rétablissement et la tension de rétablissement à fréquence industrielle présumées spécifiées en 6.104.5.2 et 6.104.7 (voir aussi 6.104.6 et l'Annexe P; pour les références aux tableaux, voir 6.104.5.2).

De plus, selon les paramètres d'essais qui sont obtenus, un essai individuel peut couvrir plusieurs valeurs assignées si les critères d'asymétrie applicables pour chacune des valeurs assignées avec leurs tolérances respectives sont rencontrés (pour les détails, voir I.2.1).

NOTE Le seul changement d'un déclencheur d'ouverture ou de fermeture ne constitue pas un mécanisme d'entraînement alternatif. Si la durée d'ouverture du disjoncteur est exclusivement réduite en raison de l'utilisation d'un déclencheur à action plus rapide, il convient de vérifier si le pourcentage de la composante apériodique, indiqué aux Tableaux 15 à 22 pour ce déclencheur, est toujours couvert ou non par les essais réels. Si un pourcentage plus élevé de la composante apériodique est nécessaire, il suffit de répéter la séquence d'essais T100a uniquement; le reste des essais de type reste valable, à condition que le déclencheur soit soumis aux essais conformément aux paragraphes et aux normes correspondants.

6.106.6 Critères d'asymétrie

Les critères d'asymétrie suivants doivent être obtenus lorsqu'on effectue T100a:

– amplitude de la dernière alternance de courant;
– durée de la dernière alternance de courant;
– composante apériodique au zéro de courant (paramètre contrôlant di/dt et les paramètres de TTR suivants).

Plusieurs paramètres d'essais doivent être simultanément reproduits lors de T100a, de façon à obtenir une coupure valable. Ces critères sont différents selon que les essais sont réalisés avec un circuit d'essais directs ou par une méthode d'essais synthétiques.

Le pourcentage présumé de composante apériodique au zéro de courant doit être:

– mesuré à partir d'un essai d'étalonnage du courant présumé, ou
– calculé à partir du pourcentage de composante apériodique à la séparation des contacts au cours de l'essai et à partir de la constante de temps de la composante apériodique du circuit d'essai. La constante de temps de la composante apériodique du circuit d'essai doit être mesurée à partir de l'oscillogramme d'un essai d'étalonnage de courant présumé dans la région correspondant à l'instant de séparation des contacts.

L'instant d'établissement du court-circuit au cours des essais réels et au cours de l'essai d'étalonnage de courant présumé doit être comparable (dans la limite de ±10°).

Pour l'essai d'étalonnage de courant présumé, il est nécessaire de prolonger la durée du courant d'au moins une alternance de courant supplémentaire, afin de pouvoir mesurer précisément le pourcentage présumé de la composante apériodique au zéro de courant prévu.

NOTE Le pourcentage de la composante apériodique au zéro de courant au cours des essais réels peut également être calculé à l'aide de la formule suivante:

$$p_0 = p_{\mathrm{cs}} \times \mathrm{e}^{\left(-\frac{t_\mathrm{a}}{\tau}\right)}$$

où

p_0 est la composante apériodique au zéro de courant au cours de l'essai réel;

p_{cs} est la composante apériodique à la séparation des contacts mesurée au cours de l'essai réel;

t_a est la durée d'arc;

τ est la constante de temps de la composante apériodique du circuit d'essai mesurée au cours de l'essai d'étalonnage de courant présumé.

Les critères d'asymétrie applicables pour chaque méthode particulière d'essais sont décrits en 6.106.6.1 et 6.106.6.2.

6.106.6.1 Essais en triphasé

6.106.6.1.1 Amplitude du courant d'essai et durée de la dernière alternance de courant

Les critères donnés en 6.102.10.2.1.2 b) pour les essais en monophasé s'appliquent aussi à la phase ayant la composante apériodique maximale (grande alternance ou grande alternance allongée). L'amplitude et la durée des alternances de courant dans les deux autres phases sont automatiquement rencontrées à l'intérieur de tolérances raisonnables.

NOTE Il convient que la durée présumée de la grande alternance allongée soit déterminée à partir d'un essai d'étalonnage du courant présumé. Il est recommandé que la durée de la grande alternance de courant obtenue lors de l'essai d'étalonnage du courant présumé et qui sera allongée durant l'essai de coupure réel soit à l'intérieur des limites données en 6.102.10.2.1.2 b). Si la durée de cette alternance rencontre les critères donnés en 6.102.10.2.1.2 b), alors la durée résultante de la grande alternance allongée durant l'essai de coupure réel est automatiquement rencontrée à l'intérieur de tolérances raisonnables.

Le disjoncteur peut modifier la forme de la dernière alternance de courant au-delà des critères donnés en 6.102.10.2.1.2 b). Pour de tels cas, la forme de l'alternance du courant présumé doit être préalablement déterminée à partir d'un essai d'étalonnage du courant présumé. L'essai est réputé valable si l'instant de l'établissement du courant est à l'intérieur d'un intervalle de ±10° par rapport à celui obtenu lors de l'essai d'étalonnage du courant présumé.

6.106.6.1.2 Pourcentage de la composante apériodique au zéro de courant

Le pourcentage de la composante apériodique au zéro de courant pour la phase ayant la composante apériodique la plus élevée doit être inférieur ou égal à (voir Note 1) ceux donnés aux Tableaux 15 à 22. La composante apériodique résultante dans les deux autres phases est automatiquement rencontrée.

Pour l'essai d'étalonnage de courant, il est recommandé de prolonger la durée du courant d'au moins une alternance de courant supplémentaire, afin de pouvoir mesurer précisément le pourcentage présumé de la composante apériodique au zéro de courant prévu.

Si le pourcentage de la composante apériodique au zéro du courant dans une opération d'ouverture est supérieur (voir Note 1) à la valeur spécifiée, il convient que le disjoncteur soit réputé avoir satisfait à la séquence d'essais T100a, pour autant que la moyenne des pourcentages de la composante apériodique au zéro du courant obtenus lors des opérations d'ouverture pour la séquence d'essais n'excède pas la valeur spécifiée du pourcentage de la composante apériodique au zéro du courant. Dans tous les essais de la séquence d'essais, la composante apériodique au zéro du courant ne doit pas être supérieure à 110 % de la valeur spécifiée.

NOTE 1 La composante apériodique au zéro du courant contrôle le di/dt et la TTR résultants. Une composante apériodique inférieure au zéro du courant produit un di/dt supérieur ainsi qu'une amplitude et un du/dt supérieurs de la TTR. Une tolérance de –5 % est donnée à l'Annexe B.

NOTE 2 Il peut être difficile de mesurer avec une précision suffisante la composante apériodique au zéro du courant, car le disjoncteur peut modifier la forme de la dernière alternance de courant. La composante apériodique au zéro du courant peut être déterminée à partir des résultats obtenus d'un essai précédent d'étalonnage du courant présumé. L'essai est réputé valable si l'instant de l'établissement du courant est à l'intérieur d'un intervalle de ±10° par rapport à celui obtenu lors de l'essai d'étalonnage du courant présumé.

6.106.6.2 Essais en monophasé

6.106.6.2.1 Amplitude du courant d'essai et durée de la dernière alternance de courant

Les critères donnés en 6.102.10.2.1.2 b) doivent être satisfaits.

Le disjoncteur peut modifier la forme de la dernière alternance de courant au-delà des critères donnés en 6.102.10.2.1.2 b). Pour de tels cas, la forme de l'alternance du courant présumé doit être préalablement déterminée à partir d'un essai d'étalonnage du courant présumé. L'essai est réputé valable si l'instant de l'établissement du courant est à l'intérieur d'un intervalle de ±10° par rapport à celui obtenu lors de l'essai d'étalonnage du courant présumé.

6.106.6.2.2 Pourcentage de la composante apériodique au zéro de courant

Le pourcentage de la composante apériodique au zéro de courant doit être inférieur ou égal à (voir Note 1) ceux donnés aux Tableaux 15 à 22.

Si le pourcentage de la composante apériodique au zéro du courant dans une opération d'ouverture est supérieur (voir Note 1) à la valeur spécifiée, le disjoncteur doit être considéré comme ayant satisfait à la séquence d'essais T100a, pour autant que la moyenne des pourcentages de la composante apériodique au zéro du courant obtenus lors des opérations d'ouverture pour la séquence d'essais n'excède pas la valeur spécifiée du pourcentage de la composante apériodique au zéro du courant. Dans tous les essais de la séquence d'essais, le niveau asymétrique au zéro du courant ne doit pas être supérieur à 110 % de la valeur spécifiée.

NOTE 1 La composante apériodique au zéro du courant contrôle le di/dt et la TTR résultants. Une composante apériodique inférieure au zéro du courant produit un di/dt supérieur ainsi qu'une amplitude et un du/dt supérieurs de la TTR. Une tolérance de –5 % est donnée à l'Annexe B.

NOTE 2 Il peut être difficile de mesurer avec une précision suffisante la composante apériodique au zéro du courant, car le disjoncteur peut modifier la forme de la dernière alternance de courant. La composante apériodique au zéro du courant peut être déterminée à partir des résultats obtenus d'un essai précédent d'étalonnage du courant présumé. L'essai est réputé valable si l'instant de l'établissement du courant est à l'intérieur d'un intervalle de ±10° par rapport à celui obtenu lors de l'essai d'étalonnage du courant présumé.

6.106.6.3 Procédures d'ajustement des paramètres d'essais

Plusieurs paramètres d'essais peuvent être modifiés pour rencontrer les critères d'asymétrie. Par exemple:

a) L'amplitude et la durée de la dernière alternance de courant peuvent être ajustées par plusieurs moyens, tels que:
   - l'augmentation ou la diminution de la valeur efficace du courant de court-circuit utilisé lors de l'essai (à ±10 % de la valeur demandée);
   - la modification de la fréquence du courant d'essai à l'intérieur des tolérances données en 6.103.2;
   - l'utilisation d'un déclenchement anticipé ou d'un déclenchement retardé, le déclenchement anticipé étant permis seulement si le déplacement des contacts débute après l'établissement du courant;

NOTE 1 Le déclenchement anticipé est défini comme étant l'alimentation du déclencheur d'ouverture avant le temps prévu dans des conditions de service (avant la durée minimale de fonctionnement du relais de protection: 0,5 cycle). Le déclenchement anticipé peut signifier que l'alimentation du déclencheur d'ouverture est effectuée avant l'établissement du courant. Cela est permis seulement si le déplacement des contacts débute après l'établissement du courant.

NOTE 2 Le déclenchement retardé est défini comme étant l'alimentation du déclencheur d'ouverture après le temps prévu dans des conditions de service (après la durée minimale de fonctionnement du relais de protection: 0,5 cycle).

   - la modification de l'instant d'établissement du courant (composante apériodique initiale).

b) Les paramètres de la TTR peuvent être compensés en changeant le facteur d'amplitude du circuit de réglage de la TTR. L'Annexe P donne la méthode de calcul pour déterminer les paramètres de la TTR présumée applicables durant des conditions de défauts asymétriques.

6.107 Essais au courant critique

6.107.1 Cas d'application

Ces essais sont des essais en court-circuit complémentaires des séquences d'essais de court-circuit fondamentales couvertes par 6.106 et ne sont applicables qu'aux disjoncteurs qui ont un courant critique. On considère que c'est le cas si une des durées d'arc minimales obtenues au cours des séquences d'essai T10, T30 ou T60 est supérieure d'un demi-cycle, ou plus, par rapport aux durées d'arc minimales des séquences d'essais adjacentes. Dans le cas d'essais triphasés, les durées d'arc des trois phases doivent être prises en compte.

6.107.2 Courant d'essai

Si applicable, le fonctionnement du disjoncteur vis-à-vis du courant critique doit faire l'objet de deux séquences d'essais.

Le courant d'essai pour ces deux séquences d'essais doit être égal à la moyenne du courant coupé spécifié pour la séquence d'essais pendant laquelle les durées d'arc augmentées ont été obtenues (voir 6.107.1) et du courant coupé:

a) spécifié pour la séquence d’essais avec le courant immédiatement supérieur, pour une séquence d'essais, et
b) spécifié pour la séquence d'essais avec le courant immédiatement inférieur, pour l'autre séquence d'essais.

Dans le cas de durées d'arc prolongées pendant la séquence T10, les essais au courant critique doivent être effectués avec un courant égal à 20 % du pouvoir de coupure assigné en court-circuit pour une séquence d'essais et avec un courant égal à 5 % du pouvoir de coupure assigné en court-circuit pour l'autre séquence d'essais.

6.107.3 Séquence d'essais au courant critique

La séquence d'essais au courant critique se compose de la séquence de manœuvres assignée avec le courant défini en 6.107.2 et avec un pourcentage de composante apériodique à la séparation des contacts inférieur à 20 %. La tension de rétablissement transitoire et à fréquence industrielle doit être celle qui est associée à la séquence d’essais fondamentale en court-circuit ayant le courant coupé spécifié immédiatement supérieur au courant critique.

La séquence d'essais au courant critique peut être effectuée sur un disjoncteur remis en état.

6.108 Essais de défaut monophasé ou de double défaut à la terre

6.108.1 Cas d'application

Les disjoncteurs doivent être capables de couper les courants de court-circuit sur une phase qui peuvent se produire dans deux différents cas:

– cas de défauts monophasés dans des réseaux à neutre effectivement à la terre ou,
– cas de doubles défauts à la terre dans des réseaux à neutre non effectivement à la terre, c’est-à-dire avec des défauts à la terre sur deux phases différentes, l’un se produisant en amont du disjoncteur et l'autre en aval du disjoncteur.

En fonction de la condition de mise à la terre du neutre du réseau dans lequel le disjoncteur sera utilisé, du type d'organe de manœuvre (unipolaire ou tripolaire) et selon que le disjoncteur a été testé en essais T100s monophasés ou triphasés, des essais de coupure monophasés additionnels peuvent être nécessaires (voir Figure 45).

Ces essais ont pour but de démontrer

– que le disjoncteur est capable d'interrompre un courant de défaut en unipolaire avec les paramètres appropriés;

– que le fonctionnement des disjoncteurs ayant un organe de manœuvre tripolaire, et munis d’un déclencheur d’ouverture commun aux trois pôles, n'est pas influencé défavorablement par l'apparition d'efforts non équilibrés produits dans le cas d'un courant de défaut monophasé.

L’essai de coupure d’un défaut monophasé doit être effectué sur un pôle d’extrémité, conduisant à la contrainte maximale sur le mécanisme d’accouplement entre pôles, alors que l’essai de coupure d’un double défaut à la terre peut être effectué sur n’importe quel pôle.

NOTE Si deux essais de coupure monophasée sont effectués pour un disjoncteur d’usage général et muni d’un organe de manœuvre tripolaire, les essais peuvent être effectués sur deux phases différentes afin de ne pas trop contraindre le pôle en essai.

6.108.2 Courant d'essai et tension de rétablissement

Le courant coupé et la tension de rétablissement pour les essais additionnels de coupure monophasée sont présentés à la Figure 45.

Le pourcentage de composante apériodique du courant coupé à la séparation des contacts ne doit pas dépasser 20 % de la composante périodique. La tension transitoire de rétablissement doit satisfaire aux exigences des points a) et b) de 6.104.5.1 avec les valeurs normalisées dérivées des Tableaux 1, 2, 3 et 4. Les valeurs à utiliser pour les essais de défaut monophasé et de double défaut à la terre sont données dans le Tableau 28 et sont marquées par l’indice (sp).

Tableau 28 – Paramètres de TTR pour les essais de défaut monophasé et de double défaut à la terre

Régime de neutre	Tension assignée					
	U_r < 100 kV TTR à 2 paramètres		$U_r \geq$ 100 kV TTR à 4 paramètres			
	$u_{C,sp}$	$t_{3,sp}$	$u_{1,sp}$	$t_{1,sp}$	$u_{c,sp}$	$t_{2,sp}$
Effectivement à la terre	$k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$t_3 \times u_{c,sp} / u_c$	$0,75 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$t_1 \times u_{1,sp} / u_1$	$k_{af} \times u_{1,sp} / 0,75$	$\cancel{4 \times t_{1,sp}}$ [a]
Non effectivement à la terre	$k_{af} \times \sqrt{2} \times U_r$		$0,75 \times \sqrt{2} \times U_r$			

[a] 4 × $t_{1,\ sp}$ pour les tensions assignées comprises entre 100 kV et 800 kV inclus, 3 × $t_{1,\ sp}$ pour les tensions assignées supérieures à 800 kV.

Les autres paramètres sont reliés à $u_{1,sp}$, $u_{c,sp}$, $t_{1,sp}$ et $t_{3,sp}$ comme défini en 6.104.5.1 pour la séquence d’essais T100. Si nécessaire, on peut mettre à profit les dispositions de 6.104.5.2 relatives aux limitations dues aux stations d’essais.

6.108.3 Séquence d'essais

La séquence d'essais, pour chacun des deux cas de défaut spécifiés, doit comprendre un seul essai de coupure.

La durée d'arc pendant la manœuvre de coupure ne doit pas être plus courte que la valeur suivante t_a:

$$t_a \geq t_{a100s} + 0,7 \times T/2$$

où

t_{a100s} – est le minimum des durées d'arc du premier pôle qui coupe pendant les trois manœuvres de coupure de la séquence d'essais T100s, si la séquence d'essais de défaut aux bornes T100s est faite en triphasé;

– est la durée d'arc minimale de la séquence d'essais de défaut aux bornes T100s, si la séquence d'essais T100s est faite en monophasé.

T est la durée d'une période à fréquence industrielle.

Si la durée d'arc minimale dans les conditions d'essais de défaut monophasé ou de double défaut à la terre est plus courte que la durée d'arc minimale de la séquence d'essais de défaut aux bornes T100s de plus de 0,1 × T, l'essai peut être effectué à une durée d'arc plus courte, d'après la formule suivante:

$$t_a \geq t_{\text{arc min single phase}} + 0{,}9 \times T/2$$

où:

$t_{\text{arc min single phase}}$ est la durée d'arc minimale dans les conditions d'essais de défaut monophasé ou de double défaut à la terre ;

T est la durée d'une période à fréquence industrielle.

NOTE Il n'est pas nécessaire de déterminer la durée d'arc minimale pour la coupure de défaut monophasé ou de double défaut à la terre. Cependant, le constructeur peut montrer qu'il est possible d'obtenir une durée d'arc minimale plus courte que celle du T100s dans ces conditions. Les essais peuvent ensuite être effectués, comme indiqué ci-dessus, avec cette durée d'arc minimale plus courte.

Pour réduire le nombre d'essais, il est permis de remplacer les deux essais applicables par un seul essai, sous réserve que les deux conditions d'essais soient respectées simultanément. Cette possibilité est permise seulement avec l'accord du constructeur.

6.109 Essais de défaut proche en ligne

6.109.1 Cas d'application

Les essais de défaut proche en ligne sont des essais de court-circuit complémentaires des séquences d'essais de court-circuit fondamentales couvertes par 6.106. Ces essais doivent être faits pour déterminer la capacité d'un disjoncteur à couper des courants de court-circuit dans des conditions de défaut proche en ligne, caractérisées par une tension transitoire de rétablissement qui est la combinaison d'une composante côté alimentation et d'une composante côté ligne.

~~Les essais de défaut proche en ligne ne sont applicables qu'aux disjoncteurs de classe S2 prévus pour être directement raccordés à des lignes aériennes, quel que soit le type de réseau du côté alimentation, et ayant une tension assignée supérieure ou égale à 15 kV et un pouvoir de coupure assigné en court-circuit supérieur à 12,5 kA.~~

Les essais de défaut proche en ligne sont requis pour les disjoncteurs de classe S2 prévus pour être directement raccordés à des lignes aériennes, quel que soit le type de réseau du côté alimentation, et ayant une tension assignée supérieure ou égale à 15 kV et inférieure à 100 kV et un pouvoir de coupure assigné en court-circuit supérieur à 12,5 kA. Des essais de défauts proches en ligne sont également exigés pour tous les disjoncteurs prévus pour être directement raccordés à des lignes aériennes et dont la tension assignée est égale ou supérieure à 100 kV et le pouvoir de coupure assigné en court-circuit supérieur à 12,5 kA.

6.109.2 Courant d'essai

Le courant d'essai doit tenir compte des impédances côté alimentation et côté ligne. L'impédance côté alimentation doit être celle correspondant approximativement à 100 % du pouvoir de coupure assigné en court-circuit I_{sc} et à la valeur phase-terre de la tension assignée U_r.

Des valeurs normalisées d'impédance côté ligne sont spécifiées et correspondent à une réduction de la composante périodique du courant coupé assigné en court-circuit de:

– 90 % (L_{90}) et 75 % (L_{75}) pour les disjoncteurs de tension assignée égale ou supérieure à 48,3 kV;
– 75 % (L_{75}) pour les disjoncteurs de tension assignée supérieure ou égale à 15 kV et inférieure à 48,3 kV.

Lors d'un essai, la longueur de ligne représentée sur le côté charge du disjoncteur peut être différente de la longueur de ligne correspondant aux courants égaux à 90 % et 75 % du pouvoir de coupure assigné en court-circuit.

Pour les tensions assignées supérieures ou égales à 48,3 kV, il est admis de s'écarter de ces longueurs théoriques de –20 % à 0 % pour les essais à 90 % du pouvoir de coupure assigné en court-circuit et de ±20 % pour les essais à 75 % du pouvoir de coupure assigné en court-circuit.

Pour les tensions assignées supérieures ou égales à 15 kV et inférieures à 48,3 kV, il est admis de s'écarter de cette longueur théorique de –20 % à 0 % pour les essais à 75 % du pouvoir de coupure assigné en court-circuit.

Ces tolérances de longueur de ligne donnent les écarts suivants possibles des courants de court-circuit:

– L_{90} avec un écart de 0 %: I_L = 90 % de $I_{sc;}$
– L_{90} avec un écart de –20 %: I_L = 92 % de $I_{sc;}$
– L_{75} avec un écart de +20 %: I_L = 71 % de $I_{sc;}$
– L_{75} avec un écart de 0 %: I_L = 75 % of I_{sc};
– L_{75} avec un écart de –20 %: I_L = 79 % de $I_{sc.}$

Pour le cas indiqué en 6.109.4, point c), une autre séquence d'essais (L_{60}) à 60 % du pouvoir de coupure assigné en court-circuit est exigée. Il est admis de s'écarter de cette longueur théorique de $\pm$ 20 %. Il en résulte les valeurs possibles suivantes du courant de court-circuit:

– L_{60} avec un écart de +20 %: I_L= 55 % de $I_{sc;}$
– L_{60} avec un écart de –20 %: I_L = 65 % de $I_{sc.}$

Pour plus d'information, voir l'Annexe J et l'Article L.3.

6.109.3 Circuit d'essai

Le circuit d'essai doit être monophasé et comprendre un circuit d'alimentation et un circuit côté ligne (voir Figures 46, 47 et 48). Les exigences fondamentales sont données en 4.105.

Concernant le temps de retard du côté alimentation et du côté ligne et les exigences de TTRI (voir 4.102.1), deux exigences principales sont spécifiées et doivent être distinguées:

a) côté alimentation: avec temps de retard (t_d) et sans TTRI;
côté ligne: avec temps de retard (t_{dL});

b1) côté alimentation: avec TTRI;
côté ligne: avec temps de retard (t_{dL});

b2) côté alimentation: avec temps de retard (t_d);
côté ligne: avec temps de retard ~~négligeable~~ retard inférieur à 100 ns (t_{dL}).

~~La représentation de la TTRI du côté alimentation peut être négligée si l'oscillation de tension côté ligne a un temps de retard négligeable (voir 6.104.5.2). Une oscillation de tension avec~~

~~un temps de retard côté ligne inférieur à 100 ns est considérée comme étant un retard négligeable.~~

La représentation de la TTRI du côté alimentation peut être négligée si on utilise une oscillation de tension côté ligne avec un temps de retard inférieur à 100 ns.

La Figure 16b montre la détermination du retard côté ligne dans le cas d'une vitesse d'accroissement non linéaire. La tangente à la TTR côté ligne tracée en parallèle à la ligne passant par 0,2 × u_L et 0,8 × u_L coupe la ligne de zéro au temps t_{dL}.

~~NOTE 1 Dans le cas d'utilisation d'un circuit d'alimentation sans TTRI et un temps de retard négligeable côté ligne, dans les limites de la spécification mais proche de 100 ns, en fonction des caractéristiques assignées du disjoncteur la tension aux bornes du disjoncteur au temps t_i peut être inférieure dans une certaine mesure à celle qui serait obtenue avec un circuit d'alimentation avec TTRI et un temps de retard côté ligne.~~

NOTE 1 (Vide)

Prenant en compte ce qui précède, trois types de circuits d'essais caractérisés par leurs temps de retard peuvent être utilisés:

– circuit SLF a): côté alimentation avec un temps de retard (t_d) et côté ligne avec un temps de retard (t_{dL}) (voir A.4.1); circuit de la Figure 46;
– circuit SLF b1): côté alimentation avec TTRI et côté ligne avec un temps de retard (t_{dL}) (voir A.4.1); circuit de la Figure 47;
– circuit SLF b2): côté alimentation avec un temps de retard (t_d) et côté ligne un temps de retard ~~négligeable~~ retard inférieur à 100 ns (t_{dL}) (voir A.4.3); circuit de la Figure 48.

Le circuit a) doit être utilisé seulement dans le cas où il n'y a pas d'exigences de TTRI. Le circuit b2) peut être utilisé en remplacement du circuit b1) sauf si les deux bornes ne sont pas électriquement identiques (par exemple si une capacité additionnelle est utilisée comme indiqué dans la Note 4 de 6.109.3).

Pour choisir le circuit d'essai, voir l'organigramme Figure 49.

Les autres caractéristiques des circuits d'alimentation et côté ligne doivent être en accord avec les explications et les calculs donnés dans l'Annexe A.

Le cas échéant, un disjoncteur de tension assignée supérieure à 800 kV peut faire l'objet d'un essai avec une ligne ayant un retard inférieur à 100 ns et une impédance d'onde de 450 Ω (voir 6.104.5.1). Si le disjoncteur échoue pendant cette procédure d'essai au bout d'un temps correspondant à la première crête de TTRI, l'essai peut être répété, le circuit d'essai requis ayant la TTRI spécifiée et une ligne ayant une impédance d'onde de 330 Ω et le retard spécifié (t_{dL}) Dans les deux cas, il n'est pas requis d'effectuer T100s et T100a avec des circuits reproduisant la TTRI assignée.

Si les exigences de tension rétablie du côté alimentation ne peuvent pas être respectées en raison des limitations du laboratoire d'essais, un défaut du temps de retard côté alimentation peut être compensé par un accroissement de l'amplitude de la tension côté ligne. La valeur accrue $u_{L,mod}$* est calculée comme suit (voir aussi les Figures 16 et 50):

$$t_d < t'_d \le t_L \qquad u_{L,mod}^* = u_L^* + L_f \times \text{VATR} \times (t'_d - t_d)$$

$$t_d < t_L \le t'_d \qquad u_{L,mod}^* = u_L^* + L_f \times \text{VATR} \times (t_L - t_d)$$

où

VATR est la pente exigée de la vitesse de rétablissement de tension côté alimentation (kV/µs) ;

L_f est le facteur de courant de défaut en ligne I_L/I_{sc} (0,9 ou 0,75 ou 0,6);

t_d est le temps de retard exigé côté alimentation (µs);

t'_d est le temps de retard réel côté alimentation (µs);

t_L est le temps jusqu'à la crête de tension u_L* de la tension transitoire côté ligne (µs);

u_L* est la valeur exigée de la tension rétablie, en valeur crête, côté ligne (kV);

$u_{L,mod}$* est la valeur ajustée de la tension rétablie, en valeur crête, côté ligne (kV).

Si les essais sont effectués sur un disjoncteur avec une borne à la terre, comme cela peut être le cas en essais synthétiques, des mesures ou des calculs de facteurs de répartition de tension entre le côté ligne et le côté alimentation doivent être faits. L'élément le plus contraint par l'oscillation de tension côté ligne est le moins contraint par l'oscillation côté alimentation. Il est reconnu que la contrainte la plus importante est celle qui est produite par la ligne. Les facteurs de répartition de tension doivent être comme suit:

– essais par éléments séparés: facteurs calculés ou mesurés sur l'élément situé du côté ligne;
– essais sur plusieurs éléments: facteurs calculés ou mesurés sur les éléments situés du côté ligne. Il faut s'assurer que les facteurs appliqués ne contraignent pas excessivement le disjoncteur en raison de la répartition de tension entre les éléments essayés. Une nouvelle mesure ou calcul peut être nécessaire pour la portion de disjoncteur à essayer.

La mesure de la TTR présumée doit être faite avec la ligne reliée au circuit réel de manière à prendre en compte les effets dus aux diviseurs de tension, aux capacités parasites et aux inductances du circuit d'essai.

Une capacité additionnelle peut être introduite soit côté ligne ou côté alimentation du disjoncteur, soit en parallèle au disjoncteur pour ajuster les temps de retard des différentes parties du circuit.

NOTE 2 Le terme «réel» s'entend comme distinct de la valeur nominale (90 %, 75 % ou 60 %); l'utilisation du courant présumé coupé en court-circuit conformément à 6.104.3 n'est pas proscrite.

NOTE 3 Si une capacité additionnelle est ajoutée pour ajuster le temps de retard de la ligne à la valeur normalisée donnée dans le Tableau 8, la vitesse d'accroissement de tension côté ligne va atteindre sa valeur normalisée ($du_L/dt = - s \times I_L$) après la réduction due au retard introduit par cette capacité additionnelle.

NOTE 4 Lorsque la capacité de coupure du disjoncteur n'est pas suffisante pour obtenir la coupure d'un défaut proche en ligne, une capacité additionnelle en tête de ligne ou en parallèle aux éléments de coupure d'un disjoncteur peut être utilisée, à la fois pendant l'essai et en service. De cette manière, la contrainte sur le disjoncteur est réduite. Il convient que la valeur et l'emplacement de cette capacité additionnelle soient indiqués dans le rapport d'essais.

Dans le cas de capacités additionnelles de valeur élevée, l'impédance d'onde de la ligne et le temps de retard côté ligne peuvent sembler être diminués, en raison de l'effet de cette capacité additionnelle. Cependant, la valeur correcte de l'impédance d'onde de la ligne elle-même (par avance ajustée en accord avec les valeurs normalisées données dans le Tableau 8) reste inchangée. Dans la mesure où la période de réduction de l'effet de retard dû à la capacité additionnelle peut être plus longue que le temps à la première crête de la tension de rétablissement côté ligne, la valeur plus faible de la vitesse d'accroissement de tension peut être mal interprétée comme étant due à une valeur diminuée de l'impédance d'onde de ligne. Par conséquent, les valeurs du temps de retard et de l'impédance d'onde évaluées pour la ligne reliée à la capacité additionnelle ne sont pas significatives pour l'essai.

Dans le rapport d'essais, il est recommandé d'indiquer la TTR spécifiée se rapportant aux caractéristiques assignées du disjoncteur et, à des fins de comparaison, la tension présumée du circuit d'essai utilisé.

6.109.4 Séquences d'essais

Les essais de défaut proche en ligne doivent être des essais monophasés. La série de séquences d'essais est spécifiée ci-dessous. Chacune d'entre elles se compose de la séquence de manœuvres assignée. Pour faciliter les essais, les manœuvres de fermeture peuvent être effectuées à vide.

Le circuit d'essai doit être en accord avec 6.109.3.

Pour ces séquences d'essais, le pourcentage de composante apériodique à l'instant de séparation des contacts doit être inférieur à 20 % de la composante périodique.

Les séquences d'essais correspondant aux courants d'essais suivant 6.109.2 sont comme suit:

a) Séquence d'essais L_{90}

   Au courant de L_{90} donné en 6.109.2 et avec la tension transitoire de rétablissement présumée appropriée.

   Cette séquence d'essais est obligatoire uniquement pour les disjoncteurs de tension assignée supérieure ou égale à 48,3 kV.

b) Séquence d'essais L_{75}

   Au courant de L_{75} donné en 6.109.2 et avec la tension transitoire de rétablissement présumée appropriée.

c) Séquence d'essais L_{60}

   Au courant de L_{60} donné en 6.109.2 et avec la tension transitoire de rétablissement présumée appropriée.

Cette séquence d'essais est obligatoire seulement pour les disjoncteurs de tension assignée supérieure ou égale à 48,3 kV et seulement si la durée d'arc minimale obtenue pendant la séquence d'essais L_{75} dépasse d'un quart de cycle, ou plus, la durée d'arc minimale déterminée pendant la séquence d'essais L_{90}.

6.109.5 Essais de défaut proche en ligne avec une source d'essai de court-circuit de puissance réduite

Lorsque la puissance de court-circuit maximale disponible dans la station d'essais n'est pas suffisante pour réaliser les essais de défaut proche en ligne sur un pôle complet de disjoncteur, on peut effectuer des essais par éléments séparés (voir 6.102.4.2).

Les essais de défaut proche en ligne peuvent également être effectués à une tension à fréquence industrielle réduite, les dispositions de 6.109.3 étant moins sévères. Ces dispositions doivent être respectées le mieux possible et, pour la tension transitoire de rétablissement, au moins jusqu'à trois fois le temps spécifié pour la première crête côté ligne. Cette méthode est utilisée si les essais fondamentaux de court-circuit indiqués en 6.106 ont été satisfaisants et en supposant que la contrainte diélectrique sur le disjoncteur au voisinage de la valeur de crête de la TTR est indépendante des contraintes appliquées immédiatement après le passage par zéro du courant. Cette méthode d'essai peut également être utilisée en combinaison avec les essais par éléments séparés.

Si les essais de défaut proche en ligne sont effectués avec une tension réduite à fréquence industrielle et si la durée d'arc maximale selon 6.102.10.2.2.1 obtenue dans les conditions de défaut proche en ligne, et pour toute séquence d'essais, dépasse de plus de 2 ms celle qui a été obtenue lors de la séquence d'essais T100s, une manœuvre d'ouverture avec la durée d'arc maximale du défaut proche en ligne doit être effectuée en appliquant les conditions d'essais du défaut aux bornes T100s. Les paramètres de TTR pour cette manœuvre additionnelle peuvent être réduits aux valeurs correspondant à un facteur de premier pôle égal à 1,0 comme cela est habituel pour les essais de défaut proche en ligne. On considérera que le disjoncteur a réussi les essais de défaut proche en ligne uniquement, si le courant a été interrompu avec succès pendant cette manœuvre additionnelle d'ouverture.

6.110 Essais d'établissement et de coupure en discordance de phases

6.110.1 Circuit d'essai

Le facteur de puissance du circuit d'essai ne doit pas dépasser 0,15.

Les essais sont réalisés généralement avec un circuit d'essais monophasé. Par suite, ce paragraphe ne considère que la procédure d'essais monophasés.

NOTE Il est permis d'effectuer des essais triphasés en remplacement d'essais monophasés. Lorsque des essais triphasés sont effectués, il convient que la procédure d'essais fasse l'objet d'un accord entre le constructeur et l'utilisateur.

Il convient de disposer le circuit d'essai de telle façon que chaque côté du disjoncteur soit soumis à la moitié environ de la tension appliquée et de la tension de rétablissement (voir Figure 51).

S'il n'est pas possible d'adopter ce circuit dans la station d'essais, il est admis d'utiliser, avec l'accord du constructeur, deux tensions égales décalées de 120° au lieu de 180°, à condition que la tension totale aux bornes du disjoncteur corresponde à celle indiquée en 6.110.2 (voir Figure 52).

La réalisation d'essais avec mise à la terre d'une borne du disjoncteur n'est admise qu'avec l'accord du constructeur (voir Figure 53).

6.110.2 Tensions d'essais

Pour les tensions d'essai utilisées au cours des manœuvres de fermeture et d'ouverture, les éléments suivants s'appliquent:

a) pour les disjoncteurs destinés à être utilisés dans des réseaux à neutre relié effectivement à la terre, la tension appliquée et la tension de rétablissement à fréquence industrielle doivent avoir une valeur égale à 2,0/√3 fois la tension assignée;

b) pour les disjoncteurs destinés à être utilisés dans des réseaux à neutre relié non effectivement à la terre, la tension appliquée au cours de la manœuvre de fermeture doit avoir une valeur égale à 2,0/√3 fois la tension assignée et la tension de rétablissement à fréquence industrielle doivent avoir une valeur égale à 2,5/√3 fois la tension assignée.

La tension transitoire de rétablissement doit être conforme aux indications de 4.106.

6.110.3 Séquences d'essais

Les séquences d'essais à réaliser sont indiquées au Tableau 29. Pour les durées d'arc, voir 6.102.10.2.1 et 6.102.10.2.2.

Au cours des manœuvres d'ouverture de chaque séquence d'essais, la composante apériodique du courant coupé à la séparation des contacts doit être inférieure à 20 % de la composante périodique.

Pour la manœuvre de fermeture du cycle de fermeture-ouverture de la séquence d'essais OP2:

a) la tension appliquée doit être égale à $2U_r/\sqrt{3}$; afin de favoriser le bon déroulement des essais, la tension appliquée pour les disjoncteurs destinés à être utilisés dans des réseaux à neutre non effectivement à la terre, peut être augmentée jusqu'à $2,5U_r/\sqrt{3}$, avec l'accord du constructeur.

NOTE 1 Une tension à fréquence industrielle de 2,0 p.u. est spécifiée pour la fermeture, étant donné qu'il s'agit de la valeur la plus élevée à laquelle le premier pôle qui ferme (qui est soumis à des contraintes par la durée de préarc la plus longue) est normalement exposé.

~~NOTE 2 Des tensions à fréquence industrielle de 2,0 p.u. et 2,5 p.u. sont spécifiées pour la coupure, respectivement, dans les réseaux à neutre relié effectivement à la terre et dans les réseaux à neutre relié non effectivement à la terre, étant donné qu'elles couvrent la grande majorité des applications des disjoncteurs destinés à effectuer des manœuvres lors de discordances de phases (voir 8.103.3). L'angle de discordance de phases correspondant à 2,0 p.u. dans les réseaux à neutre relié effectivement à la terre est d'environ 105°, et l'angle de discordance de phases correspondant à 2,5 p.u. dans les réseaux à neutre relié non effectivement à la terre est d'environ 115°.~~

NOTE 2 Des tensions de rétablissement à fréquence industrielle correspondant à des facteurs de discordance de phases de 2,0 p.u. et 2,5 p.u. sont spécifiées pour la coupure, respectivement, dans les réseaux à neutre relié effectivement à la terre et dans les réseaux à neutre relié non effectivement à la terre, étant donné qu'elles couvrent la grande majorité des applications des disjoncteurs destinés à effectuer des manœuvres lors de discordances de phases (voir 8.103.3). L'angle de discordance de phases correspondant à 2,0 p.u. dans les réseaux à neutre relié effectivement la terre est d'environ 105° pour des tensions assignées allant jusqu'à 800 kV et d'environ 115° pour des tensions assignées supérieures à 800 kV. L'angle de discordance de phases correspondant à 2,5 p.u. dans les réseaux à neutre relié non effectivement à la terre est d'environ 115°. Toutefois, des valeurs d'angle supérieures sont satisfaites lorsque l'on considère d'autres facteurs tels que la non simultanéité des crêtes de tension, un k_{pp} inférieur (voir la CEI 62271-306 [4]).

b) la fermeture doit se produire dans les limites de ± 15° de la crête de la tension appliquée.

c) la fermeture doit produire un courant symétrique avec la durée de pré-amorçage la plus longue. Le courant établi doit être égal à la valeur assignée du courant établi en discordance de phases.

   1) si la durée de pré-amorçage lors d'un établissement à la crête de la tension appliquée est plus courte ou égale à un demi-cycle à la fréquence assignée, alors le courant établi peut être réduit à une valeur plus petite, mais pas inférieure à 1 kA ;

   2) si la durée de pré-amorçage lors d'un établissement à la crête de la tension appliquée ne dépasse pas un quart de cycle à fréquence assignée avec une tolérance de 20%, en raison des limitations des moyens d'essais, il est permis de remplacer le cycle de manœuvre CO de la séquence OP2 par la séquence de manœuvres suivante:

      – C sous la pleine tension;

      – CO avec C à vide

Tableau 29 – Séquences d'essais à effectuer pour vérifier les caractéristiques assignées en discordance de phases

Séquence d'essais	Séquence de manœuvres	Courant coupé en pour cent du pouvoir de coupure assigné en discordance de phases
OP1	O – O – O	30
OP2	CO – O – O ou en alternance C* – C**O – O – O C* = C sous pleine tension C** = C à vide	100

NOTE 1 Pour les disjoncteurs équipés de résistances de fermeture, la capacité thermique des résistances peut être essayée séparément.

NOTE 2 La séquence d'essais OP1 peut ne pas être effectuée sur les disjoncteurs dont les caractéristiques d'arc ne nécessitent pas les essais au courant critique de 6.107.1 pour un courant inférieur à celui associé à la séquence T10 de défaut aux bornes.

6.111 Essais d'établissement et de coupure de courants capacitifs

6.111.1 Cas d'application

Les essais d'établissement et de coupure de courants capacitifs sont applicables à tous les disjoncteurs auxquels une ou plusieurs des caractéristiques suivantes ont été assignées:

– pouvoir de coupure assigné de lignes à vide;

– pouvoir de coupure assigné de câbles à vide;

– pouvoir de coupure assigné de batterie unique de condensateurs;

– pouvoir de coupure assigné de batteries de condensateurs à gradins;

– pouvoir de fermeture assigné de batteries de condensateurs à gradins.

Les valeurs recommandées pour les pouvoirs assignés d'établissement et de coupure de courants capacitifs sont données au Tableau 9.

NOTE 1 La détermination des surtensions lors de l'enclenchement et de l'interruption de courants capacitifs n'est pas couverte par cette norme.

NOTE 2 Une note explicative concernant l'établissement et l'interruption de courants capacitifs est donnée en I.4.

6.111.2 Généralités

Les réallumages sont permis durant les essais d'établissement et de coupure de courants capacitifs. Deux classes de disjoncteurs sont définies selon leur performance relative au réamorçage:

– la classe C1: faible probabilité de réamorçage lors de l'interruption de courants capacitifs, tel que démontré par des essais de type spécifiques (6.111.9.2);
– la classe C2: très faible probabilité de réamorçage lors de l'interruption de courants capacitifs, tel que démontré par des essais de type spécifiques (6.111.9.1).

NOTE 1 Le niveau de probabilité est relié à la performance obtenue lors des séries d'essais de type.

NOTE 2 Les phénomènes qui surviennent suite à un réamorçage ou un réallumage ne sont pas représentatifs des conditions de service, étant donné que les circuits d'essais ne reproduisent pas de manière adéquate les conditions de tensions apparaissant suite à de tels événements.

Pour les essais en laboratoire, les lignes et les câbles peuvent être partiellement ou complètement remplacés par des circuits artificiels avec des éléments concentrés: condensateurs, réactances, résistances.

La fréquence du circuit d'essais doit être la fréquence assignée avec une tolérance de ±2 %.

NOTE 3 Des essais effectués à 60 Hz peuvent être considérés pour démontrer les caractéristiques de coupure à 50 Hz.

NOTE 4 Des essais effectués à 50 Hz peuvent être considérés pour démontrer les caractéristiques de coupure à 60 Hz sous réserve que, pendant les premières 8,3 ms, la tension aux bornes du disjoncteur ne soit pas inférieure à celle qui existerait dans un essai à 60 Hz à la tension spécifiée. Si des réamorçages surviennent après 8,3 ms, à une tension instantanée supérieure à celle qui apparaîtrait lors d'un essai à 60 Hz à la tension spécifiée, il convient que la série d'essais soit répétée à 60 Hz.

NOTE 5 La spécification du circuit d'essais peut être remplacée par une spécification de la tension de rétablissement.

6.111.3 Caractéristiques des circuits d'alimentation

Le circuit d'essais doit remplir les exigences suivantes:

a) les caractéristiques du circuit d'essais doivent être telles que la variation de tension à la fréquence industrielle, lors de l'établissement et de l'interruption du courant, soit inférieure à 2 % pour la séquence d'essais 1 (LC1, CC1 et BC1) et inférieure à 5 % pour la séquence d'essais 2 (LC2, CC2 et BC2). Lorsque la variation de tension est supérieure aux valeurs spécifiées, il est permis, en variante, d'effectuer les essais avec la tension de rétablissement spécifiée (6.111.10) ou des essais synthétiques.
b) l'impédance du circuit d'alimentation ne doit pas être trop basse au point que son courant de court-circuit excède le pouvoir de coupure assigné en court-circuit du disjoncteur.

Pour les essais d'établissement et de coupure de courants de lignes à vide, de câbles à vide, ou de batteries uniques de condensateurs, la tension transitoire de rétablissement présumée du circuit d'alimentation doit ne pas être plus sévère que la tension transitoire de rétablissement spécifiée en 6.104.5.2 pour la séquence d'essais en court-circuit T100.

Pour les essais de coupure de courants de batteries de condensateurs à gradins, la capacité du circuit d'alimentation et l'impédance entre les condensateurs du côté alimentation et du côté charge doivent être telles qu'elles donnent le pouvoir de fermeture assigné de batteries de condensateurs à gradins lors de l'essai à 100 % du pouvoir de coupure assigné de batteries de condensateurs à gradins.

NOTE 1 Si le disjoncteur est prévu pour être utilisé sur un réseau ayant une longueur appréciable de câbles du côté source d'alimentation, il convient d'utiliser un circuit d'alimentation comprenant cette capacité additionnelle associée.

NOTE 2 Pour les essais au pouvoir de coupure et de fermeture de batteries de condensateurs à gradins où des essais séparés d'établissement sont exécutés, on peut, pour les essais de coupure, choisir un circuit d'alimentation avec une capacité plus faible. Il convient toutefois de ne pas choisir une capacité trop faible afin que la tension transitoire de rétablissement du circuit d'alimentation ne dépasse pas celle qui est spécifiée pour la séquence d'essais en court-circuit de 6.104.5.2.

6.111.4 Mise à la terre du circuit d'alimentation

Pour les essais monophasés en laboratoire, l'une ou l'autre des bornes du circuit d'alimentation peut être mise à la terre. Toutefois, quand il est nécessaire d'assurer une répartition adéquate de la tension entre les éléments du disjoncteur, un autre point du circuit d'alimentation peut être mis à la terre.

Pour les essais en triphasé, la mise à la terre doit être indiquée ci-après:

a) pour les essais d'établissement et de coupure de courants de batteries de condensateurs, le point neutre du circuit d'alimentation doit être mis à la terre. Pour les batteries de condensateurs avec neutre mis effectivement à la terre, l'impédance homopolaire doit ne pas excéder le triple de l'impédance en séquence directe. Pour les batteries de condensateurs à neutre isolé, ce ratio n'est pas pertinent;
b) pour les essais d'établissement et de coupure de courants de lignes à vide et de câbles à vide, la mise à la terre du circuit d'alimentation doit correspondre, en principe, aux conditions de mise à la terre des circuits sur lesquels le disjoncteur sera utilisé:
   – pour les essais en triphasé d'un disjoncteur prévu pour utilisation dans des réseaux à neutre effectivement à la terre, le point neutre du circuit d'alimentation doit être mis à la terre et son impédance homopolaire doit ne pas excéder le triple de l'impédance en séquence directe;
   – pour les essais en triphasé d'un disjoncteur prévu pour utilisation dans des réseaux à neutre non-effectivement à la terre, le point neutre du circuit d'alimentation doit être isolé.

NOTE Pour des raisons de commodité de réalisation des essais, un autre circuit d'essais peut être utilisé à condition que le laboratoire d'essais puisse démontrer que des valeurs équivalentes de tensions de rétablissement seront obtenues. Par exemple, un circuit d'essais avec le neutre du circuit d'alimentation mis à la terre et une batterie de condensateurs à neutre isolé peuvent être remplacés, dans plusieurs cas, par un circuit d'essais dont le neutre du circuit d'alimentation est isolé et le neutre de la batterie de condensateurs mis à la terre.

De plus, il convient de porter une attention particulière à l'influence des condensateurs utilisés pour l'ajustement de la TTR du circuit d'alimentation sur les valeurs de la tension de rétablissement, particulièrement pour des courants capacitifs de faible amplitude. Le Tableau 32 donne les valeurs requises de la tension de rétablissement.

6.111.5 Caractéristiques du circuit capacitif à établir et à couper

Il y a trois possibilités:

a) essais en triphasé où, dans le cas d'essais d'établissement et de coupure de courants de lignes à vide ou de courants de câbles à vide, il est possible d'utiliser des lignes ou des câbles en parallèle respectivement ou de remplacer partiellement ou complètement la ligne ou le câble triphasé(e) réel(le) par des batteries de condensateurs concentrées. La capacité résultante en séquence directe doit être approximativement égale à deux fois les essais de capacité en séquence homopolaire représentant des câbles à ceinture à trois âmes pour les tensions assignées supérieures ou égales à 52 kV et trois fois la capacité en séquence homopolaire pour les tensions assignées inférieures à 52 kV;
b) essais en monophasé dans un circuit d'essai triphasé, avec deux phases du circuit capacitif reliées directement au circuit d'alimentation triphasé et une phase reliée au circuit d'alimentation par le pôle du disjoncteur en essai;

c) essais de laboratoire en monophasé, où dans le cas d’essais d'établissement et de coupure de courants de lignes à vide ou de courants de câbles à vide, il est permis de remplacer partiellement ou complètement les lignes ou les câbles réel(le)s respectivement par des batteries de condensateurs concentrées et d'utiliser tout couplage en parallèle des conducteurs de phases avec courant de retour par la terre ou par un conducteur.

Les caractéristiques du circuit capacitif doivent être telles qu'avec tous les dispositifs de mesurage nécessaires, y compris les diviseurs de tension, la chute de tension côté charge ne dépasse pas 10 % à la fin d'un intervalle de temps de 300 ms après l'extinction définitive de l'arc.

Lorsque le circuit d'essai n’est pas capable de fournir la tension de rétablissement pendant 300 ms, la capacité de tenue du disjoncteur doit être démontrée d'une autre façon. Cette démonstration peut être faite en effectuant un essai supplémentaire sans courant, en appliquant la tension de rétablissement requise, une période de la fréquence industrielle après la séparation des contacts. Par exemple, la tension de rétablissement demandée peut être obtenue en appliquant une tension à composante continue sur une borne et une tension à composante alternative sur l'autre borne pendant la durée requise. Il doit y avoir cinq applications de tensions dans chaque polarité. Lorsque les essais d’établissement et de coupure de courants capacitifs sont effectués en triphasé, cet essai diélectrique additionnel doit être effectué sur chacune des trois phases. La pression pour la coupure et l’isolement au cours de cet essai doit, si applicable, être celle spécifiée pour l’essai d’établissement et de coupure de courants capacitifs correspondant.

6.111.5.1 Essais d'établissement et de coupure de courants de lignes à vide et de courants de câbles à vide

Lorsqu'on utilise des condensateurs pour simuler les lignes aériennes ou des câbles, une résistance non inductive, dont la valeur n'est pas supérieure à 5 % de l'impédance capacitive, peut être raccordée en série avec les condensateurs. Des valeurs plus élevées peuvent influer exagérément sur la tension de rétablissement. Si, la résistance étant connectée, la valeur de crête du courant d'appel est encore trop élevée, une impédance alternative (par exemple du type LR) peut être utilisée à la place de la résistance, sous réserve que le courant et la tension à l'instant de la coupure, et la tension de rétablissement, ne diffèrent pas sensiblement des valeurs spécifiées.

Il faut être prudent lorsqu'on utilise de telles impédances, étant donné qu'elles peuvent causer une surtension après un réallumage, ce qui peut donner lieu à d'autres réallumages ou à des réamorçages.

NOTE Dans le cas d’essais d'établissement et de coupure de courants de câbles à vide, une courte ligne aérienne peut être utilisée en série avec un câble pour les essais, à condition que le courant de ligne à vide ne dépasse pas 1 % du courant de câble à vide.

6.111.5.2 Essais d'établissement et de coupure de batterie unique de condensateurs

Le neutre des condensateurs doit être isolé, sauf pour les tensions assignées égales ou supérieures à 52 kV; dans ce cas, les conditions de mise à la terre des condensateurs en essai doivent être les mêmes que lorsque les condensateurs sont en service si le disjoncteur est prévu pour être utilisé dans des réseaux à neutre effectivement à la terre.

NOTE Les performances relatives à la fermeture des batteries de condensateurs à gradins sont acquises lorsque:

– la valeur de crête du pouvoir de fermeture exigé est inférieure ou égale à la valeur assignée et

– la fréquence en essai du courant d'appel est supérieure ou égale à 77 % de la valeur assignée. L'application de cette règle est limitée aux fréquences inférieures à 6 000 Hz.

6.111.6 Forme d'onde du courant

Il convient que la forme d'onde du courant à interrompre soit aussi voisine que possible d'une sinusoïde. Cette condition est considérée comme remplie si le rapport de la valeur efficace du courant à la valeur efficace de la composante fondamentale ne dépasse pas 1,2.

Le courant à interrompre ne doit pas passer par zéro plus d'une fois par demi-période à fréquence industrielle.

6.111.7 Tension d'essai

Pour des essais directs en triphasé et pour des essais en monophasé avec le circuit capacitif à couper suivant la disposition du point b) de 6.111.5, la tension d'essai mesurée entre les phases au niveau du disjoncteur immédiatement avant l'ouverture ne doit pas être inférieure à la tension assignée U_r du disjoncteur.

Pour les essais directs en monophasé en laboratoire, la tension mesurée au niveau du disjoncteur immédiatement avant l'ouverture ne doit pas être inférieure au produit de $U_r/\sqrt{3}$ par le facteur de tension capacitif k_c suivant:

a) **1,0** pour les essais correspondant au service normal dans les réseaux à neutre à la terre sans influence mutuelle significative entre phases voisines du circuit capacitif, typiquement des batteries de condensateurs à neutre mis à la terre et des câbles à champ radial.

b) **1,2** pour les essais sur les câbles à ceinture et pour les essais d'établissement et de coupure de courants de lignes à vide suivant le point c) de 6.111.5, correspondant aux conditions normales de service dans les réseaux à neutre effectivement à la terre pour les tensions assignées égales ou supérieures à 52 kV.

c) **1,4** pour les essais correspondant à

   – la coupure dans les conditions normales de service dans des réseaux à neutre non effectivement à la terre;

   – la coupure de courants de batteries de condensateurs à neutre isolé.

   De plus, le facteur **1,4** s'applique pour les essais sur câbles à ceinture et pour les essais d'établissement et de coupure de courants de lignes à vide suivant le point c) de 6.111.5, correspondant aux conditions normales de service dans les réseaux à neutre effectivement à la terre pour les tensions assignées inférieures à 52 kV.

Lorsque la vérification du pouvoir de coupure de courants capacitifs en présence de défauts phase-terre ou de défauts biphasés à la terre est requise, les facteurs suivants s'appliquent (voir aussi 6.111.9.3 pour les courants d'essais).

d) **1,4** pour les essais correspondant à la coupure en présence de défauts monophasés ou biphasés à la terre dans un réseau à neutre effectivement à la terre ;

e) **1,7** pour les essais correspondant à la coupure dans les réseaux à neutre non effectivement à la terre en présence de défauts monophasés ou biphasés à la terre.

Pour les essais sur éléments séparés, la tension d'essai doit être choisie de façon à correspondre à l'élément le plus contraint du pôle de disjoncteur.

La tension d'essai à fréquence industrielle et la tension continue résultant de la charge résiduelle sur le circuit capacitif doivent être maintenues pendant une durée d'au moins 0,3 s après la coupure.

NOTE 1 Les facteurs de tension indiqués ci-dessus en b) et c) sont applicables aux lignes de construction monoterne. Les exigences relatives aux essais d'établissement et de coupure des lignes comportant plusieurs circuits ne peuvent être supérieures qu'à ces facteurs.

NOTE 2 Quand la non-simultanéité de séparation des contacts entre les différents pôles du disjoncteur dépasse un sixième de période de la fréquence assignée, il est recommandé d'accroître le facteur de tension ou d'effectuer seulement des essais en triphasé.

6.111.8 Courant d'essais

Les courants d'essai pour les diverses séquences d'essais doivent être définis en suivant les règles données dans la présente norme. Les valeurs préférentielles des courants capacitifs assignés sont spécifiées au Tableau 9. Elles sont choisies dans un but de normalisation et couvrent la majorité des applications types. Si des valeurs différentes sont nécessaires, toute valeur appropriée, pouvant être différente des valeurs préférentielles, peut être spécifiée comme valeur assignée.

6.111.9 Séquences d'essais

Les séquences d'essais de chaque série d'essais doivent être effectuées sur un spécimen sans aucune remise en état. Les abréviations suivantes s'appliquent:

- courant de lignes à vide, séquence d'essais 1 LC1
- courant de lignes à vide, séquence d'essais 2 LC2
- courant de câbles à vide, séquence d'essais 1 CC1
- courant de câbles à vide, séquence d'essais 2 CC2
- courant de batteries de condensateurs, séquence d'essais 1 BC1
- courant de batteries de condensateurs, séquence d'essais 2 BC2

Ces séquences d’essais peuvent être combinées afin de démontrer l’aptitude d’un disjoncteur à couvrir plusieurs applications ou caractéristiques assignées (par exemple LC et/ou CC et/ou BC). Si une telle méthode de combinaison est utilisée, les règles suivantes s’appliquent:

- La tension d’essai, telle que définie en 6.111.7, doit être égale à la valeur la plus élevée pour laquelle la performance du disjoncteur doit être démontrée.
- Les séquences d’essais et les courants d’essai doivent être comme suit:
  1) une séquence d’essais 2, couvrant toutes les séquences d’essais 2 de la combinaison, avec un courant représentant au moins 100 % des caractéristiques assignées du courant capacitif le plus élevé à démontrer;
  2) une séquence d’essais 1 avec un courant compris entre 10 % et 40 % des caractéristiques assignées du courant capacitif le plus élevé à démontrer;
  3) une séquence d’essais 1 pour chaque caractéristique assignée de courant capacitif plus faible, si la plage comprise entre 10 % et 40 % de cette caractéristique assignée n’est pas couverte par une séquence d’essais 1 précédente;
  4) toutes les autres exigences pour les séquences d’essais individuelles doivent également être satisfaites (par exemple le type et le nombre de manœuvres, de conditions de pression et de circuits d’essais). Lorsque des manœuvres CO sont spécifiées pour une application et des manœuvres O pour une application différente, les manœuvres CO sont considérées couvrir les manœuvres O si les conditions d’essais sont identiques.

NOTE L’exemple suivant est donné pour montrer comment ces règles sont appliquées sur les essais monophasés de classe C2 effectués sur un disjoncteur assigné pour 145 kV; le facteur de tension est supposé être le même pour toutes les caractéristiques assignées.

Si des caractéristiques assignées de courants de lignes à vide et de courants de câbles à vide sont attribuées, les essais suivants doivent être réalisés:

- une séquence d’essais 1 à la pression minimale de fonctionnement pour la manœuvre et la coupure, se composant de 48 manœuvres O; le courant doit couvrir 10 % à 40 % à la fois du pouvoir de coupure assigné de lignes à vide (50 A pour une tension assignée de 145 kV) et du pouvoir de coupure assigné de câbles à vide (160 A pour une tension assignée de 145 kV). Ainsi, le courant d’essai doit être compris entre 16 A et 20 A.
- une séquence d’essais 2 à la pression assignée pour la manœuvre et la coupure, se composant de 24 manœuvres O et de 24 cycles de manœuvres CO; le courant ne doit pas être inférieur au pouvoir de coupure assigné de lignes à vide (50 A pour une tension assignée de 145 kV) et au pouvoir de coupure assigné de câbles à vide (160 A pour une tension assignée de 145 kV). Ainsi, le courant doit être de 160 A ou plus.

Si, en plus, une caractéristique assignée de courants de batteries de condensateurs est aussi attribuée, et si les essais pour les trois caractéristiques assignées différentes sont à combiner, il convient de réaliser les essais suivants:

– en premier lieu, une séquence d'essais 2 à la pression assignée pour la manœuvre et la coupure, se composant de 120 cycles de manœuvres CO; il y a lieu que le courant ne soit pas inférieur au pouvoir de coupure assigné de lignes à vide (50 A pour une tension assignée de 145 kV), au pouvoir de coupure assigné de câbles à vide (160 A pour une tension assignée de 145 kV) et au pouvoir de coupure assigné de batterie unique de condensateurs (400 A pour toutes les tensions assignées). Ainsi, il convient que le courant soit de 400 A ou plus ;
– une séquence d'essais 1 à la pression minimale de fonctionnement pour la manœuvre et la coupure, se composant de 48 manœuvres O; il convient que le courant représente 10 % à 40 % du courant le plus élevé à démontrer, à savoir 400 A. Ainsi, il y a lieu que le courant soit compris entre 40 A et 160 A. Cette séquence d'essais peut couvrir aussi les exigences relatives à l'établissement et à la coupure de courants de câbles à vide; ainsi, il convient que le courant soit compris entre 40 A et 64 A ;
– une autre séquence d'essais 1 à la pression minimale de fonctionnement pour la manœuvre et la coupure, se composant de 48 manœuvres O; il convient que le courant soit compris entre 5 A et 20 A – dans le cas où la séquence d'essais 1 précédente a été effectuée avec un courant de 40 A à 64 A, comme expliqué ci-dessus, et si les conditions pour l'établissement et la coupure de courants de câbles à vide sont déjà satisfaites – ou entre 16 A et 20 A – dans le cas où cette deuxième séquence d'essais couvre à la fois les exigences du pouvoir de coupure de lignes à vide et de câbles à vide.

6.111.9.1 Conditions d'essais pour les disjoncteurs de classe C2

6.111.9.1.1 Séquences d'essais pour la classe C2

Les essais d'établissement et de coupure de courants capacitifs pour les disjoncteurs de classe C2 doivent être effectués après avoir réalisé, comme essais de conditionnement, la séquence d'essais T60 (T60 est reliée à la composante périodique du pouvoir de coupure assigné en court-circuit). Il y a lieu que le montage d'essais soit tel que la condition du disjoncteur ne soit pas perturbée entre les essais. Cependant, si ce n'est pas possible et que les règles de sécurité locales exigent la dépressurisation pour pouvoir avoir accès à la cellule d'essais, il est alors permis de diminuer la pression dans le disjoncteur à condition que le même gaz soit réutilisé lors du remplissage suivant du disjoncteur.

En variante, les essais de préconditionnement peuvent être effectués comme suit:

– même courant d'essai que la séquence d'essais T60;
– ~~essais à basse tension sans application de la TTR spécifiée~~ la tension d'essai doit être la tension phase-terre;
– ~~trois essais d'ouverture~~ l'établissement doit survenir dans les limites de ± 25° de la crête (sur une même phase pour les essais en triphasé) et doit être distribué de manière régulière dans les deux polarités;
– durées d'arc: les mêmes que celles obtenues lors de la séquence d'essais T60 ou celles annoncées par le constructeur pour la séquence d'essais T60;
– essais aux conditions de manœuvres assignées ou minimales.

NOTE 1 Pour des considérations pratiques, pour les disjoncteurs de tensions assignées inférieures à 52 kV, le constructeur peut choisir d'ajouter d'autres séquences d'essais à la séquence d'essais T60 comme essais de conditionnement.

NOTE 2 Si plusieurs essais d'établissement et de coupure de courants capacitifs sont effectués, par exemple, essais d'établissement et de coupure de courants de lignes à vide, de câbles à vide et de batteries de condensateurs sans aucune remise en état du disjoncteur, alors les essais de préconditionnement selon la séquence d'essais T60 ne doivent être effectués qu'une seule fois, et ce, avant tout essai d'établissement et de coupure de courants capacitifs.

Les essais d'établissement et de coupure de courants capacitifs doivent comprendre les séquences d'essais spécifiées au Tableau 30.

Tableau 30 – Séquences d'essais pour la classe C2

Séquence d'essais	Tension appliquée aux déclencheurs	Pression des fluides pour la manœuvre et la coupure	Courant d'essai en pourcentage du pouvoir de coupure assigné de courants capacitifs %	Type de manœuvre ou séquence de manœuvres
1: LC1, CC1et BC1	Tension maximale	Pression minimale	10 à 40	O
2: LC2, CC2et BC2	Tension maximale	Pression assignée	Non inférieur à 100	O et CO ou CO

NOTE 1 Les essais sont effectués avec la tension maximale des déclencheurs de façon à obtenir un meilleur contrôle lors des manœuvres d'ouverture.

NOTE 2 Pour des raisons de commodité de réalisation des essais, les cycles de manœuvres CO peuvent être effectués au cours de la séquence d'essais 1 (LC1, CC1 et BC1).

Pour les disjoncteurs dont les éléments de coupure sont scellés à vie, la pression minimale pour l'interruption est remplacée par la pression nominale pour l'interruption moins la chute de pression due aux fuites durant la vie de l'appareil. Pour les disjoncteurs à vide, les conditions de pression pour l'interruption ne sont pas applicables.

Pour les essais d'établissement-coupure, les contacts du disjoncteur doivent ne pas être séparés tant que subsistent des courants transitoires. Pour obtenir cela, le temps entre les manœuvres de fermeture et d'ouverture peut être ajusté mais doit demeurer le plus près possible de la durée de fermeture-ouverture telle que définie en 3.7.143.

Aucune charge appréciable ne doit subsister sur les circuits capacitifs avant les manœuvres d'établissement.

Pour les essais d'établissement et de coupure de batteries de condensateurs à gradins, le courant établi doit être égal au pouvoir de fermeture assigné de batteries de condensateurs à gradins avec une tolérance de $^{+10}_{-0}$ %. La tolérance sur la valeur inhérente du courant d'appel à la fermeture de batteries de condensateurs à gradins doit être de $^{+10}_{-0}$ %. Pour tous les essais d'établissement, les fermetures doivent survenir dans les limites de ±25° de la crête de la tension appliquée (sur une phase pour les essais en triphasé) et être également réparties sur les deux polarités.

Lorsque, dans le cas des essais d'établissement et de coupure de batteries de condensateurs à gradins et en raison des limitations de la station d'essais, il n'est pas possible de satisfaire aux exigences des cycles de manœuvre CO, il est alors permis pour satisfaire les exigences de la séquence d'essais 2 (BC2), d'effectuer une série séparée d'essais d'établissement suivie d'une série d'essais comportant des manœuvres CO.

Il est également permis de ne pas effectuer ces essais séparés en deux étapes successives, l'une se composant de toutes les manœuvres C et l'autre de toutes les manœuvres CO, mais de combiner les manœuvres C et CO, à condition que le nombre de manœuvres d'établissement soit supérieur ou égal au nombre de manœuvres de coupure à tout instant au cours de cet essai.

La série séparée d'essais d'établissement doit comprendre les conditions suivantes:

– le même nombre de manœuvres;

  lors des essais d'établissement et de coupure de batteries de condensateurs à gradins, le pouvoir de fermeture doit être au moins égal au pouvoir de fermeture assigné de batteries de condensateurs à gradins;

– la tension d'essai doit être la même que celle de la séquence d'essais 2 (BC2);

– la fermeture doit survenir dans les limites de 15° de la crête (sur une même phase pour les essais en triphasé) et doit être distribuée de manière régulière dans les deux polarités.

Après la série séparée de manœuvres d'établissement, les manœuvres CO doivent être réalisées avec des manœuvres de fermeture à vide. Les manœuvres CO doivent être effectuées sur le même pôle, sans remise en état intermédiaire.

NOTE 3 Lors de l'établissement et de la coupure de courants capacitifs, la manœuvre d'ouverture dans un cycle de manœuvres CO n'est pas influencée par le préamorçage lors de la manœuvre de fermeture précédente mais peut être affectée par le comportement du fluide utilisé pour l'interruption lors d'une manœuvre de fermeture (par exemple, différences locales de densité, turbulences, mouvement du fluide). Par conséquent, les manœuvres de fermeture et d'ouverture peuvent être séparées comme mentionné ci-dessus si on considère seulement les contraintes électriques, mais ne peuvent l'être si on considère la dynamique du fluide d'extinction. Une manœuvre de fermeture à vide précédant la manœuvre d'ouverture est donc nécessaire pour ces raisons.

L'amortissement présumé du courant d'appel lors de manœuvres de batteries de condensateurs à gradins, c'est-à-dire le rapport entre la deuxième crête et la première crête de même polarité, doit être égal ou supérieur à 0,75 pour les disjoncteurs de tensions assignées inférieures à 52 kV et égal ou supérieur à 0,85 pour les disjoncteurs de tensions assignées égales ou supérieures à 52 kV.

Pour les manœuvres d'ouverture, la durée d'arc minimale est déterminée en faisant varier le moment de la séparation des contacts lors de l'ouverture par intervalles d'environ 6°. Par cette méthode, il peut être nécessaire d'effectuer plusieurs essais pour démontrer la durée d'arc minimale et la durée d'arc maximale.

NOTE 4 Avec l'accord du constructeur, des tensions supérieures à la limite maximale des tensions d'alimentation des déclencheurs peuvent être utilisées durant ces essais de façon à obtenir des durées d'ouverture et de fermeture stables.

Si une durée d'arc maximale est obtenue au lieu de la durée d'arc minimale visée, l'essai est valable et doit être inclus dans le nombre total d'essais requis. Lors d'un tel événement, les actions suivantes sont nécessaires:

– avancer l'ordre d'ouverture de 6° et répéter l'essai. Le nouveau réglage doit être conservé pour les autres essais avec la durée d'arc minimale;

– faire un essai d'ouverture en moins de façon à obtenir le même nombre total d'essais.

Le nombre de manœuvres avec la durée d'arc minimale, demandé en 6.111.9.1.2, 6.111.9.1.3, 6.111.9.1.4 et 6.111.9.1.5, doit être obtenu même si le nombre total de manœuvres est dépassé.

Un réallumage suivi par une interruption à un zéro de courant ultérieur doit être considéré comme une coupure avec une durée d'arc longue.

~~L'ordre recommandé pour les séquences d'essais d'établissement et de coupure de lignes à vide et de câbles à vide est le suivant:~~

~~– essais de court-circuit selon la séquence d'essais T60 (obligatoire au début de la série d'essais);~~

~~– essais de coupure de courants capacitifs, séquence d'essais 1 (LC1 ou CC1);~~

~~– essais d'établissement et de coupure de courants capacitifs, séquence d'essais 2 (LC2 ou CC2).~~

Aucun ordre préférentiel n'est spécifié pour les séquences d'essais d'établissement et de coupure de lignes à vide et de câbles à vide à l'exception du fait que l'essai de préconditionnement requis au niveau T60 doit être effectué au début de l'essai.

L'ordre obligatoire pour les séquences d'essais d'établissement et de coupure de batteries de condensateurs (uniques ou à gradins) est le suivant:

– essais de court-circuit selon la séquence d'essais T60;
– essais d'établissement et coupure de courants capacitifs, séquence d'essais 2 (BC2);
– essais de coupure de courants capacitifs, séquence d'essais 1 (BC1).

Pour chacune des séquences d'essais, l'ordre des manœuvres tel qu'indiqué de 6.111.9.1.2 à 6.111.9.1.5 est suggéré mais non obligatoire.

Pour les disjoncteurs ayant un arrangement asymétrique des pièces de passage de courant, le raccordement des bornes au circuit d'essais doit être inversé entre la séquence d'essais 1 (LC1, CC1 et BC1) et la séquence d'essais 2 (LC2, CC2 et BC2).

6.111.9.1.2 Essais triphasés d'établissement et de coupure de courants de lignes à vide et de câbles à vide

Chacune des séquences d'essais doit comprendre un total de 24 manœuvres ou cycles de manœuvres effectués comme suit:

Séquence d'essais 1 (LC1 et CC1):

– 4 O distribuées dans une polarité (intervalle: 15°);
– 6 O avec la durée d'arc minimale dans une polarité;
– 4 O distribuées dans l'autre polarité (intervalle: 15°);
– 6 O avec la durée d'arc minimale dans l'autre polarité;
– essais additionnels distribués pour obtenir 24 O (intervalle: 15°).

Séquence d'essais 2 (LC2 et CC2):

– 4 CO distribuées dans une polarité (intervalle: 15°);
– 6 CO avec la durée d'arc minimale dans une polarité;
– 4 CO distribuées dans l'autre polarité (intervalle: 15°);
– 6 CO avec la durée d'arc minimale dans l'autre polarité;
– essais additionnels distribués pour obtenir 24 CO (intervalle: 15°).

~~Pendant ces essais, toutes les durées d'arc minimales doivent être obtenues sur la même phase.~~

À l'exception des essais complémentaires, toutes les durées d'arc distribuées et minimales doivent être obtenues sur la même phase.

NOTE Si, à cause de la durée d'ouverture du disjoncteur, il n'est pas possible d'obtenir un contrôle précis du moment de la séparation des contacts, alors l'exigence d'obtenir les durées d'arc minimales sur la même phase peut être omise.

Les manœuvres C peuvent être effectuées à vide.

6.111.9.1.3 Essais monophasés d'établissement et de coupure de courants de lignes à vide et de câbles à vide

Chacune des séquences d'essais doit comprendre un total de 48 manœuvres ou cycles de manœuvres effectués comme suit:

Séquence d'essais 1 (LC1 et CC1):

– 12 O distribuées dans une polarité (intervalle: 15°);
– 6 O avec la durée d’arc minimale dans une polarité;
– 12 O distribuées dans l'autre polarité (intervalle: 15°);
– 6 O avec la durée d’arc minimale dans l'autre polarité;
– essais additionnels distribués pour obtenir 48 O (intervalle: 15°).

Séquence d'essais 2 (LC2 et CC2):

– 6 O et 6 CO distribuées dans une polarité (intervalle: 30°);
– 3 O et 3 CO avec la durée d’arc minimale dans une polarité;
– 6 O et 6 CO distribuées dans l'autre polarité (intervalle: 30°);
– 3 O et 3 CO avec la durée d’arc minimale dans l'autre polarité;
– essais additionnels distribués pour obtenir 24 O et 24 CO (intervalle: 30°).

Les manœuvres C peuvent être effectuées à vide.

6.111.9.1.4 Essais triphasés d'établissement et de coupure de courants de batteries de condensateurs (uniques ou à gradins)

La séquence d'essais 1 (BC1) doit comprendre un total de 24 essais O. La séquence d'essais 2 (BC2) doit comprendre un total de 80 essais CO comme suit:

Séquence d'essais 1 (BC1):

– 4 O distribuées dans une polarité (intervalle: 15°);
– 6 O avec la durée d’arc minimale dans une polarité;
– 4 O distribuées dans l'autre polarité (intervalle: 15°);
– 6 O avec la durée d’arc minimale dans l'autre polarité;
– essais additionnels distribués pour obtenir 24 O (intervalle: 15°).

Séquence d'essais 2 (BC2):

– 4 CO distribuées dans une polarité (intervalle: 15°);
– 32 CO avec la durée d’arc minimale dans une polarité;
– 4 CO distribuées dans l'autre polarité (intervalle: 15°);
– 32 CO avec la durée d’arc minimale dans l'autre polarité;
– essais additionnels distribués pour obtenir 80 CO (intervalle: 15°).

Durant ces essais, toutes les durées d'arc minimales doivent être obtenues sur la même phase.

Pour les manœuvres C dans les essais de batterie unique de condensateurs, le courant établi fourni par le circuit d’essai est considéré comme suffisant. Dans le cas d’essais d’établissement et de coupure de courants de batterie de condensateurs à gradins, pour faciliter les essais, les manœuvres C de la séquence d’essais 2 peuvent être effectuées à vide; une série d’essais d’établissement séparés conformément à 6.111.9.1.1 doit ensuite être effectuée.

NOTE Si, à cause de la durée d'ouverture du disjoncteur, il n'est pas possible d'obtenir un contrôle précis du moment de la séparation des contacts, alors l'exigence d'obtenir les durées d'arc minimales sur la même phase peut être omise.

6.111.9.1.5 Essais monophasés d'établissement et de coupure de courants de batteries de condensateurs (unique ou à gradins)

La séquence d'essais 1 (BC1) doit comprendre un total de 48 essais O. La séquence d'essais 2 (BC2) doit comprendre un total de 120 essais CO.

Séquence d'essais 1 (BC1):

– 12 O distribuées dans une polarité (intervalle: 15°);
– 6 O avec la durée d'arc minimale dans une polarité;
– 12 O distribuées dans l'autre polarité (intervalle: 15°);
– 6 O avec la durée d'arc minimale dans l'autre polarité;
– essais additionnels distribués pour obtenir 48 O (intervalle: 15°).

Séquence d'essais 2 (BC2):

– 12 CO distribuées dans une polarité (intervalle: 15°);
– 42 CO avec la durée d'arc minimale dans une polarité;
– 12 CO distribuées dans l'autre polarité (intervalle: 15°);
– 42 CO avec la durée d'arc minimale dans l'autre polarité;
– essais additionnels distribués pour obtenir 120 CO (intervalle: 15°).

Pour les manœuvres C dans les essais de batterie unique de condensateurs, le courant établi fourni par le circuit d'essai est considéré comme suffisant. Dans le cas d'essais d'établissement et de coupure de courants de batterie de condensateurs à gradins, pour faciliter les essais, les manœuvres C de la séquence d'essais 2 peuvent être effectuées à vide; une série d'essais d'établissement séparés conformément à 6.111.9.1.1 doit ensuite être effectuée.

6.111.9.2 Conditions d'essais pour les disjoncteurs de classe C1

6.111.9.2.1 Séquences d'essais pour la classe C1

Les essais d'établissement et de coupure de courants capacitifs pour les disjoncteurs de classe C1 doivent comprendre les séquences d'essais spécifiées dans le Tableau 31 sans essais de conditionnement (6.111.9.1.1).

Pour les essais d'établissement-coupure, les contacts du disjoncteur doivent ne pas être séparés tant que subsistent des courants transitoires. Pour obtenir cela, le temps entre les manœuvres de fermeture et d'ouverture peut être ajusté mais doit demeurer le plus près possible de la durée de fermeture-ouverture telle que définie en 3.7.143.

Aucune charge appréciable ne doit subsister sur les circuits capacitifs avant les manœuvres d'établissement.

Pour toutes les manœuvres d'établissement, la fermeture doit survenir dans les limites de ~~±15°~~ ±25° de la crête de la tension appliquée (sur une phase pour les essais en triphasé) et être distribuée de façon égale dans les deux polarités. Lors des essais d'établissement et de coupure de batteries de condensateurs à gradins, le pouvoir de fermeture inhérent doit être au moins égal au pouvoir de fermeture de batteries de condensateurs à gradins.

Lorsque, dans le cas d'essais d'établissement et de coupure de courants de batterie de condensateurs à gradins, en raison des limitations de la station d'essais, il n'est pas possible de satisfaire aux exigences d'un cycle de manœuvres CO, il est alors permis, pour satisfaire aux exigences de la séquence d'essais 2 (BC2), d'effectuer une série séparée d'essais d'établissement suivie d'une série d'essais comportant des manœuvres CO.

Il est également permis de ne pas effectuer ces essais séparés en deux étapes successives, l'une se composant de toutes les manœuvres C et l'autre de toutes les manœuvres CO, mais de combiner les manœuvres C et CO, à condition que le nombre de manœuvres d'établissement soit supérieur ou égal au nombre de manœuvres de coupure à tout instant au cours de cet essai.

La série séparée d'essais d'établissement doit comprendre les conditions suivantes:

– le même nombre de manœuvres;

  lors des essais d'établissement et de coupure de batteries de condensateurs à gradins, le pouvoir de fermeture doit être au moins égal au pouvoir de fermeture assigné de batteries de condensateurs à gradins;

– la tension d'essai doit être la ~~même que celle de la séquence d'essais 2 (BC2)~~ tension phase-terre;

– l'établissement doit survenir dans les limites de ~~15°~~ ± 25° de la crête (sur une même phase pour les essais en triphasé) et doit être distribué de manière régulière dans les deux polarités.

Après la série séparée de manœuvres d'établissement, les manœuvres CO doivent être réalisées avec des manœuvres de fermeture à vide. Les manœuvres CO doivent être effectuées sur le même pôle, sans remise en état intermédiaire.

Tableau 31 – Séquences d'essais pour la classe C1

Séquence d'essais	Tension appliquée aux déclencheurs	Pression des fluides pour la manœuvre et l'interruption	Courant d'essai en pourcentage du pouvoir de coupure assigné de courants capacitifs %	Type de manœuvre ou de séquence de manœuvres
1: LC1, CC1 et BC1	Tension maximale	Pression assignée	10 à 40	O
2: LC2, CC2 et BC2	Tension maximale	Pression assignée [a]	Non inférieur à 100	CO

NOTE 1 Les essais sont effectués avec la tension maximale des déclencheurs de façon à obtenir un meilleur contrôle lors des manœuvres d'ouverture.

NOTE 2 Pour des raisons de commodité de réalisation des essais, des manœuvres CO peuvent être effectuées dans la séquence d'essais 1 (LC1, CC1 et BC1).

[a] Si applicable, la pression pour la manœuvre et la coupure doit être la pression minimale de fonctionnement pour au moins trois cycles de manœuvres CO, une à la durée d'arc minimale et deux à la durée d'arc maximale. Ce n'est pas applicable aux disjoncteurs avec système à pression scellé.

NOTE 1 Lors de l'établissement et de la coupure de courants capacitifs, la manœuvre d'ouverture dans un cycle de manœuvres CO n'est pas influencée par le préamorçage lors de la manœuvre de fermeture précédente mais peut être affectée par le comportement du fluide utilisé pour l'interruption lors d'une manœuvre de fermeture (par exemple, différences locales de densité, turbulences, mouvement du fluide). Par conséquent, les manœuvres de fermeture et d'ouverture peuvent être séparées si on considère seulement les contraintes électriques, mais ne peuvent l'être si on considère la dynamique du fluide d'extinction. Une manœuvre de fermeture à vide précédant la manœuvre d'ouverture est donc nécessaire pour ces raisons.

L'amortissement présumé du courant d'appel lors de manœuvres de batteries de condensateurs à gradins, c'est-à-dire le rapport entre la deuxième crête et la première crête de même polarité, doit être égal ou supérieur à 0,75 pour les disjoncteurs de tensions assignées inférieures à 52 kV et égal ou supérieur à 0,85 pour les disjoncteurs de tensions assignées égales ou supérieures à 52 kV.

Pour les manœuvres d'ouverture, la durée d'arc minimale est déterminée en variant le moment de la séparation des contacts lors de l'ouverture par intervalles d'environ 6°. Par cette méthode, il peut être nécessaire d'effectuer plusieurs essais pour démontrer la durée d'arc minimale et la durée d'arc maximale.

NOTE 2 Avec l'accord du constructeur, des tensions supérieures à la limite maximale des tensions d'alimentation des déclencheurs peuvent être utilisées durant ces essais de façon à obtenir des durées d'ouverture et de fermeture stables.

Si une durée d'arc maximale est obtenue au lieu de la durée d'arc minimale visée, l'essai est valable et doit être inclus dans le nombre total d'essais requis. Lors d'un tel événement, les actions suivantes sont nécessaires:

– avancer l'ordre d'ouverture de 6° et répéter l'essai. Le nouveau réglage doit être conservé pour les autres essais avec la durée d'arc minimale;
– faire un essai d'ouverture de moins de façon à obtenir le même nombre total d'essais.

Le nombre de manœuvres et de cycles de manœuvres avec la durée d'arc minimale indiquée en 6.111.9.2.2 pour les essais en triphasé ou en 6.111.9.2.3 pour les essais en monophasé doit être obtenu, même si le nombre total spécifié de manœuvres est dépassé.

Un réallumage suivi par une interruption à un zéro de courant ultérieur doit être considéré comme une coupure avec une durée d'arc longue.

Pour chacune des séquences d'essais, l'ordre des manœuvres, comme indiqué en 6.111.9.2.2 pour les essais en triphasé ou en 6.111.9.2.3 pour les essais en monophasé, est suggéré mais non obligatoire.

Pour les disjoncteurs ayant un arrangement asymétrique des pièces de passage du courant, le raccordement des bornes au circuit d'essai doit être inversé entre la séquence d'essais 1 (LC1, CC1 et BC1) et la séquence d'essais 2 (LC2, CC2 et BC2).

Aucun ordre préférentiel n'est spécifié pour les essais d'établissement et de coupure de courants capacitifs.

6.111.9.2.2 Essais monophasés et triphasés d'établissement et de coupure de courants capacitifs

La séquence d'essais 1 (LC1, CC1 et BC1) doit comprendre un total de 24 essais O. La séquence d'essais 2 (LC2, CC2 et BC2) doit comprendre un total de 24 essais CO.

Séquence d'essais 1 (LC1, CC1 et BC1)

– 6 O distribuées dans une polarité (intervalle: 30°);
– 3 O avec la durée d'arc minimale dans une polarité;
– 3 O avec la durée d'arc minimale dans l'autre polarité;
– 6 O avec la durée d'arc maximale dans l'autre polarité;
– essais additionnels distribués pour obtenir 24 O (intervalle: 30°).

Séquence d'essais 2 (LC2, CC2 et BC2)

– 6 CO distribuées dans une polarité (intervalle: 30°);
– 3 CO avec la durée d'arc minimale dans une polarité;
– 3 CO avec la durée d'arc minimale dans l'autre polarité;
– 6 CO avec la durée d'arc maximale dans l'autre polarité;
– essais additionnels distribués pour obtenir 24 CO (intervalle: 30°).

Pour les essais d'établissement et de coupure de lignes à vide et de câbles à vide, les manœuvres C peuvent être effectuées à vide. Pour les manœuvres C dans les essais de batterie unique de condensateurs, le courant établi fourni par le circuit d'essai est considéré comme suffisant. Dans le cas d'essais d'établissement et de coupure de courants de batterie de condensateurs à gradins, pour faciliter les essais, les manœuvres C de la séquence d'essais 2 peuvent être effectuées à vide; une série d'essais d'établissement séparés conformément à 6.111.9.1.1 doit ensuite être effectuée.

L'ordre recommandé pour les séquences d'essais est le suivant:

– établissement et coupure de courants capacitifs, séquence d'essais 1 (LC1 ou CC1 ou BC1);
– établissement et coupure de courants capacitifs, séquence d'essais 2 (LC2 ou CC2 ou BC2).

6.111.9.3 Conditions d'essais correspondant à la coupure en présence de défauts à la terre

a) Lignes et câbles

Lorsque des essais correspondant à l'établissement et à la coupure de courants de lignes à vide et de câbles à vide en présence de défauts à la terre sont requis, les conditions suivantes s'appliquent:

Les essais en monophasé en laboratoire doivent être effectués à une tension telle qu'indiquée en 6.111.7 et à un courant capacitif égal à

– 1,25 fois le pouvoir de coupure assigné de courant capacitif dans les réseaux à neutre effectivement à la terre;
– 1,7 fois le pouvoir de coupure assigné de courant capacitif dans les réseaux à neutre non effectivement à la terre.

Les procédures d'essais sont données en 6.111.9.1 et 6.111.9.2, à l'exception du nombre total d'essais qui est divisé par deux pour chacune des séquences d'essais applicables.

NOTE Si les essais correspondant à la coupure en présence de défauts à la terre sont effectués en utilisant le nombre de manœuvres prescrit en 6.111.9.1 ou 6.111.9.2 respectivement, alors ces essais couvrent les exigences données en 6.111.9.1 ou 6.111.9.2 et les essais de 6.111.9.1 ou 6.111.9.2 n'ont pas besoin d'être effectués.

b) Batteries uniques de condensateurs

Les essais ne sont pas nécessaires pour les batteries de condensateurs dans les réseaux à neutre effectivement à la terre.

La manœuvre de batteries de condensateurs à neutre effectivement à la terre dans les réseaux à neutre non effectivement à la terre peut entraîner des contraintes plus élevées. Comme cela n'est pas une condition normale de réseau, ces exigences d'essais ne sont pas considérées dans cette norme.

c) Batteries de condensateurs à gradins

Comme cela n'est pas une condition normale de réseau, ces exigences d'essais ne sont pas considérées dans cette norme.

6.111.10 Essais avec TTR spécifiée

En variante à l'utilisation des circuits d'essai décrits de 6.111.3 à 6.111.5, les essais d'établissement et de coupure peuvent être effectués en utilisant des circuits produisant une tension de rétablissement présumée conforme aux exigences suivantes:

– l'enveloppe de la tension d'essai de rétablissement présumée est définie par (voir Figure 54):

$u'_c \geq u_c$

$t'_2 \leq t_2$.

– De plus, la partie initiale de la tension de rétablissement présumée doit rester en dessous de la droite joignant l'origine au point, définie par u_1 et t_1.

– Il convient de veiller à s'assurer que la tension de rétablissement réelle ne dépasse pas la tension d'essai théorique de l'essai direct monophasé correspondant (courbe 1-cos) de plus de 6 % de la valeur de crête de la tension d'essai (c'est-à-dire environ 3% de la tension de rétablissement crête u_c présentée à la Figure 54).

NOTE L'utilisation d'une résistance en série (6.111.5.1 et 6.111.5.2) dans le circuit de charge provoque un déphasage pouvant entraîner le dépassement de la limite donnée ci-dessus. Dans ces cas, la valeur de la résistance peut être diminuée ou un circuit LR approprié peut être utilisé à la place (6.111.5.1 et 6.111.5.2).

Les valeurs spécifiées de u_1, t_1, u_c et t_2 sont données au Tableau 32.

Tableau 32 – Valeurs spécifiées de u_1, t_1, u_c et t_2

Séquences d'essais	Valeurs de la tension de rétablissement de la Figure 54 en fonction de la valeur crête de la tension d'essai		Coordonnées de temps de la Figure 54	
	u_c p.u.	u_1 p.u.	t_1	t_2 (ms)
1	≥ 1,98	≤ 0,02k_{af}*	≥ t_1 ou t_3 de 4.102.3 pour le défaut aux bornes	8,7 ms pour 50 Hz
2	≥ 1,95	≤ 0,05k_{af}*		7,3 ms pour 60 Hz

NOTE Pour les essais synthétiques en monophasé, la tension de rétablissement présumée est calculée en se basant sur la tension d'essai correspondante d'un essai direct en monophasé.

~~* k_{af} = facteur d'amplitude = 1,4 (voir Tableaux 1, 3 et 5) pour les disjoncteurs de classe S1 et pour les disjoncteurs de tension assignée supérieure ou égale à 100 kV.~~

~~* k_{af} = facteur d'amplitude = 1,54 (voir Tableau 2) pour les disjoncteurs de classe S2.~~

* k_{af} = 1,4 (voir Tableaux 1, 3 et 5) pour les disjoncteurs de classe S1 et pour les disjoncteurs de tension assignée de 100 kV jusqu'à 800 kV;

k_{af} = 1,5 (voir Tableau 5) pour les disjoncteurs de tension assignée supérieure à 800 kV;

k_{af} = 1,54 (voir Tableau 2) pour les disjoncteurs de classe S2.

6.111.11 Critères de réussite des essais

6.111.11.1 Généralités

Les disjoncteurs des classes individuelles doivent avoir réussi les essais si les conditions suivantes sont remplies:

a) le comportement du disjoncteur pendant l'établissement et la coupure des courants capacitifs de toutes les séquences d'essais prescrites satisfait aux conditions données en 6.102.8;

b) l'état du disjoncteur après la série d'essais correspond aux conditions données en 6.102.9.4. Si aucun réamorçage n'est survenu durant les séquences d'essais 1 (LC1 ou CC1 ou BC1) et 2 (LC2 ou CC2 ou BC2), une inspection visuelle est suffisante.

Lorsque des essais combinés conformément à 6.111.9 sont effectués, les conditions de réussite aux essais s'appliquent à chaque combinaison de séquences d'essais 1 et 2 appropriée pour couvrir l'application ou les caractéristiques assignées pour lesquelles les essais ont été réalisés.

6.111.11.2 Disjoncteur de classe C2

Le disjoncteur doit avoir réussi les essais si aucun réamorçage n'est survenu au cours des séquences d'essais 1 (LC1 ou CC1 ou BC1) et 2 (LC2 ou CC2 ou BC2).

Si un réamorçage est survenu au cours des séquences d’essais complètes 1 (LC1 ou CC1 ou BC1) et 2 (LC2 ou CC2 ou BC2), les deux séquences d’essais doivent alors être répétées sur le même appareillage sans aucune maintenance. Si aucun réamorçage supplémentaire ne se produit au cours de cette série d’essais additionnelle, le disjoncteur doit avoir réussi les essais. Il ne doit se produire aucun contournement extérieur et aucun contournement phase-terre.

Dans le cas d’essais combinés conformément à 6.111.9, le disjoncteur doit avoir réussi l'essai pour les applications ou caractéristiques assignées pour lesquelles une séquence d'essais 2 et une séquence d'essais 1 correspondante ont été effectuées sans réamorçage. Lorsqu’en raison des réamorçages, les séquences d’essais doivent être répétées, l’ensemble affecté de paires de séquences d’essais (séquence d’essais 1 et séquence d’essais 2) doit être répété. Si dans plus d'une séquence d’essais 1, un réamorçage est survenu, chacune d’entre elles doit être répétée avec une seule séquence d’essais 2. Si un réamorçage est survenu dans la séquence d’essais 2, cette séquence d’essais et n’importe laquelle des séquences d’essais 1 doivent être répétées.

6.111.11.3 Disjoncteur de classe C1

Le disjoncteur doit avoir réussi les essais si jusqu’à un réamorçage est survenu au cours des séquences d’essais 1 (LC1 ou CC1 ou BC1) et 2 (LC2 ou CC2 ou BC2).

Si deux réamorçages sont survenus au cours des séquences d’essais complètes 1 (LC1 ou CC1 ou BC1) et 2 (LC2 ou CC2 ou BC2), les deux séquences d’essais doivent alors être répétées sur le même appareillage sans aucune maintenance. Si pas plus d’un réamorçage supplémentaire se produit au cours de cette série d’essais additionnelle, le disjoncteur doit avoir réussi les essais. Il ne doit se produire aucun contournement extérieur et aucun contournement phase-terre.

Dans le cas d’essais combinés conformément à 6.111.9, le disjoncteur doit avoir réussi l'essai pour les applications ou caractéristiques assignées pour lesquelles une séquence d'essais 2 et une séquence d'essais 1 correspondante ont été effectuées avec moins de deux réamorçages au total. Lorsqu’en raison des réamorçages, les séquences d’essais doivent être répétées, l’ensemble affecté de paires de séquences d’essais (séquence d’essais 1 et séquence d’essais 2) doit être répété. Si dans plus d'une séquence d’essais 1, des réamorçages sont survenus, chacune d’entre elles doit être répétée avec une seule séquence d’essais 2. Si des réamorçages sont survenus uniquement dans la séquence d’essais 2, cette séquence d’essais et n’importe laquelle des séquences d’essais 1 doivent être répétées.

6.111.11.4 Critères pour reclasser en classe C1 un disjoncteur essayé avec les exigences de la classe C2

Un disjoncteur ayant satisfait aux exigences de classe C2 pour une séquence d’essais particulière (LC, CC, BC) peut être de classe C1 pour le même cycle, sans essais supplémentaires.

Un disjoncteur soumis aux essais conformément au programme d’essais de la classe C2 mais qui n’a pas atteint les performances de classe C2, peut être qualifié comme un disjoncteur de classe C1 si les exigences de 6.111.11.1 sont satisfaites et si la condition suivante est remplie:

a) Essais d'établissement et de coupure de courants de lignes à vide ou de courants de câbles à vide

   Le nombre total de réamorçages au cours des essais d’établissement et de coupure de courants de lignes à vide (LC1 et LC2) ou des essais d’établissement et de coupure de courants de câbles à vide (CC1 et CC2) ne dépasse pas deux dans la première série de manœuvres d’essai, c’est-à-dire 96 dans le cas d’essais en monophasé et 48 dans le cas d’essais en triphasé, voir 6.111.9.1.2 ou 6.111.9.1.3 respectivement. En cas d’un seul réamorçage au cours de la première série de manœuvres d’essai, une répétition de séries peut être effectuée conformément à 6.111.11.2. Le comportement du disjoncteur au cours des répétitions de séries ne doit être pris en considération pour la re-classification.

b) Essais d'établissement et de coupure de courants de batterie de condensateur

Le nombre total de réamorçages au cours des essais d'établissement et de coupure de courants de batterie de condensateur (BC1 et BC2) ne dépasse pas cinq dans la première série de manœuvres, c'est-à-dire 168 dans le cas d'essais en monophasé et 104 dans le cas d'essais en triphasé, voir 6.111.9.1.4 ou 6.111.9.1.5 respectivement. En cas d'un seul réamorçage au cours de la première série de manœuvres d'essai, une répétition de séries peut être effectuée conformément à 6.111.11.2. Le comportement du disjoncteur au cours des répétitions de séries ne doit pas être pris en considération pour la re-classification.

La procédure de re-classification est montrée aux Figures 55 et 56.

6.112 Exigences spéciales pour les essais de coupure et de fermeture des disjoncteurs de classe E2

6.112.1 Disjoncteurs de classe E2 non prévus pour le cycle de refermeture automatique

L'endurance électrique des disjoncteurs qui ne sont pas prévus pour être utilisés avec le cycle de refermeture automatique (ex. les disjoncteurs de réseaux à liaisons par câbles) est démontrée en effectuant les séquences d'essais fondamentales décrites en 6.106 sans maintenance intermédiaire. Des essais supplémentaires ne sont pas exigés.

6.112.2 Disjoncteurs de classe E2 prévus pour le cycle de refermeture automatique

Les disjoncteurs prévus pour effectuer le cycle de refermeture automatique, ce qui est le cas habituellement des disjoncteurs de réseaux aériens, doivent effectuer la séquence d'essais d'endurance électrique conformément au Tableau 33 en suivant l'ordre spécifié et en complément des séquences d'essais fondamentales de 6.106 qui doivent être effectuées sans maintenance intermédiaire.

La séquence d'essais doit être réalisée sur un disjoncteur propre à l'état neuf, identique à celui qui a été soumis aux séquences d'essais fondamentales décrites en 6.106. Aucune maintenance intermédiaire ne doit être effectuée. Les paramètres d'essai doivent être conformes aux indications de 6.106, en tenant compte des exceptions suivantes:

a) dans le cas de disjoncteurs à gaz, les essais doivent être réalisés à la pression assignée pour l'isolement et/ou la manœuvre et avec la tension d'alimentation assignée, des dispositifs de fermeture et d'ouverture d'une part, et, d'autre part, des circuits auxiliaires et de commande;
b) les valeurs de t doivent être choisies de manière à favoriser le bon déroulement des essais;
c) il convient que l'intervalle de temps minimal entre les séquences de manœuvre soit établi par le constructeur.

Les durées d'arc doivent être aléatoires pour les essais à 10 % et à 30 %. Leur réglage doit être fait conformément à 6.102.10 pour les essais à 60 % et à 100 %.

L'état du disjoncteur après l'essai doit correspondre aux conditions de 6.102.9.2 et 6.102.9.3.

Tableau 33 – Séquence de manœuvre pour l'essai d'endurance électrique des disjoncteurs de classe E2 prévus pour le cycle de refermeture automatique selon 6.112.2

Courant d'essai (pourcentage du pouvoir de coupure assigné en court-circuit) %	**Séquences de manœuvre**	**Nombre de séquences de manœuvre (liste 1)** [a]	**Nombre de séquences de manœuvre (liste 2)** [a]	**Nombre de séquences de manœuvre (liste 3)** [a]
10	O	84	12	-
	O – 0,3 s – CO	14	6	-
	O – 0,3 s – CO – *t* – CO	6 [b]	4 [b]	1 [b]
30	O	84	12	-
	O – 0,3 s – CO	14	6	-
	O – 0,3 s – CO – *t* – CO	6 [b]	4 [b]	1 [b]
60	O	2	8	15
	O – 0,3 s – CO – *t* – CO	2 [b]	8 [b]	15 [b]
100 % (symétrique)	O – 0,3 s – CO – *t* – CO	2 [b]	4 [b]	2 [b]

[a] La liste 1 est privilégiée. La liste 2 peut être utilisée comme variante à la liste 1 pour les disjoncteurs utilisés pour les réseaux à neutre relié effectivement à la terre. Des calculs ont été effectués sur la base de la publication [7]. Ces calculs sont applicables pour certains types de disjoncteurs (disjoncteurs à simple pression de SF_6 et disjoncteurs à vide). Les résultats des calculs peuvent être différents pour d'autres types de disjoncteurs. A l'aide de ces calculs et en réglant l'usure générée par la liste 1 à 100 %, la liste 2 donne 125 % et la liste 3 134 %. Par conséquent, la liste 3 peut être utilisée comme variante à la liste 1 et à la liste 2 pour réduire le nombre de circuits d'essais différents.

[b] Lorsque l'échantillon n'est pas remis en état après les séquences d'essais de court-circuit fondamentales décrites en 6.106, on peut tenir compte des essais déjà réalisés pour établir le nombre de séquences de manœuvres additionnelles à effectuer pour se conformer aux exigences du Tableau 33. En pratique, cela signifie réduire de 1 les chiffres marqués par [b].

7 Essais individuels

L'Article 7 de la CEI 62271-1 est applicable avec le complément suivant:

7.1 Essais diélectriques du circuit principal

Le paragraphe 7.1 de la CEI 62271-1 est applicable avec le complément suivant:

Pour des disjoncteurs construits par montage en série d'éléments identiques de coupure et de fermeture, la tension d'essai à appliquer aux bornes de chacun des éléments en position d'ouverture est la fraction la plus élevée de la tension de tenue totale résultant de la répartition réelle de la tension à fréquence industrielle déterminée sur le disjoncteur complètement ouvert et avec une borne mise à la terre.

En se référant à la Figure 2 de la CEI 62271-1 qui représente un schéma de disjoncteur tripolaire, la tension d'essai doit être appliquée conformément au Tableau 34.

Tableau 34 – Application de la tension lors des essais diélectriques du circuit principal

Condition d'essai n°	Disjoncteur	Tension appliquée à	Terre connectée à
1	Fermé	AaCc	BbF
2	Fermé	Bb	AaCcF
3	Ouvert	ABC	abcF

NOTE Si l'isolation entre pôles est de l'air à pression atmosphérique, les conditions d'essai n° 1 et 2 peuvent être combinées, la tension d'essai étant appliquée entre toutes les parties du disjoncteur connectées ensemble et le support.

7.2 Essais diélectriques des circuits auxiliaires et de commande

Le paragraphe 7.2 de la CEI 62271-1 est applicable.

7.3 Mesurage de la résistance du circuit principal

Le paragraphe 7.3 de la CEI 62271-1 est applicable.

7.4 Essai d'étanchéité

Le paragraphe 7.4 de la CEI 62271-1 est applicable.

7.5 Contrôles visuels et du modèle

Le paragraphe 7.5 de la CEI 62271-1 s'applique avec le complément suivant:

Le disjoncteur doit être contrôlé afin de vérifier sa conformité avec la spécification de la commande.

Les points suivants doivent être contrôlés, lorsque cela s'applique:

– langue et indications portées sur les plaques signalétiques;
– identification des équipements auxiliaires;
– couleur et qualité de la peinture et protection contre la corrosion des surfaces métalliques;
– valeurs des résistances et des condensateurs reliés au circuit principal.

7.101 Essais de fonctionnement mécanique

Les essais de fonctionnement mécanique doivent comprendre:

a) à la tension maximale spécifiée d'alimentation des dispositifs de manœuvre et des circuits auxiliaires et de contrôle et à la pression maximale spécifiée d'alimentation (si cela est applicable):
   – cinq manœuvres de fermeture;
   – cinq manœuvres d'ouverture.
b) à la tension minimale spécifiée d'alimentation des dispositifs de manœuvre et des circuits auxiliaires et de contrôle et à la pression minimale spécifiée d'alimentation (si cela est applicable):
   – cinq manœuvres de fermeture;
   – cinq manœuvres d'ouverture.

c) à la tension assignée d'alimentation des dispositifs de manœuvre et des circuits auxiliaires et de contrôle et à la pression assignée d'alimentation (si cela est applicable);

   – cinq cycles de manœuvres de fermeture-ouverture, le mécanisme de déclenchement étant commandé par la fermeture des contacts principaux;

   – de plus, pour les disjoncteurs prévus pour la refermeture automatique rapide (voir 4.104), cinq cycles de manœuvres d'ouverture-fermeture O – t – C où t est au plus égal à la durée spécifiée pour la séquence de manœuvres assignée.

Il convient que les essais de fonctionnement mécanique soient de préférence effectués sur le disjoncteur complet; cependant, lorsque les disjoncteurs sont assemblés et transportés en éléments séparés, les essais individuels de série peuvent être faits sur les composants conformément aux prescriptions du paragraphe 6.101.1.2. Dans ce cas, le constructeur doit délivrer un programme d'essais de mise en service, pour confirmer la compatibilité des éléments séparés et des composants lorsqu'ils forment le disjoncteur complet. Des lignes directrices pour les essais de réception sont données en 10.2.101.

Lors de toutes les séquences de manœuvres prescrites, on doit effectuer les mesures suivantes et enregistrer les manœuvres d'ouverture et de fermeture:

– le mesurage des durées de manœuvres;

– le mesurage de la consommation du fluide pendant la manœuvre, par exemple la différence de pression (si cela est applicable).

Le comportement mécanique doit être conforme à celui du prototype utilisé pour les essais de type. Un cycle de manœuvre à vide, par exemple, comme décrit en 6.101.1.1, peut être effectué pour enregistrer les diagrammes espace-temps à l'issue des essais individuels. Lorsque cela est fait, la courbe doit se situer dans l'enveloppe définie lors du tracé de référence de la caractéristique de déplacement mécanique, en 6.101.1.1, depuis la séparation des contacts jusqu'à la fin de leur course.

Lorsque les essais mécaniques individuels sont effectués sur des sous-ensembles, les caractéristiques de déplacement mécanique de référence réalisée à la fin des essais de mise en service sur site doivent être conformes, comme ci-dessus.

Si les mesures sont effectuées sur le site, le constructeur doit établir la procédure de mesure préférentielle. Si d'autres procédures sont utilisées, les résultats peuvent être différents et la comparaison avec la course instantanée des contacts impossible à réaliser.

Les caractéristiques de déplacement mécanique peuvent être enregistrées directement à l'aide d'un capteur de déplacement ou d'un dispositif équivalent sur le système de contact du disjoncteur, ou à un autre emplacement de la liaison motrice des contacts où il y a une connexion directe, et où on peut obtenir une image représentative de la course des contacts. On doit, de préférence, réaliser des caractéristiques de déplacement mécanique continues, comme sur la Figure 23 a). Lorsque les mesures sont effectuées sur le site, d'autres méthodes peuvent être employées pour enregistrer des points de la course pendant une manœuvre.

Dans ces cas, le nombre de points enregistrés doit être suffisant pour pouvoir déterminer le temps et la vitesse des contacts lors de leur séparation et/ou de leur toucher, ainsi que le temps de la course totale.

Après l'achèvement des séquences de manœuvres exigées, les essais et inspections suivants doivent être exécutés (si cela est applicable):

– vérification des raccordements;

– les contacts auxiliaires ou de commande doivent indiquer de manière satisfaisante les positions d'ouverture ou de fermeture du disjoncteur;

– tous les équipements auxiliaires doivent fonctionner correctement aux limites des tensions d'alimentation des dispositifs de commande et des circuits auxiliaires et de commande, et/ou des pressions des fluides pour la manœuvre;

De plus, les essais et inspections suivants doivent être effectués (si cela est applicable):

– mesurage des résistances des dispositifs de chauffage (s'il en existe) et des bobines de commande;
– inspection de la filerie de commande, des circuits de chauffage et des équipements auxiliaires et contrôle du nombre des contacts auxiliaires, conformément à la spécification de commande;
– inspection de l'armoire de commande (systèmes électrique, mécanique, pneumatique et hydraulique);
– temps de réarmement;
– caractéristiques fonctionnelles de la soupape de sécurité;
– fonctionnement des verrouillages électriques, mécaniques, pneumatiques ou hydrauliques et des dispositifs de signalisation;
– fonctionnement du dispositif d'anti-pompage;
– caractéristiques générales du matériel, dans les tolérances indiquées des tensions d'alimentation de commande;
– inspection des bornes de mise à la terre du disjoncteur.

Pour les disjoncteurs à déclenchement autonome, les déclencheurs ou les relais doivent être réglés au repère minimal sur l'échelle de réglage du courant.

Il doit être montré que les déclencheurs à maximum de courant provoquent correctement l'ouverture du disjoncteur pour un courant dans le circuit principal n'excédant pas 110 % du courant de déclenchement minimal correspondant à la valeur de réglage figurant sur l'échelle de réglage du courant. Un essai d'injection secondaire peut être réalisé comme méthode alternative.

Pour ces essais, le courant traversant les déclencheurs à maximum de courant ou les transformateurs de courant peut être fourni par une source à basse tension convenable.

Pour les disjoncteurs équipés de déclencheurs d'ouverture à minimum de tension, il doit être montré que le disjoncteur s'ouvre et peut être fermé lorsque des tensions comprises entre les limites spécifiées sont appliquées aux déclencheurs (voir 5.8.4 de la CEI 62271-1).

Si des réglages sont requis pendant les essais de fonctionnement mécanique, la séquence complète des essais doit être répétée après les réglages.

8 Lignes directrices pour le choix des disjoncteurs selon le service

8.101 Généralités

Un disjoncteur convenable pour un certain emploi en service est choisi dans les meilleures conditions en considérant les valeurs assignées individuelles qu'exigent les conditions en charge normale et en cas de défaut.

La liste complète des caractéristiques assignées est indiquée à l'Article 4. Les paragraphes dont la référence figure ci-dessous traitent des caractéristiques assignées individuelles suivantes.

Type de caractéristiques	*Paragraphe*
Tension assignée	8.102.1
Niveau d'isolement assigné	8.102.2
Fréquence assignée	8.102.3
Courant assigné en service continu	8.102.4
Pouvoir de coupure assigné en court-circuit	8.103.1
Tension transitoire de rétablissement assignée dans le cas de défaut aux bornes	8.103.2
Pouvoirs de coupure et de fermeture assignés en discordance de phases	8.103.3
Pouvoir de fermeture assigné en court-circuit	8.103.4
Séquence de manœuvres assignée	8.103.5
Durée de court-circuit assignée	8.103.6
Classe d'endurance électrique (E1 ou E2 (avec/sans refermeture automatique)), s'il y a lieu	8.104

Pour les caractéristiques assignées qui ne sont pas traitées dans l'Article 8, on pourra se référer, s'il y a lieu, à l'Article 4 comme précisé ci-après:

Type de caractéristiques	*Paragraphe*
Courant de courte durée admissible assigné	4.5
Valeur de crête du courant admissible assigné	4.6
Tension assignée d'alimentation des dispositifs de fermeture et d'ouverture et des circuits auxiliaires et de commande	4.8
Fréquence assignée d'alimentation des dispositifs de fermeture et d'ouverture et des circuits auxiliaires	4.9
Pressions assignées d'alimentation en gaz comprimé pour la manœuvre et pour la coupure	4.10
Caractéristiques assignées pour les défauts proches en ligne	4.105
Performance de réamorçage pendant les essais de coupure de courant capacitifs (classe C1 ou C2)	4.107
Caractéristiques des conditions de manœuvre capacitives (par exemple conditions de mise à la terre, type de charge, etc.)	4.107
Pouvoir de coupure assigné de lignes à vide	4.107.1
Pouvoir de coupure assigné de câbles à vide	4.107.2
Pouvoir de coupure assigné de batterie unique de condensateurs	4.107.3
Pouvoir de coupure assigné de batteries de condensateurs à gradins	4.107.4
Pouvoir de fermeture assigné de batterie unique de condensateurs	4.107.5
Pouvoir de fermeture assigné de batterie unique de condensateurs à gradins	4.107.6
Nombre de manœuvres mécaniques (classe M1 ou M2)	4.110

D'autres paramètres sont à considérer lors du choix d'un disjoncteur, par exemple:

Conditions atmosphériques et climatiques locales	8.102.5
Emploi à altitudes élevées	8.102.6
Durée d'ouverture	8.103.1
Manœuvre de charges inductives	4.108

Il est recommandé de déterminer les contraintes imposées par les conditions en cas de défaut auxquelles un disjoncteur doit faire face, en calculant les courants de court-circuit au lieu où l'installation du disjoncteur est prévue dans le réseau, selon une méthode de calcul reconnue.

Lorsque l'on procède au choix d'un disjoncteur, il est recommandé de tenir compte du futur développement probable du réseau dans son ensemble, de telle sorte que le disjoncteur puisse convenir, non seulement pour les besoins immédiats, mais aussi pour les exigences futures.

Les disjoncteurs ayant satisfait aux essais de type correspondant à une combinaison de valeurs assignées (c'est-à-dire la tension, le courant en service continu, les pouvoirs de fermeture et de coupure) conviennent pour toutes valeurs assignées inférieures (à l'exception de la fréquence assignée) sans essais supplémentaires. La manœuvre des charges inductives (courants magnétisants de transformateurs, moteurs à haute tension et réactances shunt) sont spécifiées dans la CEI 62271-110.

NOTE Certains types de défauts se présentant en service, tels que les défauts évolutifs et certaines conditions de service telles que la commande de fours à arc, ne sont pas pris en considération dans la présente norme et, de ce fait, il est recommandé de les considérer comme des conditions spéciales et de faire intervenir un accord entre le constructeur et l'utilisateur.

Cela est également applicable aux disjoncteurs utilisés pour toutes manœuvres conduisant à l'apparition d'une tension de rétablissement à fréquence industrielle supérieure à celle qui correspond à la tension assignée du disjoncteur, ce qui peut être le cas en certains points du réseau, et, en particulier, à l'extrémité de longues lignes. Dans ce cas particulier, il est recommandé que la valeur du courant à couper à la tension la plus élevée susceptible d'apparaître aux bornes du disjoncteur lors de son ouverture, fasse l'objet d'un accord similaire.

8.102 Choix des valeurs assignées pour les conditions de service

8.102.1 Choix de la tension assignée

Il convient de choisir la tension assignée du disjoncteur au moins égale à la tension la plus élevée du réseau à l'endroit où le disjoncteur doit être installé.

Il convient de choisir la tension assignée d'un disjoncteur parmi les valeurs normales indiquées en 4.1 de la CEI 62271-1.

Pour le choix de la tension assignée, il est recommandé de tenir compte également des niveaux d'isolement correspondants, spécifiés en 4.2 (voir également 8.102.2).

8.102.2 Coordination des isolements

Il convient de choisir le niveau d'isolement assigné d'un disjoncteur suivant 4.2.

Les valeurs de ces tableaux s'appliquent à la fois aux disjoncteurs pour l'intérieur et aux disjoncteurs pour l'extérieur. Il convient de spécifier dans l'appel d'offres si le disjoncteur doit être du type intérieur ou du type extérieur.

La coordination des isolements dans un réseau électrique a pour but de réduire les dommages causés aux équipements électriques par les surtensions et de tendre à localiser les amorçages (lorsque l'on ne peut pas, économiquement, les éviter) en des points où ils ne causeront aucun dégât.

Il convient de prendre des précautions pour limiter les surtensions sur les bornes des disjoncteurs à des valeurs fixées inférieures au niveau d'isolement (voir la CEI 60071-2).

Lorsqu'un disjoncteur est prévu pour être placé dans un endroit nécessitant un niveau d'isolement supérieur, il convient de le spécifier dans l'appel d'offres (voir 9.101).

Pour les disjoncteurs destinés à des manœuvres de synchronisation alors que des surtensions de manœuvre importantes peuvent se produire simultanément, se reporter à 4.2 et 6.2.7.2.

Lors du choix de disjoncteurs, il est également nécessaire de considérer leur comportement au regard de phénomènes transitoires et des surtensions. L'expérience montre que des effets néfastes de phénomènes transitoires et le risque de surtensions dans certains cas critiques peuvent être minimisés par

– le choix approprié du type de disjoncteur;
– des changements du circuit ou l'emploi d'équipement complémentaire pour l'amortissement et la limitation des phénomènes transitoires (circuits RC, parasurtenseurs, résistances non linéaires, etc.).

Ces précautions doivent être discutées avec le constructeur pour chaque cas. On peut convenir d'essais spéciaux pour l'évaluation de la solution retenue.

8.102.3 Fréquence assignée

Il convient de consulter le constructeur si un disjoncteur doit être utilisé à une fréquence autre que sa fréquence assignée (voir 4.3 de la CEI 62271-1).

Lorsque des disjoncteurs de caractéristiques 50 Hz sont essayés à 60 Hz et vice versa, il convient d'être attentif dans l'interprétation des résultats d'essais, en prenant en compte tous les faits intéressants tels que le type de disjoncteur et le type d'essai effectué.

8.102.4 Choix du courant assigné en service continu

Il convient que le courant assigné en service continu d'un disjoncteur soit choisi parmi les valeurs normales indiquées en 4.4.

Il convient de noter que les disjoncteurs n'ont aucune capacité de surintensité continue spécifiée. De ce fait, lorsqu'on choisit un disjoncteur, il est recommandé que son courant assigné en service continu convienne pour tous les courants de charge qui peuvent se produire en service. Lorsque des surintensités intermittentes, fréquentes et importantes sont prévisibles, il convient de consulter le constructeur.

8.102.5 Conditions atmosphériques et climatiques locales

Les conditions atmosphériques et climatiques normales pour les disjoncteurs sont indiquées dans l'Article 2.

On fait une distinction entre les disjoncteurs des classes «moins 5 intérieur», «moins 15 intérieur», «moins 25 intérieur», «moins 10 extérieur», «moins 25 extérieur» et «moins 40 extérieur», qui correspondent à différentes températures minimales de l'air ambiant. Il convient de consulter le constructeur si le disjoncteur est destiné à être installé dans un endroit où la température de l'air ambiant peut descendre au-dessous de –25 °C pour un disjoncteur pour l'intérieur ou au-dessous de –40 °C pour un disjoncteur pour l'extérieur, ou dans des endroits où la température de l'air ambiant peut dépasser 40 °C (ou si la valeur moyenne sur une période de 24 h dépasse 35 °C).

Pour les disjoncteurs pour l'extérieur, les conditions atmosphériques dans certaines zones sont défavorables du fait de la fumée, des vapeurs chimiques, des projections salines ou d'autres conditions analogues. Lorsque l'existence de telles conditions défavorables est connue, il convient d'apporter une attention particulière à la réalisation des parties du disjoncteur, particulièrement des isolateurs, qui sont normalement exposées à l'atmosphère.

Le comportement d'un isolateur dans de telles atmosphères dépend aussi de la fréquence des manœuvres de lavage ou de nettoyage et de la fréquence du lavage naturel par la pluie. Comme la qualité d'un isolateur, dans de telles conditions, dépend de nombreux facteurs, il n'est pas possible de donner des définitions précises des atmosphères normalement et fortement polluées. L'expérience dans la zone où l'isolateur doit être employé constitue le meilleur guide.

Si un disjoncteur doit être placé à un endroit où la pression due au vent excède 700 Pa, il convient de consulter le constructeur.

Trois classes différentes de disjoncteurs sont spécifiées en ce qui concerne la couche de glace. Ces classes correspondent à une couche de glace n'excédant pas 1 mm, 10 mm et 20 mm respectivement. Si un disjoncteur doit être placé dans un endroit où des couches de glace dépassant 20 mm sont prévisibles, il convient qu'un accord intervienne entre le constructeur et l'utilisateur en ce qui concerne la possibilité pour le disjoncteur de fonctionner correctement dans de telles conditions.

S'il y a lieu, il convient de prendre en compte les niveaux de qualification sismique auxquels il est fait référence en 2.2.4 de la CEI 62271-1.

Pour les installations intérieures, les conditions d'humidité sont données en 2.1.1e) de la CEI 62271-1. Lors du choix d'un disjoncteur, il est recommandé d'indiquer les cas où des valeurs d'humidité importantes sont prévues et où la condensation peut se produire. Il convient de trouver un accord entre le constructeur et l'utilisateur quant à la responsabilité et au degré de précautions nécessaire contre l'apparition de condensation indiquée dans la Note 3 de 2.1.1 e) de la CEI 62271-1.

Pour les disjoncteurs pour l'intérieur, il convient de consulter le constructeur pour toutes conditions spéciales de service, par exemple lors de la présence de vapeurs chimiques, d'une atmosphère agressive, de projections salines, etc.

8.102.6 Emploi à des altitudes élevées

Les conditions normales de service spécifiées dans l'Article 2 de la CEI 62271-1 se rapportent à des disjoncteurs prévus pour être utilisés à des altitudes ne dépassant pas 1 000 m.

Pour des installations à des altitudes supérieures à 1 000 m, 2.2.1 de la CEI 62271-1 est applicable.

8.103 Choix des valeurs assignées pour les conditions de fonctionnement sur défaut

8.103.1 Choix du pouvoir de coupure assigné en court-circuit

Comme il est indiqué en 4.101, le pouvoir de coupure assigné en court-circuit s'exprime par deux valeurs:

a) la valeur efficace de sa composante périodique;

b) la constante de temps de la composante apériodique du pouvoir de coupure assigné en court-circuit qui entraîne un pourcentage de la composante apériodique à la séparation des contacts.

Le pourcentage de la composante apériodique varie en fonction du temps à partir du début du court-circuit et avec la constante de temps de la composante apériodique correspondante du pouvoir de coupure assigné en court-circuit. Lorsque le disjoncteur est conforme aux exigences normalisées ou aux constantes de temps spéciales de la composante apériodique indiquées en 4.101.2, le pourcentage de la composante apériodique que peut supporter le disjoncteur au premier zéro de courant possible, est défini par les valeurs données aux Tableaux 15 à 22, pour la gamme correspondante de durées minimales d'interruption. La durée minimale d'interruption est définie en 3.7.159.

~~Les courbes de la Figure 9 correspondent à une composante périodique constante et à un facteur de puissance en court-circuit donnés dans le Tableau 35, correspondant à la valeur normale de constante de temps τ = 45 ms et aux valeurs pour les applications particulières respectives de 60 ms, 75 ms et 120 ms.~~

Les courbes de la Figure 9 correspondent à une composante périodique constante et à un facteur de puissance en court-circuit donnés dans le Tableau 35, correspondant à une constante de temps apériodique τ = 45 ms (c'est-à-dire, la constante de temps apériodique pour des tensions assignées allant jusqu'à 800 kV, cette valeur comprise), 60 ms, 75 ms et 120 ms (c'est-à-dire, la constante de temps apériodique normale pour des tensions assignées supérieures à 800 kV).

Les essais effectués avec une composante apériodique plus élevée au zéro de courant couvrent les essais avec une composante apériodique plus faible, à condition que les paramètres de l'alternance de courant (crête et durée) se situent dans les tolérances données en 6.102.10.2.1.2 b) et que les conditions de TTR associées à la composante apériodique plus faible soient satisfaites.

Tableau 35 – Relation entre le facteur de puissance en court-circuit, la constante de temps et la fréquence industrielle

Constante de temps τ (ms)	Facteur de puissance en court-circuit cosφ 50 Hz	 60 Hz
45	0,071	0,059
60	0,053	0,044
75	0,042	0,035
120	0,026	0,022

~~Lorsque le point d'utilisation est électriquement suffisamment éloigné des machines tournantes, la diminution de la composante périodique est négligeable et il est seulement nécessaire de vérifier que, dans le cas de 50 Hz, le facteur de puissance en court-circuit n'est pas inférieur à 0,071 pour la constante de temps normalisée de τ = 45 ms et que la durée minimale de la protection par relais de l'équipement de protection n'est pas inférieure à une demi-période de la fréquence assignée. Dans ces conditions, il suffit que le pouvoir de coupure assigné en court-circuit du disjoncteur choisi ne soit pas inférieur à la valeur efficace du courant de court-circuit à l'endroit où le disjoncteur doit être installé.~~

Lorsque le point d'utilisation est électriquement suffisamment éloigné des machines tournantes, la diminution de la composante périodique au moment du défaut est négligeable et il est seulement nécessaire de vérifier que, dans le cas de 50 Hz, le facteur de puissance en court-circuit n'est pas inférieur à 0,071 pour la constante de temps apériodique normalisée de τ = 45 ms, ou 0,026 dans le cas d'une constante de temps apériodique normalisée τ = 120 ms, et que la durée minimale de la protection par relais de l'équipement de protection n'est pas inférieure à une demi-période de la fréquence assignée. Dans ces conditions, il suffit que le pouvoir de coupure assigné en court-circuit du disjoncteur choisi ne soit pas inférieur à la valeur efficace du courant de court-circuit à l'endroit où le disjoncteur doit être installé.

Les séquences d'essais de court-circuit fondamentales, voir 6.106, avec les essais au courant critique, voir 6.107 et, s'il y a lieu, les essais de défaut proche en ligne, voir 6.109, ont été choisis pour démontrer que le disjoncteur est capable de couper toutes les valeurs du courant jusqu'au pouvoir de coupure assigné en court-circuit. Par conséquent, dans les cas où le courant de court-circuit présumé est inférieur, il n'est pas nécessaire d'effectuer une série d'essais de court-circuit basée sur un pouvoir de coupure assigné en court-circuit inférieur.

Dans certains cas, le pourcentage de la composante apériodique au zéro de courant le plus tôt possible peut être supérieur aux valeurs données aux Tableaux 15 à 22. Par exemple, lorsque les disjoncteurs sont à proximité des centres de production, la composante périodique peut décroître plus rapidement que dans le cas normal. Le courant de court-circuit peut ainsi ne pas passer par zéro pendant un certain nombre de périodes. Dans ce cas, la contrainte du disjoncteur peut être réduite, par exemple en retardant son ouverture, ou en insérant par l'intermédiaire d'un autre disjoncteur un dispositif d'amortissement supplémentaire et en ouvrant les disjoncteurs successivement. Si on ne peut pas adopter les valeurs normalisées ou les valeurs des constantes de temps spéciales de la composante apériodique, il convient de spécifier le pourcentage désiré dans l'appel d'offres et il est recommandé que les essais fassent l'objet d'un accord entre le constructeur et l'utilisateur; dans cette relation, l'attention est attirée sur le point b) de 8.103.2.

NOTE Le zéro de courant peut être avancé sous l'effet de la tension d'arc du disjoncteur et/ou des coupures de courants de court-circuit sur les autres phases à des zéros de courant antérieurs. Dans ce cas, les disjoncteurs normaux conviennent avec, sous réserve, une investigation particulière.

Il convient que le pouvoir de coupure assigné en court-circuit soit choisi parmi les valeurs normalisées indiquées en 4.101.1.

8.103.2 Choix de la tension transitoire de rétablissement (TTR) dans le cas de défaut aux bornes, du facteur de premier pôle et des caractéristiques assignées pour les défauts proches en ligne

Il est recommandé que la tension transitoire de rétablissement (TTR) présumée du réseau ne dépasse pas le tracé de référence représentant la tension transitoire de rétablissement assignée, spécifiée pour le disjoncteur; il est recommandé que cette onde traverse le segment de droite spécifié, définissant le retard, au voisinage du zéro de la tension, mais ne le retraverse pas ensuite (voir 4.102.2). Des valeurs normales sont indiquées en 6.104.5.

NOTE 1 Les tensions transitoires de rétablissement qui apparaissent lors de la coupure des courants de court-circuit les plus élevés ne sont pas forcément plus sévères que celles qui peuvent apparaître dans d'autres cas. Par exemple, la vitesse d'accroissement de la tension transitoire de rétablissement peut être plus élevée lors de la coupure de courants de court-circuit plus faibles.

Dans la gamme de tensions assignées supérieures à 1 kV et inférieures à 100 kV, et pour couvrir tous les types de réseaux (distribution, industriels et transport) et dans un but de standardisation, deux types de réseaux sont définis:

– réseaux par câbles (voir 3.1.132);
– réseaux aériens (voir 3.1.133).

Il convient que les considérations qui suivent permettent de faciliter le choix par l'utilisateur de la classe de disjoncteurs de tension assignée supérieure à 1 kV et inférieure à 100 kV:

– les valeurs normales de la TTR spécifiée dans l'édition 1.1 (édition 1 et amendement 1) de la CEI 62271-100 peuvent encore être exigées en spécifiant la classe S1 (ces valeurs normales de TTR sont données dans le Tableau 24);
– pour couvrir tous les cas de réseaux par câbles et aériens, à l'exception de ceux mentionnés en a), b) et c) ci-dessous, la classe S2 de disjoncteurs doit être spécifiée (les valeurs normales de TTR sont données dans le Tableau 25).

NOTE 2 Dans les cas particuliers où la longueur de câble(s) (ou la longueur équivalente si des condensateurs sont aussi présents) du côté alimentation du disjoncteur est entre 20 m et 100 m, le réseau est considéré comme étant un réseau aérien sauf si un calcul peut montrer que la TTR du réseau considéré est couverte par l'enveloppe définie par le Tableau 24. Si la TTR est couverte, le réseau est considéré comme étant un réseau par câbles.

~~Les valeurs normalisées indiquées pour les tensions assignées inférieures à 100 kV sont applicables à un facteur de premier pôle (k_{pp}) de 1,5. Pour les tensions assignées de 100 kV à 800 kV, le facteur de premier pôle est de 1,3 car la plupart des réseaux de tension supérieure ou égale à 100 kV ont un neutre relié effectivement à la terre. Pour les tensions assignées de 100 kV à 170 kV, le choix d'un facteur de premier pôle de 1,5 est pour les cas spéciaux d'application dans des réseaux avec un neutre relié non effectivement à la terre (voir aussi la note de 6.104.5.4).~~

~~Le facteur de premier pôle de 1,3 correspond à un réseau à neutre effectivement à la terre où des défauts triphasés isolés de la terre sont considérés comme fortement improbables. Il est recommandé d'utiliser le facteur de premier pôle 1,5 pour les applications à des réseaux à neutre non effectivement à la terre. Un facteur de premier pôle de 1,5 peut être nécessaire pour les applications à des réseaux à neutre effectivement à la terre lorsqu'on ne peut pas négliger la probabilité de défauts triphasés isolés de la terre et pour les applications à des réseaux autres qu'à neutre effectivement à la terre.~~

Les valeurs normalisées indiquées pour les tensions assignées inférieures à 100 kV sont applicables à un facteur de premier pôle k_{pp} de 1,5. Pour les tensions assignées de 100 kV à 800 kV, k_{pp} est de 1,3 car la plupart des réseaux de tension supérieure ou égale à 100 kV ont un neutre relié effectivement à la terre. Pour les tensions assignées de 100 kV à 170 kV, le choix d'un k_{pp} compris entre 1,3 et 1,5 est pour les cas spéciaux d'application dans des réseaux avec un neutre relié non effectivement à la terre (voir aussi la note du 6.104.5.4). Pour les tensions assignées supérieures à 800 kV, k_{pp} est égal à 1,2.

Les valeurs de k_{pp} de 1,3 et 1,2 correspondent à un réseau à neutre effectivement à la terre où des défauts triphasés isolés de la terre sont considérés comme fortement improbables. Il convient d'utiliser k_{pp} = 1,5 pour les applications à des réseaux à neutre non effectivement à la terre. Un k_{pp}= 1,5 peut être nécessaire pour les applications à des réseaux à neutre effectivement à la terre lorsqu'on ne peut pas négliger la probabilité de défauts triphasés isolés de la terre et pour les applications à des réseaux autres qu'à neutre effectivement à la terre.

Il ne sera généralement pas nécessaire de prendre en considération d'autres tensions transitoires de rétablissement, étant donné que les valeurs normalisées spécifiées couvrent la majorité des cas pratiques.

Toutefois, des conditions plus sévères peuvent se produire dans certains cas, par exemple:

a) Lorsqu'un court-circuit se produit près d'un transformateur mais sur le côté opposé au disjoncteur et qu'il n'y a pas de capacité additionnelle appréciable entre le transformateur et le disjoncteur. Dans ce cas la valeur de crête ainsi que la vitesse d'accroissement de la tension transitoire de rétablissement peuvent dépasser les valeurs spécifiées dans la présente norme.

   NOTE 3 Il est également recommandé de prêter attention au choix d'un disjoncteur installé au primaire d'un transformateur et pouvant avoir à couper le courant correspondant à un court-circuit au secondaire.

   ~~Pour les disjoncteurs de tensions assignées inférieures à 100 kV, de tels cas sont couverts dans l'Annexe M.~~

   Ces cas sont traités à l'Annexe M.

   ~~NOTE 4 Pour les disjoncteurs de tensions assignées supérieures ou égales à 100 kV, des valeurs de TTR pour les défauts alimentés par un transformateur sont proposés dans ANSI C37.06.1 [8] pour vitesses rapides de rétablissement de tension.~~

b) Les disjoncteurs utilisés au voisinage de réactances de limitation peuvent rencontrer des problèmes de coupure à cause de la fréquence propre élevée de ces réactances (voir 8.103.7).

c) Dans le cas d'un court-circuit intéressant les disjoncteurs proches de générateurs, la vitesse d'accroissement de la tension transitoire de rétablissement peut dépasser les valeurs spécifiées dans la présente norme.

Dans ces cas, il peut être nécessaire de prévoir un accord entre le constructeur et l'utilisateur sur des caractéristiques spéciales de la tension transitoire de rétablissement.

Les défauts proches en ligne sont applicables seulement pour les disjoncteurs prévus pour être reliés directement à des lignes aériennes (sans liaison par câble) et dont la tension assignée est égale ou supérieure à 15 kV et le pouvoir de coupure assigné en court-circuit supérieur à 12,5 kA. Lorsque les disjoncteurs sont prévus pour des installations dans lesquelles il est nécessaire de spécifier des caractéristiques assignées pour les défauts proches en ligne, il convient que l'impédance d'onde et le facteur de crête de la ligne sur laquelle ils seront utilisés ne dépassent pas les valeurs normales des caractéristiques assignées de la ligne indiquées au Tableau 8. De même, il convient que le retard ne soit pas inférieur à la valeur correspondante indiquée dans ce même tableau. Cependant, si tel n'est pas le cas, il est encore possible qu'un disjoncteur normal convienne, spécialement si le courant de court-circuit du réseau est inférieur au pouvoir de coupure assigné en court-circuit du disjoncteur. Cette possibilité peut être confirmée en calculant la TTR présumée pour les défauts proches en ligne à partir des caractéristiques assignées, par la méthode indiquée dans l'Annexe A et en la comparant à la TTR présumée déduite des caractéristiques réelles du réseau.

Si l'on prévoit des caractéristiques spéciales pour le défaut proche en ligne, il convient qu'elles fassent l'objet d'un accord entre le constructeur et l'utilisateur.

Une vitesse d'accroissement plus élevée que celle qui est spécifiée dans les Tableaux 1, 2, 3, 4 et 5 peut être obtenue si une borne du disjoncteur est reliée à un transformateur. Les disjoncteurs essayés conformément à cette norme sont considérés comme répondant à cette exigence de vitesse d'accroissement plus élevée à condition qu'ils aient subi avec succès les essais de la séquence T30 des séries d'essai en court-circuit fondamentales (voir 6.106.2).

8.103.3 Choix des caractéristiques en cas de discordance de phases

Les exigences de la présente norme couvrent la grande majorité des applications des disjoncteurs destinés à effectuer des manœuvres lors de discordances de phases. Pour faire apparaître des conditions plus sévères que celles qui sont couvertes par les essais de cette norme, il faudrait réunir simultanément plusieurs circonstances défavorables et, comme les manœuvres lors de discordances de phases sont rares, il ne serait pas économique de concevoir les disjoncteurs pour les conditions les plus extrêmes.

Il convient de prendre en compte les caractéristiques réelles de réseau lorsqu'on prévoit de fréquentes manœuvres en discordance de phases ou lorsque des contraintes sévères sont probables.

Il peut parfois être nécessaire d'utiliser un disjoncteur spécial ou un disjoncteur de tension assignée supérieure. En variante, on peut réduire, dans divers réseaux, la sévérité des contraintes dues aux manœuvres en discordance de phases en utilisant des relais possédant des éléments coordonnés sensibles à l'impédance pour déterminer l'instant de déclenchement, de façon à ce que la coupure survienne soit notablement après, soit notablement avant l'instant où l'angle de phase atteint 180°.

Dans le cas d'applications de disjoncteurs de tensions assignées supérieures à 800 kV, un angle de discordance de phases d'environ 115° est couvert; toutefois, des valeurs d'angle supérieures sont couvertes lorsqu'on tient compte d'autres facteurs tels que la non simultanéité des crêtes de tension, un k_{pp} inférieur (voir la CEI 62271-306 [4]).

8.103.4 Choix du pouvoir de fermeture assigné en court-circuit

~~Comme indiqué en 4.103, le pouvoir de fermeture assigné en court-circuit d'un disjoncteur correspond à sa tension assignée et dépend de la fréquence assignée et de la constante de temps du réseau. Pour une fréquence assignée de 50 Hz et pour la constante de temps normale τ = 45 ms, il doit être égal à 2,5 fois (c'est-à-dire approximativement à 1,8$\sqrt{2}$ fois) la composante périodique du pouvoir de coupure assigné en court-circuit. Pour une fréquence assignée de 60 Hz et pour la constante de temps normale τ = 45 ms, il doit être égal à 2,6 fois la composante périodique du pouvoir de coupure assigné en court-circuit du disjoncteur.~~

~~Dans les cas des constantes de temps spéciales, telles que définies en 4.101.2 (60 ms, 75 ms ou 120 ms), prenant en compte les explications de I.2, le pouvoir de fermeture assigné doit être de 2,7 fois la composante périodique du pouvoir de coupure assigné du disjoncteur, pour 50 Hz et 60 Hz quelque soit la fréquence assignée.~~

Comme indiqué en 4.103, le pouvoir de fermeture assigné en court-circuit d'un disjoncteur est déduit de la tension assignée et dépend de la fréquence assignée et de la constante de temps de la composante apériodique du pouvoir de coupure assigné en court-circuit. Pour une fréquence assignée de 50 Hz et pour la constante de temps τ = 45 ms, il est égal à 2,5 fois (c'est-à-dire approximativement à 1,8$\sqrt{2}$ fois) la composante périodique du pouvoir de coupure assigné en court-circuit du disjoncteur. Pour une fréquence assignée de 60 Hz et pour la constante de temps τ = 45 ms, il est égal à 2,6 fois la composante périodique du pouvoir de coupure assigné en court-circuit du disjoncteur.

Dans les cas des autres constantes de temps apériodiques, telles que définies en 4.101.2 (60 ms, 75 ms ou 120 ms), prenant en compte les explications de I.2, le pouvoir de fermeture assigné est de 2,7 fois la composante périodique du pouvoir de coupure assigné du disjoncteur, pour des fréquences assignées à la fois de 50 Hz et 60 Hz.

Il est recommandé que le pouvoir de fermeture assigné en court-circuit du disjoncteur choisi ne soit pas inférieur à la plus grande valeur de crête du courant de court-circuit prévu au point d'application.

Dans certains cas, par exemple, lorsque des moteurs à induction sont électriquement proches, la valeur maximale de crête du courant de défaut peut être supérieure à la composante périodique du courant de court-circuit multipliée par les facteurs ci-dessus. Dans de tels cas, il est recommandé d'éviter une construction spéciale et de choisir un disjoncteur normal possédant un pouvoir de fermeture assigné en court-circuit convenable.

8.103.5 Séquence de manœuvres en service

Il convient que la séquence de manœuvres assignée d'un disjoncteur soit l'une des séquences de manœuvres indiquées en 4.104. Sauf spécification contraire, les valeurs des intervalles de temps indiquées en 4.104 sont applicables et les séquences de manœuvres assignées à prévoir sont les suivantes:

a) O – 3 min – CO – 3 min – CO;

b) CO – 15 s – CO;

c) O – 0,3 s – CO – 3 min – CO (pour les disjoncteurs prévus pour la refermeture automatique rapide.)

NOTE Au lieu de 3 min, d'autres durées de 15 s (pour les tensions assignées inférieures ou égales à 52 kV) et 1 min sont aussi utilisées pour les disjoncteurs prévus pour la refermeture automatique rapide. La durée à choisir dépend en principe d'exigences du réseau telles que la continuité de service.

Si le pouvoir de coupure en court-circuit du disjoncteur au cours d'une séquence de refermeture automatique est inférieur au pouvoir de coupure assigné en court-circuit, il convient que cela soit spécifié par le constructeur.

Lorsque la séquence de manœuvres en service est plus sévère que celle qui est prévue par la présente norme, il convient que cette séquence soit spécifiée par l'utilisateur dans son appel d'offres et/ou dans sa commande, de telle sorte que le constructeur puisse modifier d'une manière appropriée les caractéristiques assignées du disjoncteur. Comme exemples de disjoncteurs pour des séquences spéciales, on peut citer ceux pour la commande des fours à arc, des chaudières à électrodes et, dans certains cas, d'installations de redresseurs. Le fonctionnement unipolaire d'un disjoncteur multipolaire, par exemple en vue d'une fermeture et d'une ouverture en monophasé, constitue aussi un emploi spécial.

8.103.6 Choix de la durée de court-circuit assignée

La valeur normale de la durée de court-circuit assignée (4.7 de la CEI 62271-1) est égale à 1 s.

Si, toutefois, une durée inférieure ou supérieure est nécessaire, il est recommandé de choisir parmi les valeurs de 0,5 s, 2 s ou 3 s comme la valeur assignée.

Pour les durées de court-circuit supérieures à la durée assignée, la relation entre le courant et le temps est, sauf indication contraire du constructeur, donnée par la formule suivante:

$$I^2 \times t = \text{constante}$$

Une durée de court-circuit doit être assignée aux disjoncteurs à déclenchement autonome seulement si la temporisation maximum est supérieure à la durée présumée. Dans ce cas, elle doit être définie de la même manière que ci-dessus.

8.103.7 Défauts en présence de réactances de limitation

En raison de la très faible capacitance inhérente à un certain nombre de réactances de limitation, la fréquence naturelle des tensions transitoires concernant ces réactances peut être très grande. Un disjoncteur installé immédiatement en série avec ce type de réactance devra subir une TTR à fréquence élevée en coupure de défaut aux bornes (la réactance étant du côté alimentation du disjoncteur) ou dans le cas de coupure d'un défaut en aval de la réactance (réactance du côté charge du disjoncteur). La fréquence de la TTR résultante excède généralement nettement les valeurs normalisées.

Dans de tels cas, il est nécessaire de prendre des mesures de correction, comme le montage de condensateurs en parallèle aux réactances ou connectées à la terre. Ces mesures de correction sont disponibles, efficaces et économiques. Il est fortement recommandé de les utiliser, à moins qu'il puisse être démontré par des essais que le disjoncteur est capable d'interrompre les défauts avec une haute fréquence de la TTR requise.

Il est recommandé que la méthode de correction soit telle que la vitesse de rétablissement de la TTR pour le courant de défaut limité par la réactance série, soit réduite à une valeur inférieure à celle des valeurs normalisées données dans les Tableaux 24 ou 25, en fonction des valeurs assignées du disjoncteur. Il doit être considéré que le courant de défaut peut être proche de 100 % du pouvoir de coupure du disjoncteur.

Compte tenu des considérations qui précèdent, il n'y a pas de valeurs normalisées de TTR et il n'est pas exigé de séquence d'essais particulières pour ce type de défaut.

8.104 Choix de l'endurance électrique pour les réseaux de tension assignée supérieure à 1 kV et jusqu'à 52 kV inclus

Les disjoncteurs de classe E2 sont définis en 3.4.113. La capacité d'endurance électrique pour ce service est démontrée par la réalisation de la séquence d'essais en court-circuit de 6.106, sans maintenance intermédiaire. Cette endurance électrique est suffisante pour les disjoncteurs utilisés sur des réseaux câblés où la refermeture automatique n'est pas exigée.

Pour les conditions d'utilisation plus sévères sur les réseaux de lignes aériennes où la refermeture automatique est nécessaire, on recommande l'utilisation d'un disjoncteur à faible maintenance, capable de satisfaire aux exigences d'endurance électrique définies en 6.112.

8.105 Choix de la manœuvre de courant capacitif

Lorsque des batteries de condensateurs sont installées dans des sous-stations où des câbles sont déjà présents, et vice versa, on sera attentif aux exigences des courants d'appel pour le disjoncteur manœuvrant ces circuits. Cette exigence peut être semblable à celle détaillée en 4.107.4.

9 Renseignements à donner dans les appels d'offres, les soumissions et les commandes

9.101 Renseignements à donner dans les appels d'offres et les commandes

En faisant un appel d'offres ou en passant commande d'un disjoncteur, il est recommandé à l'utilisateur de fournir les renseignements suivants:

a) caractéristiques propres au réseau, c'est-à-dire tensions nominale et la plus élevée, fréquence, nombre de phases, et modalités de mise à la terre du neutre;

b) conditions en service comprenant les températures minimale et maximale de l'air ambiant, cette dernière, si elle est supérieure à la valeur normale; l'altitude, si elle est supérieure à 1 000 m; et toutes conditions spéciales susceptibles d'exister ou de se produire, par exemple l'exposition inhabituelle à la vapeur d'eau, à l'humidité, aux vapeurs chimiques, aux atmosphères explosives, à une poussière excessive ou à l'air salin (voir 8.102.5 et 8.102.6);

c) caractéristiques du disjoncteur.

Il est recommandé de donner les renseignements suivants:

	Type de caractéristiques	Référence
1)	le nombre de pôles	
2)	la classe: pour l'intérieur ou pour l'extérieur	8.102.5
3)	la tension assignée	8.102.1
4)	le niveau d'isolement assigné s'il existe un choix entre différents niveaux d'isolement correspondant à une tension assignée donnée ou, s'il est différent du niveau normal, le niveau d'isolement demandé	8.102.2
5)	la fréquence assignée	8-102.3
6)	le courant assigné en service continu	8.102.4
7)	le pouvoir de coupure assigné en court-circuit	8.103.1
8)	le facteur de premier pôle	8.103.2
9)	la séquence de manœuvres assignée	8.103.5
10)	la durée de coupure	4.109
11)	la fréquence de manœuvres mécaniques (classe M1 ou M2)	4.110
12)	les essais de type spécifiés sur demande spéciale (par exemple pollution artificielle et perturbations radioélectriques, etc.)	6.2.8 et 6.3
Il est recommandé de donner les renseignements suivants, si la performance requise diffère de la performance normale		
13)	la tension transitoire de rétablissement souhaitée pour les défauts aux bornes	8.103.2
14)	les caractéristiques souhaitées pour les défauts proches en ligne	8.103.2
15)	le pouvoir de fermeture souhaité en court-circuit	8.103.4
16)	la durée de court-circuit souhaitée	8.103.6
Il est recommandé de donner les renseignements suivants en cas d'applicabilité		

17)	la performance de réamorçage pendant les essais d'établissement et de coupure de courants capacitifs (classe C1 ou C2)	4.107
18)	les caractéristiques des conditions de manœuvre capacitives (par exemple conditions de mise à la terre, type de charge capacitive, etc)	4.107
19)	le pouvoir de coupure assigné de lignes à vide	4.107.1
20)	le pouvoir de coupure assigné de câbles à vide	4.107.2
21)	le pouvoir de coupure assigné de batterie unique de condensateurs	4.107.3
22)	le pouvoir de coupure assigné de batteries de condensateurs à gradins	4.107.4
23)	le pouvoir de fermeture assigné de batterie unique de condensateurs	4.107.5
24)	le pouvoir de fermeture assigné de batteries de condensateurs à gradins	4.107.6
25)	les pouvoirs de coupure et de fermeture assignés en discordance de phases	4.106
26)	la caractéristique d'endurance électrique (classe E1 ou E2, avec ou sans cycle de refermeture automatique)	4.111
27)	le courant coupé de charges inductives	4.108
28)	tout essai au-delà des essais de type, individuels de série et de mise en service normalisés	

d) caractéristiques du mécanisme de commande du disjoncteur et de l'équipement associé, en particulier:

1) le mode de commande, manuel ou par une source d'énergie;
2) le nombre et le type des contacts auxiliaires de réserve;
3) la tension assignée d'alimentation et la fréquence assignée d'alimentation;
4) le nombre de dispositif de déclenchement, si plus d'un;
5) le nombre de dispositif d'enclenchement, si plus d'un.

e) exigences relatives à l'utilisation de gaz comprimé et exigences relatives à la construction et aux essais des réservoirs de pression.

NOTE Il est recommandé au demandeur de donner des renseignements sur toutes les conditions spéciales, non énumérées précédemment, qui pourraient avoir une influence sur la soumission ou la commande (voir aussi la note en 8.101).

9.102 Renseignements à donner avec les soumissions

Lorsque le demandeur désire connaître les caractéristiques techniques d'un disjoncteur, il est recommandé au constructeur de donner les renseignements suivants (ceux qui sont applicables) avec les notices descriptives et les plans:

a) valeurs assignées et caractéristiques:

	Type de caractéristiques	Référence
1)	le nombre de pôles	
2)	la classe: pour l'intérieur ou pour l'extérieur, température, couche de glace	8.102.5
3)	la tension assignée	8.102.1
4)	le niveau d'isolement assigné	8.102.2
5)	la fréquence assignée	8.102.3
6)	le courant assigné en service continu	8.102.4
7)	le pouvoir de coupure assigné en court-circuit	8.103.1
8)	le facteur de premier pôle	8.103.2
9)	la séquence de manœuvres assignée	8.103.5

10) la durée d'ouverture, la durée de coupure, et la durée de fermeture assignées	4.109
11) la classe M1 ou la classe M2 pour l'endurance mécanique	4.110
12) les essais de type spécifiés sur demande spéciale (par exemple pollution artificielle et perturbations radioélectriques, etc.)	6.2.8 et 6.3
Il est recommandé de donner les renseignements suivants, si la performance requise diffère de la performance normale	
13) la tension transitoire de rétablissement pour les défauts aux bornes	8.103.2
14) les caractéristiques pour les défauts proches en ligne	8.103.2
15) le pouvoir de fermeture assigné en court-circuit	8.103.4
16) la durée de court-circuit assignée	8.103.6
Il est recommandé de donner les renseignements suivants en cas d'applicabilité	
17) la performance de réamorçage pendant les essais d'établissement et de coupure de courants capacitifs (classe C1 ou C2)	4.107
18) les caractéristiques des conditions d'établissement et de coupure de courants capacitifs	4.107
19) le pouvoir de coupure assigné de lignes à vide	4.107.1
20) le pouvoir de coupure assigné de câbles à vide	4.107.2
21) le pouvoir de coupure assigné de batterie unique de condensateurs	4.107.3
22) le pouvoir de coupure assigné de batteries de condensateurs à gradins	4.107.4
23) le pouvoir de fermeture assigné de batterie unique de condensateurs	4.107.5
24) le pouvoir de fermeture assigné de batteries de condensateurs à gradins	4.107.6
25) les pouvoirs de coupure et de fermeture assignés en discordance de phases	4.106
26) la classe E1 ou la classe E2 (avec ou sans réenclenchement) pour l'endurance électrique	4.111
27) disjoncteurs de classe S1, S2 (disjoncteurs de tensions assignées inférieures à 100 kV)	6.104.5
28) le courant coupé inductif faible	4.108
29) tout essai au-delà des essais de type, individuels de série et de mise en service normalisés	

b) essais de type :

certificat ou rapport sur demande;

c) détails constructifs :

Les détails suivants sont requis s'il y a lieu, suivant la conception:

1) masse du disjoncteur complet sans le fluide d'isolation, de coupure et de manœuvre;
2) masse/volume de fluide pour l'isolation, sa qualité et la gamme opératoire, y compris la valeur minimale de fonctionnement;
3) masse/volume de fluide pour la coupure (si le fluide est différent de celui du point 2) et/ou 4)), sa qualité et la gamme opératoire, y compris la valeur minimale de fonctionnement;
4) masse/volume de fluide pour la manœuvre (si le fluide est différent de celui du point 2) et/ou 4)), sa qualité et la gamme opératoire, y compris la valeur minimale de fonctionnement;
5) la qualification en étanchéité;
6) masse/volume de fluide par pôle, à remplir jusqu'à un niveau suffisant pour empêcher toute dégradation de composant interne pendant le stockage et le transport;
7) nombre d'éléments de coupure en série par pôles;
8) distances minimales dans l'air:
   – entre pôles;
   – à la terre;

- limites du périmètre de sécurité pendant une manœuvre de coupure pour les disjoncteurs munis d'un dispositif d'évacuation à l'extérieur des gaz ionisés ou des flammes;

9) toute autre disposition spéciale pour assurer le maintien des caractéristiques assignées du disjoncteur aux températures extrêmes de l'air ambiant exigées (par exemple, chauffage, refroidissement);

d) mécanisme de commande d'un disjoncteur et équipement associé:

1) type du dispositif de fermeture;
2) si le disjoncteur convient pour la manœuvre à déclenchement libre ou à déclenchement conditionné et s'il est prévu avec un dispositif de verrouillage à fermeture empêchée;
3) tension assignée d'alimentation et/ou pression du mécanisme de fermeture, avec ses limites si elles diffèrent ou dépassent les valeurs spécifiées en 9.102 c) 4);
4) courant requis à la tension assignée d'alimentation pour fermer le disjoncteur;
5) énergie nécessaire à la fermeture du disjoncteur, par exemple mesurée en chute de pression;
6) tension assignée d'alimentation du déclencheur shunt d'ouverture;
7) courant requis à la tension assignée d'alimentation pour le déclencheur shunt d'ouverture;
8) nombre et type des contacts auxiliaires de réserve;
9) courant requis à la tension assignée d'alimentation par les autres auxiliaires;
10) réglage des dispositifs de verrouillage à haute et à basse pression;
11) le nombre de dispositif de déclenchement, si plus d'un;
12) le nombre de dispositif d'enclenchement, si plus d'un;

e) Encombrement maximal et autres renseignements:

Il est recommandé au constructeur de donner les renseignements nécessaires concernant l'encombrement maximal du disjoncteur et les renseignements détaillés nécessaires à l'établissement de la fondation.

Il est recommandé de donner des renseignements généraux concernant la maintenance du disjoncteur et de ses raccordements.

10 Règles pour le transport, le stockage, l'installation, la manœuvre et la maintenance

L'Article 10 de la CEI 62271-1 est applicable avec les compléments suivants:

10.1 Conditions à respecter pendant le transport, le stockage et l'installation

Le paragraphe 10.1 de la CEI 62271-1 est applicable.

10.2 Installation

Les paragraphes 10.2.1 à 10.2.4 de la CEI 62271-1 sont applicables avec le complément suivant:

10.2.101 Essais de mise en service

Après l'installation du disjoncteur et l'achèvement de tous les raccordements, il convient d'effectuer les essais de mise en service. L'objet de tels essais est de contrôler que le transport et le stockage n'ont pas endommagé le disjoncteur. De plus, quand une grande partie de l'assemblage et/ou du réglage est exécutée sur le site comme indiqué en 7.101, les essais sont nécessaires pour vérifier la compatibilité des sous-ensembles et contrôler la qualité du travail et les caractéristiques fonctionnelles dépendant de ce travail.

En complément des exigences de 10.2.102, un nombre minimal de 50 manœuvres à vide doit être fait à la mise en service du disjoncteur lorsque de grands sous-ensembles sont assemblés sur site sans essais de routine antérieurs sur le disjoncteur complet. Ces manœuvres doivent être faites après l'assemblage, les raccordements et les vérifications et après l'exécution du programme d'essais de mise en service. Ces manœuvres peuvent comprendre des manœuvres différées d'essais de routine faisant partie du programme d'essais de mise en service seulement lorsqu'elles sont faites après l'exécution des réglages sur site et des contrôles d'étanchéité. Le but de ces essais est de réduire les cas de mauvais fonctionnement et de défaut peu de temps après la mise en service du disjoncteur.

Le constructeur doit établir un programme d'essais et de vérifications à la mise en service. La répétition du programme complet d'essais individuels, déjà effectué en usine, doit être évitée dans la mesure où le but des essais de mise en service est de confirmer

– l'absence de dommage;
– la compatibilité d'éléments séparés;
– que le montage est correctement effectué;
– qu'après assemblage le disjoncteur a des performances correctes.

En général, cela est obtenu lorsque le programme d'essais de mise en service se compose, sans y être limité, du programme donné dans 10.2.102. Les résultats des essais doivent être enregistrés dans un compte rendu d'essais.

10.2.102 Programme d'essais et de vérifications à la mise en service

10.2.102.1 Vérifications après montage

Le paragraphe 10.2.101 exige que le constructeur établisse un programme d'essais et de vérifications à la mise en service; il convient que celui-ci soit basé sur, sans y être limité, le programme d'essais et de vérifications donné ici.

10.2.102.1.1 Vérification générale

– vérification de l'assemblage, conformément aux dessins et aux instructions du constructeur;
– vérification de l'étanchéité du disjoncteur, des serrages, des systèmes hydrauliques et des dispositifs de commande;
– vérification que l'isolation externe et, si cela s'applique, l'isolation interne, sont propres et non endommagées;
– vérification de la peinture et de la protection contre la corrosion;
– vérification de la propreté des dispositifs de commande, en particulier des déclencheurs de manœuvre;
– vérification que le raccordement à la terre est complet et suffisant jusqu'à et y compris l'interface avec le réseau de mise à la terre du poste;

et si applicable:

– enregistrement du nombre de manœuvres indiqué par le ou les compteurs à la livraison;
– enregistrement du nombre de manœuvres indiqué par le ou les compteurs à l'issue des essais de mise en service;
– enregistrement du nombre de manœuvres indiqué par le ou les compteurs lors de la première alimentation par le réseau.

10.2.102.1.2 Vérification des circuits électriques

– Conformité au schéma de filerie.

– Fonctionnement correct de la signalisation (positions, alarmes, verrouillages, etc.).

– Fonctionnement correct du chauffage et de l'éclairage.

10.2.102.1.3 Vérification du ou des fluides d'isolement et/ou d'extinction

Huile	Type, tenue diélectrique (CEI 60296), niveau
SF_6	Vérification de la pression de remplissage/de la densité et de la qualité, pour confirmer les niveaux d'acceptation, respectivement, de la CEI 60376, de la CEI 60480 et CEI 61634. Cette vérification de la qualité n'est pas exigée pour les appareils scellés et dans le cas de gaz neuf provenant de bouteilles scellées. Une vérification du point de rosée et du niveau total d'impuretés doit être effectué pour confirmer les critères d'acceptation du constructeur
Mélanges gazeux	La qualité doit être confirmée avant alimentation par le réseau
Air comprimé	Qualité (si cela est applicable) et pression

10.2.102.1.4 Vérification du ou des fluides de manœuvre, en cas de remplissage ou de complément sur site

Huile hydraulique	Niveau et, à moins d'un accord contraire, confirmation que l'humidité contenue est suffisamment faible pour éviter une corrosion interne ou d'autres dommages au système hydraulique
Azote	Pression de remplissage, et pureté (par exemple sans oxygène ou avec 1 % de gaz traceur)

10.2.102.1.5 Manœuvres de mise en service

Confirmation doit être donnée que le programme d'essais et de vérifications de mise en service exigé en 7.101 a été effectué et, si applicable, complété par les 50 manœuvres additionnelles exigées en 10.2.101.

10.2.102.2 Essais mécaniques et mesurages

10.2.102.2.1 Mesurages des pressions caractéristiques du fluide d'isolement et/ou de coupure (si applicable)

10.2.102.2.1.1 Généralités

Les mesurages suivants doivent être faits afin de les comparer à la fois avec les valeurs enregistrées en essais individuels et avec celles garanties par le constructeur. Ces valeurs servent de référence pour les futures maintenances et d'autres vérifications, et permettront de déceler une dérive éventuelle des caractéristiques de fonctionnement.

Ces mesurages comprennent, si applicable, une vérification du fonctionnement des dispositifs d'alarme et de verrouillage (manostat, relais, transducteurs, etc.).

10.2.102.2.1.2 Mesurages à effectuer

a) Si applicable, mesurages à la montée en pression:

  – valeur de désactivation du verrouillage d'ouverture/déclenchement;

– valeur de désactivation du verrouillage de fermeture;
– valeur de désactivation du verrouillage de refermeture automatique;
– valeur de disparition de l'alarme de basse pression.

b) Si applicable, mesurages à la baisse de pression:
– valeur d'apparition de l'alarme de basse pression;
– valeur d'activation du verrouillage de refermeture automatique;
– valeur d'activation du verrouillage de fermeture;
– valeur d'activation du verrouillage d'ouverture.

10.2.102.2.2 Mesurages des pressions caractéristiques du fluide de commande (si applicable)

10.2.102.2.2.1 Généralités

Il convient que les mesurages suivants (liste à adapter suivant les cas) soient en principe effectués pour être comparés à la fois aux valeurs enregistrées lors des essais individuels et aux valeurs garanties par le constructeur. Ces valeurs peuvent servir de référence lors des contrôles ultérieurs (maintenance) et permettront de déceler une dérive éventuelle des caractéristiques de fonctionnement.

Ces mesurages impliquent une vérification de la manœuvre des dispositifs de verrouillage et d'alarme (pressostats, relais, etc.).

10.2.102.2.2.2 Mesurages à effectuer

a) A la montée en pression, avec le dispositif de gonflage (pompe, compresseur, vanne commandée, etc.) en service:
– valeur de désactivation du verrouillage d'ouverture;
– valeur de désactivation du verrouillage de fermeture;
– valeur de désactivation du verrouillage de refermeture automatique (si applicable);
– valeur de disparition de l'alarme de basse pression;
– valeur d'arrêt du dispositif de regonflage;
– valeur d'ouverture de la soupape de sûreté (si applicable).

NOTE Les mesurages peuvent être combinés avec le mesurage des temps de regonflage du dispositif de commande (voir 10.2.102.2.5.2).

b) A la descente en pression, le dispositif de gonflage étant maintenu hors service:
– valeur de fermeture de la soupape de sûreté (si applicable);
– valeur de démarrage du dispositif de regonflage;
– valeur d'apparition de l'alarme de basse pression;
– valeur d'activation du verrouillage de refermeture automatique (si applicable);
– valeur d'activation du verrouillage de fermeture;
– valeur d'activation du verrouillage d'ouverture.

Dans le cas d'une commande hydraulique, il convient d’indiquer, avant le début des essais, la pression de prégonflage des accumulateurs à la température de l'air ambiant.

10.2.102.2.3 Mesurage des consommations lors des manœuvres (si applicable)

Le dispositif de gonflage étant hors service et la réserve individuelle à la pression de démarrage du dispositif de gonflage, il convient d'évaluer les consommations lors de chacune des manœuvres ou séquences suivantes:

– O tripolaire;
– C tripolaire;
– O – 0,3 s – CO tripolaire (si applicable).

Il convient de noter la pression stabilisée après chaque manœuvre ou séquence de manœuvre.

10.2.102.2.4 Vérification de la séquence assignée de fonctionnement

Il convient de vérifier la faculté du disjoncteur à effectuer sa séquence de fonctionnement assignée. Il convient de vérifier que les essais soient effectués en principe avec les dispositifs de recharge en service, à la tension d'alimentation sur le site et, si cela est applicable, en partant de la pression de démarrage du dispositif de gonflage comme en 10.2.102.2.3.

Il convient de démontrer la coordination entre les niveaux d'intervention du dispositif de verrouillage et les valeurs minimales de pression mesurées pendant la séquence de manœuvres assignée.

La tension d'alimentation sur le site est la tension en charge disponible sur le disjoncteur à partir de la source normale sur le site, et il convient qu'elle soit compatible avec la tension d'alimentation assignée des circuits auxiliaires et de commande.

10.2.102.2.5 Mesurages des durées

10.2.102.2.5.1 Durées caractéristiques du disjoncteur

a) Durées de fermeture et d'ouverture, écart de simultanéité

   Il convient d'effectuer les mesurages suivants à la pression maximale (arrêt du dispositif de gonflage) et à la tension d'alimentation des circuits auxiliaires et de commande, mesurée aux bornes de l'équipement et dans les conditions de charge types de la source de tension d'alimentation:

   – durée de fermeture de chaque pôle, écart de simultanéité des pôles et, lorsque cela est possible, écarts de simultanéité des éléments de coupure ou des groupes d'éléments d'un même pôle;

   – durée d'ouverture de chaque pôle, écart de simultanéité des pôles et, lorsque cela est possible, écart de simultanéité des éléments de coupure ou des groupes d'éléments d'un même pôle.

   Il convient d'effectuer ces mesures pour des manœuvres séparées d'ouverture et de fermeture et pour les manœuvres individuelles d'ouverture et de fermeture d'un cycle de manœuvres CO, dans le cas d'un disjoncteur avec une séquence de manœuvres assignée CO – t'' – CO, ou d'une séquence de manœuvres O – t – CO, dans le cas d'un disjoncteur avec une séquence de manœuvres assignée O – t – CO – t' – CO.

   Dans le cas de bobines de déclenchement multiples, il convient de toutes les essayer et d'enregistrer les temps pour chacune d'elles.

   Il convient d'enregistrer la tension d'alimentation avant et pendant les manœuvres. Il convient aussi d'enregistrer l'instant d'alimentation du relais de commande tripolaire, s'il existe, de manière à déterminer le temps total en fonctionnement tripolaire (temps du relais plus durée de fermeture ou d'ouverture).

   Lorsque le disjoncteur est pourvu de résistances de fermeture ou d'ouverture, il convient d'en enregistrer les durées d'insertion.

b) Fonctionnement des contacts de commande et des contacts auxiliaires

On détermine la position dans le temps du fonctionnement de l'un des contacts auxiliaires et de commande de chaque sorte (à fermeture et à ouverture) par rapport à celui des contacts principaux, à la fermeture et à l'ouverture du disjoncteur.

10.2.102.2.5.2 Durée de réarmement de l'organe de commande

a) Organe de commande fonctionnant avec un fluide

Il convient de mesurer le temps de fonctionnement du dispositif de gonflage (pompe, compresseur, vanne commandée) :

– entre la pression minimale et la pression maximale (démarrage et arrêt du dispositif de gonflage);

– lors des manœuvres ou séquences de manœuvres suivantes, en partant chaque fois de la pression minimale (démarrage du dispositif de gonflage):

  – C tripolaire;

  – O tripolaire;

  – O – 0,3 s – CO tripolaire (si applicable).

b) Organe de commande à ressort

Il convient de mesurer la durée de fonctionnement du moteur pour le réarmement, à la tension d'alimentation sur le site.

10.2.102.2.6 Enregistrement des caractéristiques de déplacement mécanique

Comme exigé en 7.101, un enregistrement des caractéristiques de déplacement mécanique peut être fait lorsque le montage complet du disjoncteur a été fait pour la première fois sur site ou si tout ou partie des essais individuels sont effectués sur site. L'enregistrement doit confirmer la qualité du fonctionnement par comparaison avec la caractéristique de déplacement mécanique qui a été obtenue pendant les essais de référence à vide détaillés en 6.101.1.1.

10.2.102.2.7 Vérification de certains fonctionnements particuliers

10.2.102.2.7.1 Refermeture automatique à la pression minimale pour la manœuvre (si applicable)

Le dispositif de gonflage étant hors service, il convient de réduire la pression automatique de commande jusqu'à la valeur de verrouillage de refermeture automatique et d'effectuer une séquence de manœuvres de refermeture automatique (dans les conditions du site, il peut être nécessaire d'utiliser une temporisation externe pour donner l'ordre de refermeture). Il convient d'effectuer cet essai à la tension d'alimentation de l'équipement avec plein passage du courant et d'enregistrer la tension d'alimentation avant et pendant les manœuvres. Il convient de relever la pression finale et de s'assurer qu'il existe une marge de sécurité suffisante jusqu'à la pression de verrouillage de l'ouverture de manière à se prémunir contre des variations de pression transitoires et d'une dérive éventuelle des pressostats.

En cas de doute, on peut réaliser une variante de l'essai ci-dessus en partant d'une pression plus basse que celle du verrouillage de la refermeture automatique (contact court-circuité). Il convient de vérifier ensuite qu'une ouverture est encore possible.

10.2.102.2.7.2 Fermeture à la pression minimale pour la manœuvre (si applicable)

Le dispositif de gonflage étant hors service, il convient de réduire la pression de commande jusqu'à la valeur de verrouillage de fermeture et d'effectuer une manœuvre de fermeture. Il convient d'effectuer cet essai à la tension d'alimentation de l'équipement avec plein passage du courant. Il convient d'enregistrer la tension d'alimentation avant et pendant les manœuvres et de relever la pression finale et de s'assurer qu'il existe une marge de sécurité suffisante jusqu'à la pression minimale pour la manœuvre d'ouverture.

En cas de doute, on peut réaliser une variante à l'essai ci-dessus en partant d'une pression plus basse que celle du verrouillage de la fermeture (contact court-circuité). Il convient de vérifier ensuite qu'une ouverture est encore possible.

10.2.102.2.7.3 Ouverture à la pression minimale pour la manœuvre (si applicable)

Le dispositif de gonflage étant hors service, il convient de diminuer la pression de commande jusqu'à la valeur de verrouillage de l'ouverture et d'effectuer une manœuvre d'ouverture. Il convient d'effectuer cet essai à la tension d'alimentation de l'équipement avec plein passage du courant. Il convient d'enregistrer la tension d'alimentation avant et pendant les manœuvres et de relever la pression finale.

10.2.102.2.7.4 Simulation d'une fermeture sur défaut et vérification du dispositif d'antipompage

Il convient de mesurer la durée pendant laquelle le disjoncteur reste fermé pendant un cycle de manœuvres CO, le circuit de déclenchement étant mis sous tension par la fermeture du contact auxiliaire.

Cet essai permet également de vérifier le fonctionnement du dispositif d'antipompage et l'absence de fonctionnement anormal de la commande pour toute cause mécanique, hydraulique ou pneumatique provoquée par la rapidité de l'envoi de l'ordre d'ouverture.

Afin de vérifier l'efficacité du dispositif d'antipompage, il convient de maintenir l'ordre de fermeture pendant 1 s à 2 s.

NOTE Un essai d'antipompage simplifié peut également être effectué à l'aide de la commande locale. Dans ce cas, on donne et on maintient un ordre de fermeture, immédiatement suivi d'un ordre d'ouverture.

10.2.102.2.7.5 Comportement du disjoncteur sur ordre de fermeture, lorsqu'un ordre d'ouverture est déjà présent

Il convient de contrôler que le disjoncteur satisfasse aux exigences techniques sur ordre de fermeture, un ordre d'ouverture étant préalablement appliqué et maintenu.

10.2.102.2.7.6 Envoi d'un ordre d'ouverture simultanément sur les deux déclencheurs (si applicable)

Il peut arriver que les deux déclencheurs (normal et secours) soient alimentés simultanément (ou quasi simultanément).

Il convient de s'assurer qu'il n'existe pas d'interférence mécanique, hydraulique ou pneumatique dans les fonctionnements, surtout si les déclencheurs n'agissent pas au même niveau.

10.2.102.2.7.7 Protection de discordance de pôles (si applicable)

Il convient de vérifier la protection contre la discordance de pôles par l'un des essais suivants:

– le disjoncteur étant ouvert, le déclencheur de fermeture d'un pôle est alimenté et on vérifie que le pôle se ferme, puis s'ouvre;
– le disjoncteur étant fermé, le déclencheur d'ouverture d'un pôle est alimenté et on vérifie que les deux autres pôles s'ouvrent ensuite.

10.2.102.3 Essais et mesurages électriques

10.2.102.3.1 Essais diélectriques

Des essais diélectriques des circuits auxiliaires doivent être effectués pour confirmer que le transport et le stockage du disjoncteur n'ont pas endommagé ces circuits. Cependant, il est reconnu que de tels circuits contiennent des composants qui peuvent être endommagés par l'application de la pleine tension d'essai pendant la durée complète de l'essai. Pour éviter ce problème, et pour éviter le retrait temporaire de connexions éprouvées, le fournisseur doit donner le détail du processus d'essai qui démontre que des dommages ne se sont pas produits, ainsi que la méthode d'enregistrement des résultats de ce processus d'essai.

Pour les essais diélectriques du circuit principal de disjoncteurs sous enveloppe métallique, la CEI 62271-200 [9] et la CEI 62271-203 [10] sont applicables.

10.2.102.3.2 Mesurage de la résistance des circuits principaux

Le mesurage de la résistance des circuits principaux n'est nécessaire que si les éléments de coupure ont été assemblés sur le site. La mesure doit être faite avec un courant continu, conformément à 7.3 de la CEI 62271-1.

10.3 Fonctionnement

Le paragraphe 10.3 de la CEI 62271-1 est applicable.

10.4 Maintenance

Le paragraphe 10.4 de la CEI 62271-1 est applicable avec le complément suivant :

De plus, il est recommandé au constructeur de donner des renseignements concernant la maintenance des disjoncteurs à la suite:

a) des manœuvres sur court-circuit;

b) des manœuvres en service normal.

Il convient que ces renseignements comprennent le nombre de manœuvres selon les points a) et b) après lequel il y a lieu de réviser le disjoncteur.

Les paragraphes 10.4.1 à 10.4.3 de la CEI 62271-1 sont applicables. Les vérifications exigées en 10.2.102.1.3 s'appliquent.

10.4.101 Résistances et condensateurs

Pour la vérification des résistances et des condensateurs, il est recommandé d'indiquer les tolérances permises sur les valeurs.

11 Sécurité

L'Article 11 de la CEI 62271-1 est applicable avec le complément suivant :

Il convient d'identifier dans le manuel d'instructions du disjoncteur tout risque connu d'impact chimique et sur l'environnement.

12 Influence du produit sur l'environnement

L'Article 12 de la CEI 62271-1 est applicable.

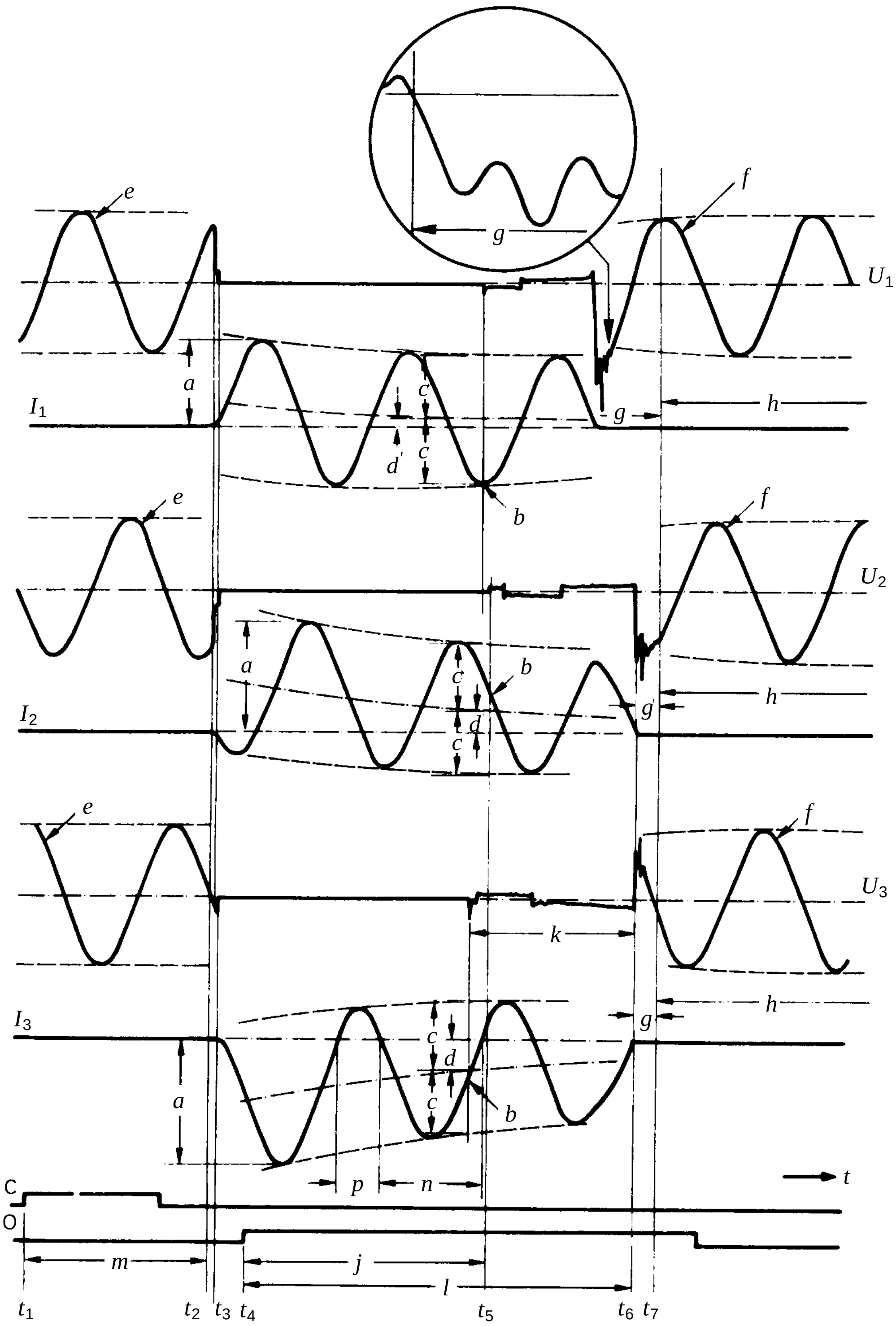


Figure 1 – Oscillogramme type d'un cycle d'établissement-coupure en court-circuit triphasé

Légende de la Figure 1:

U_1 tension entre les bornes du premier pôle qui coupe

I_1 courant dans le premier pôle qui coupe

U_2 , U_3 tension entre les bornes des deux autres pôles

I_2 , I_3 courant dans les deux autres pôles

C commande de fermeture, par exemple tension aux bornes du circuit de fermeture

O commande d'ouverture, par exemple tension aux bornes du déclencheur d'ouverture

t_1 instant du début de la manceuvre de fermeture

t_2 instant ou le courant commence à circuler dans le circuit principal

t_3 instant ou le courant est établi sur tous les pôles

t_4 instant de mise sous tension du déclencheur d'ouverture

t_5 instant de la séparation des contacts d'arc (ou de l'amorcage de l'arc) sur tous les pôles

t_6 instant de l'extinction finale de l'arc sur tous les pôles

t_7 instant de la disparition des phénomènes transitoires de tension dans le dernier pôle qui coupe

a (valeur de crête du) courant établi

b courant coupé

c valeur de crête de la composante périodique

d composante apériodique

e tension appliquée

f tension de rétablissement

g tension transitoire de rétablissement

h tension de rétablissement à fréquence industrielle

j durée d'ouverture

k durée d'arc

l durée de coupure

m durée d'établissement

n grande alternance

p petite alternance

Notes concernant les Figures 2 à 7 suivantes:

NOTE 1 En pratique, il se produira une dispersion des durées entre les courses des contacts des trois pôles. Pour plus de clarté sur les figures, la course des contacts est indiquée avec une seule ligne pour les trois pôles.

NOTE 2 En pratique, il se produira une dispersion entre le début ainsi qu'entre la fin de la circulation du courant dans les trois pôles. Pour plus de clarté sur les figures, le début ainsi que la fin de la circulation du courant sont indiqués avec une seule ligne pour les trois pôles.

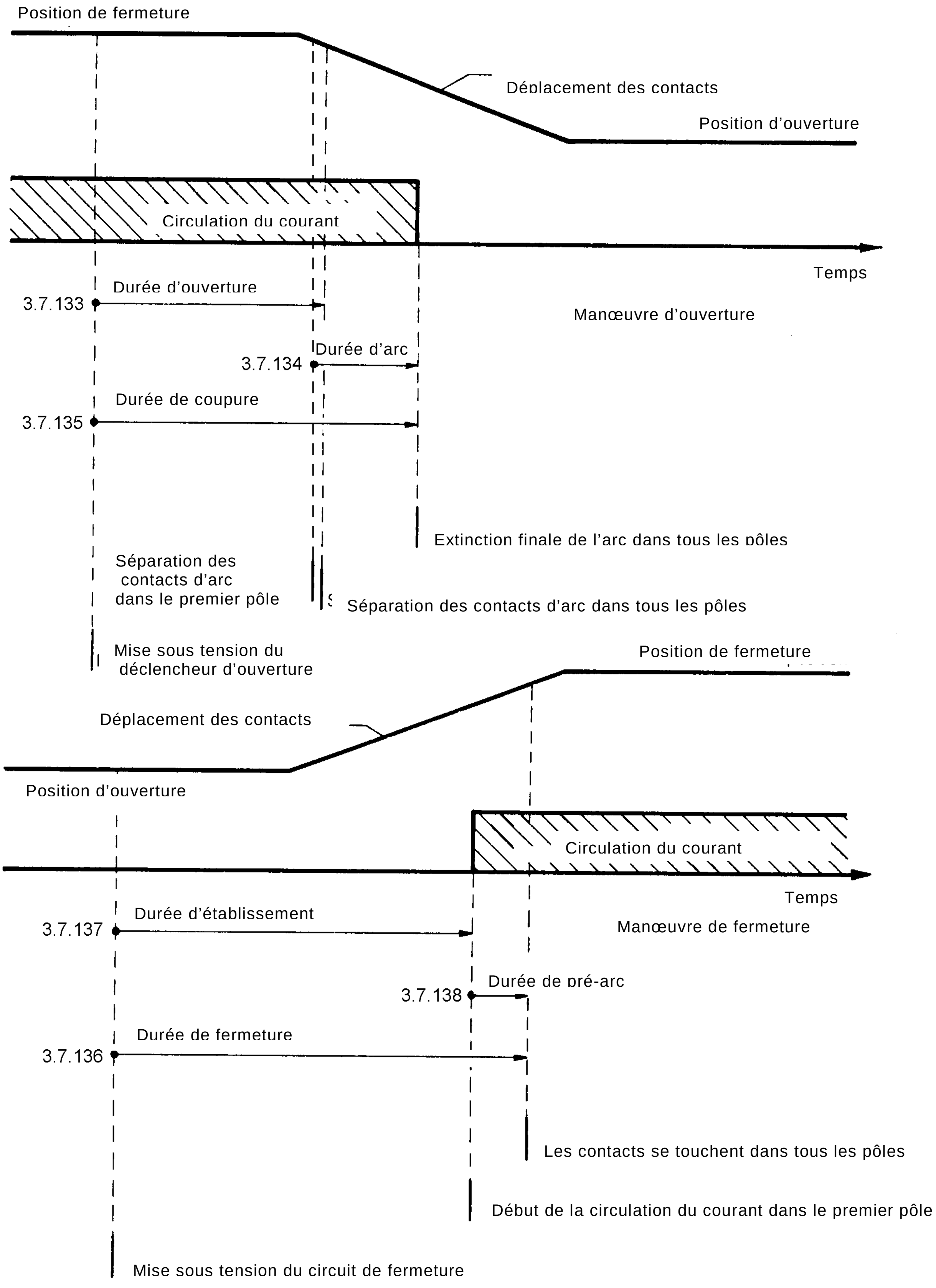


Figure 2 – Disjoncteur sans résistances intercalaires – Manœuvres d'ouverture et de fermeture

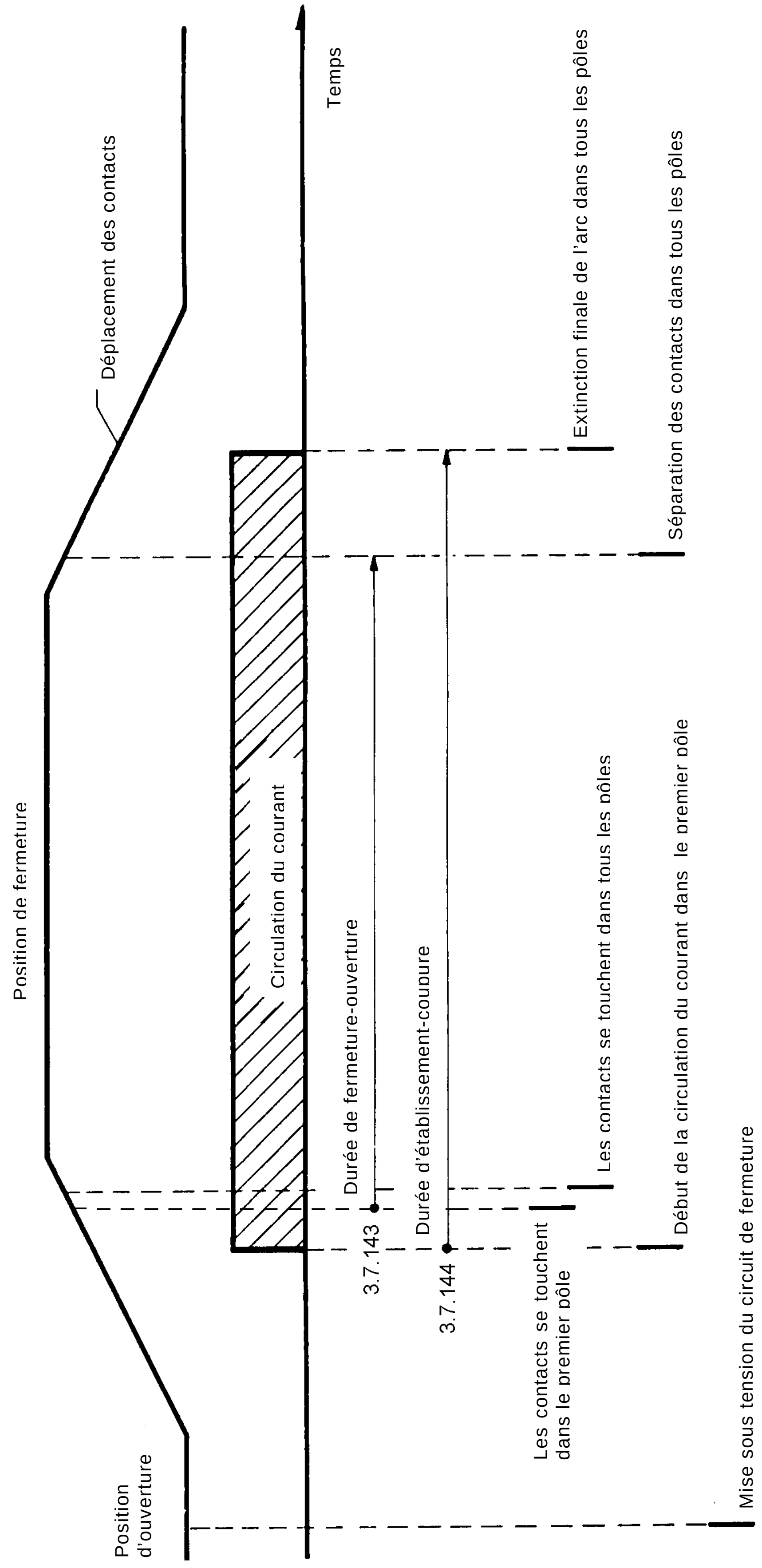


Figure 3 – Disjoncteur sans résistance intercalaire – Cycle de fermeture-ouverture

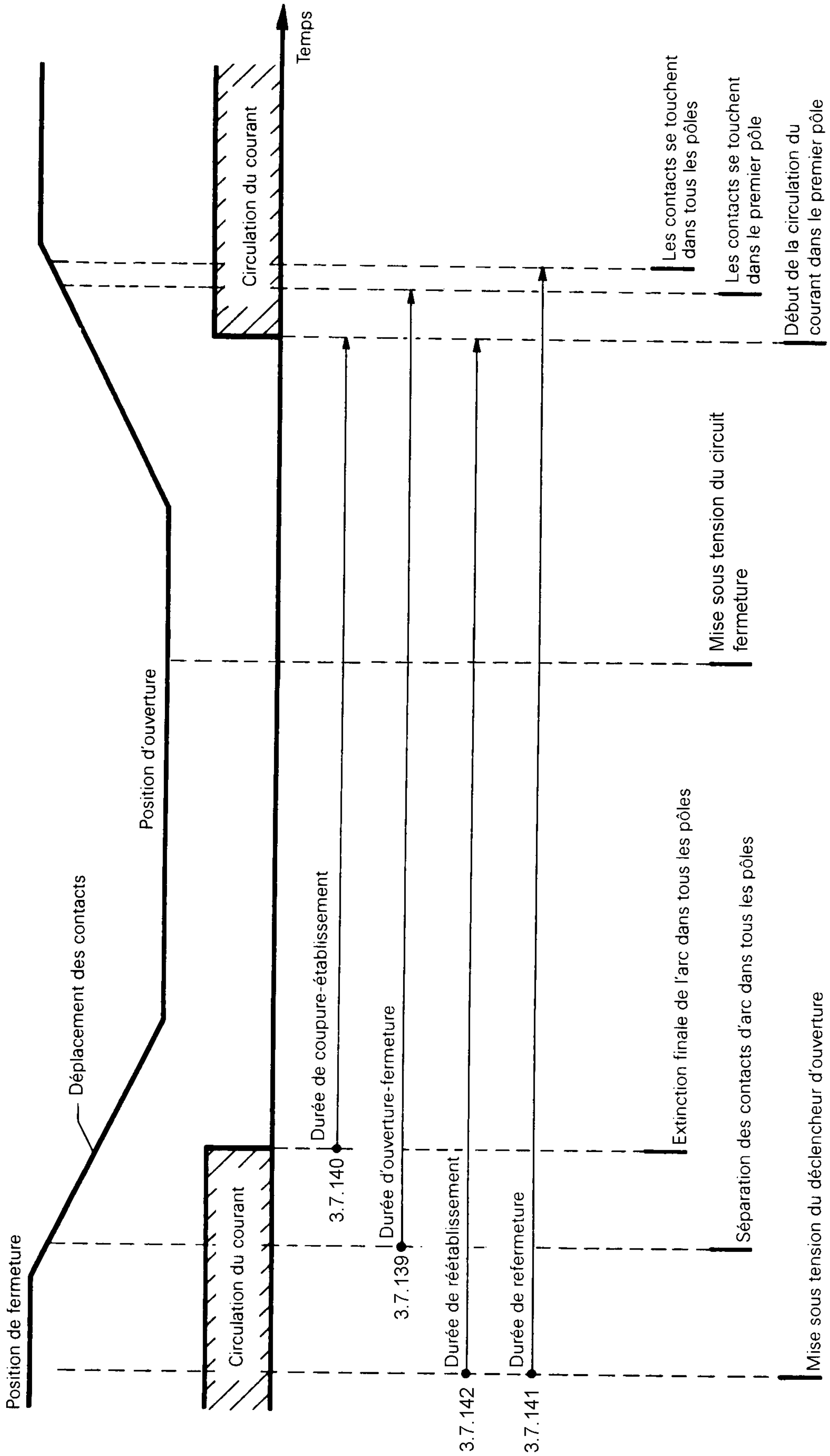


Figure 4 – Disjoncteur sans résistance intercalaire – Refermeture (refermeture automatique)

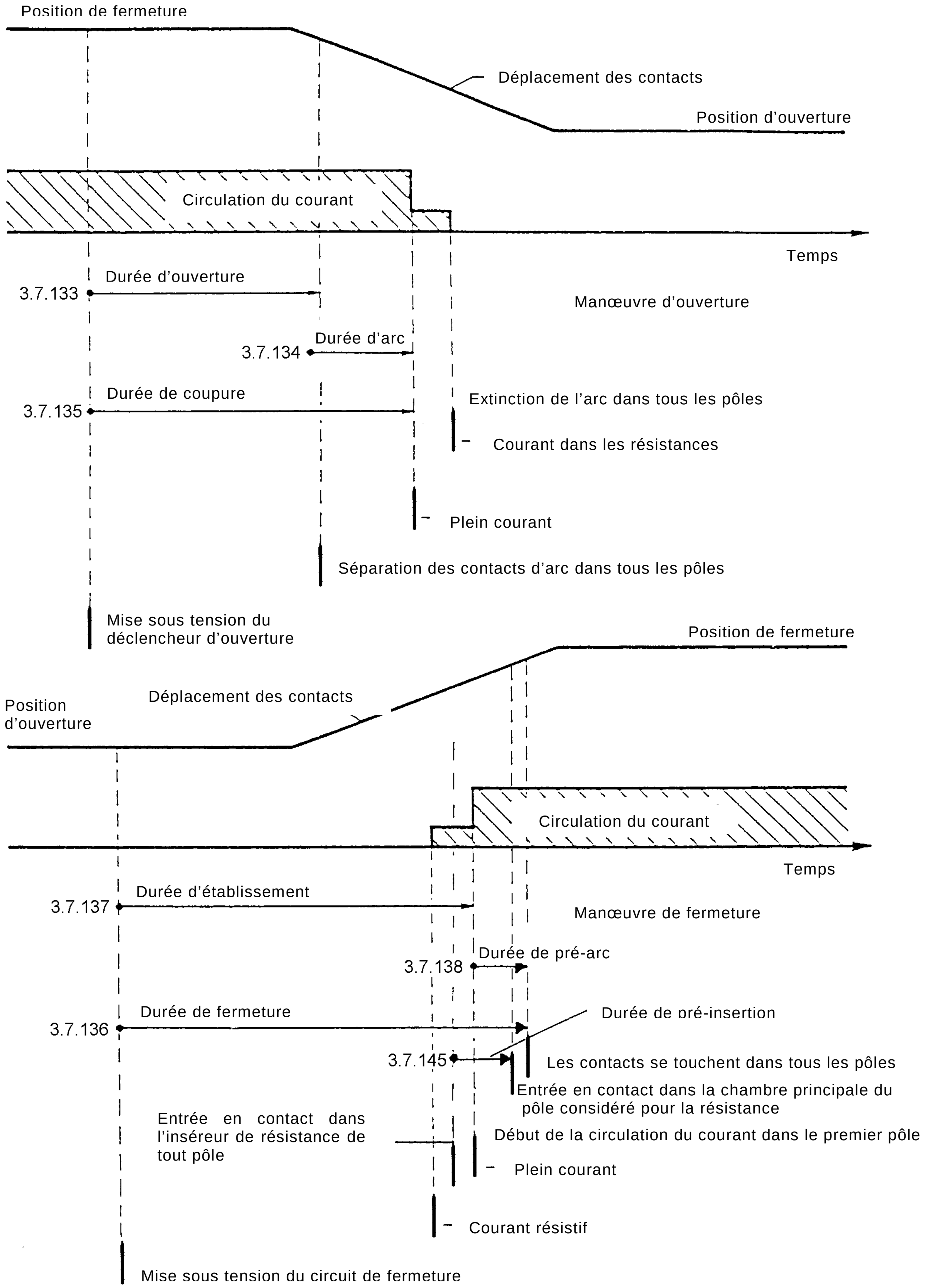


**Figure 5 – Disjoncteur avec résistances intercalaires –
Manœuvres d'ouverture et de fermeture**

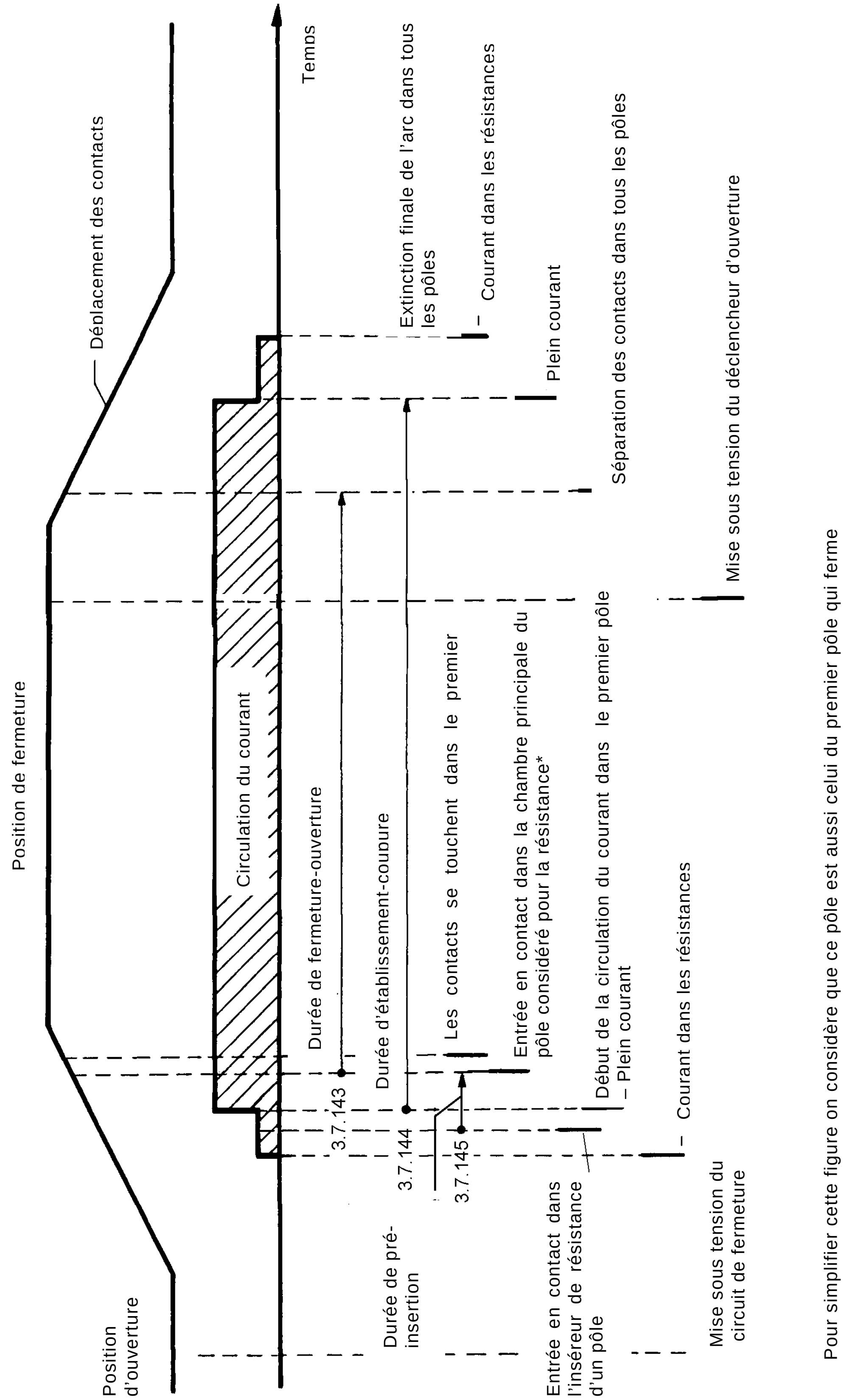


Figure 6 – Disjoncteur avec résistances intercalaires – Cycle de fermeture-ouverture

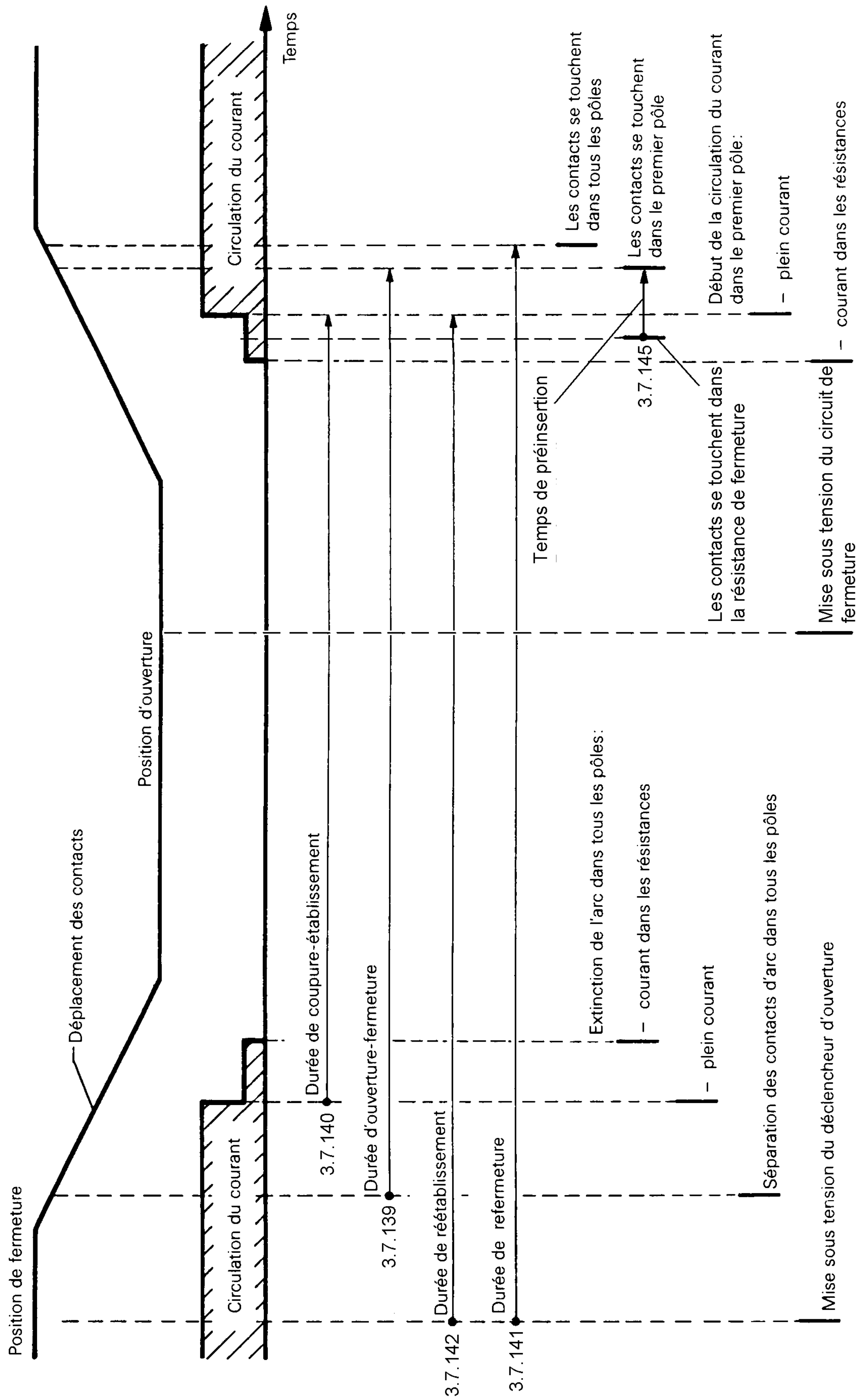
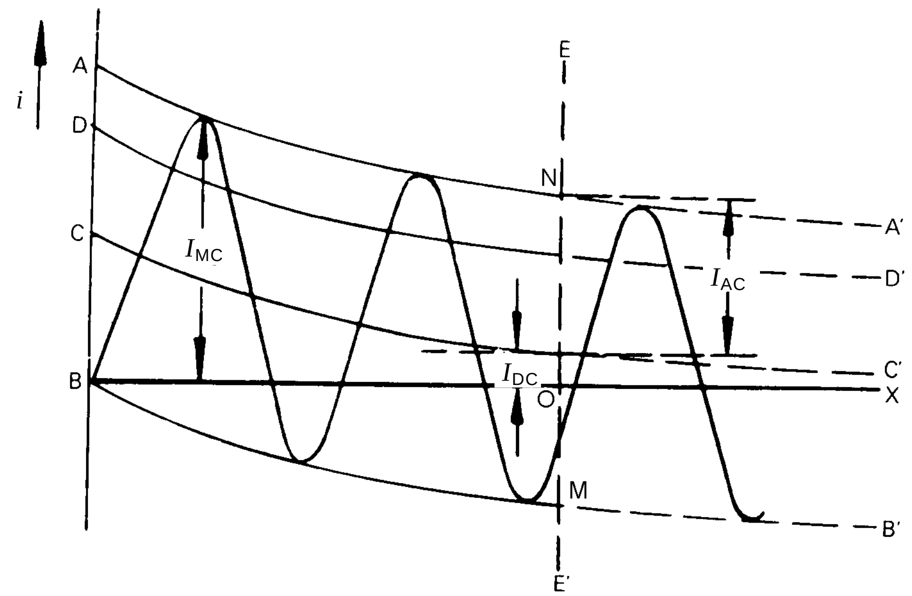


Figure 7 – Disjoncteur avec résistances intercalaires – Refermeture (refermeture automatique)



AA‘ BB’	enveloppe de l’onde de courant
BX	ligne de zéro
CC‘	déplacement de la ligne de zéro de l’onde de courant à chaque instant
DD‘	valeur efficace de la composante périodique du courant à chaque instant, mesurée à partir de CC‘
EE‘	instant de la séparation des contacts (amorçage de l’arc)
I_{MC}	courant établi
I_{AC}	valeur de crête de la composante périodique du courant au moment EE‘
$\frac{I_{AC}}{\sqrt{2}}$	valeur efficace de la composante périodique du courant au moment EE‘
I_{DC}	composante apériodique du courant au moment EE‘

$\frac{I_{DC}}{I_{AC}} \times 100 = \frac{\overline{ON} - \overline{OM}}{\overline{MN}} \times 100 = \left(\frac{2 \times \overline{ON}}{\overline{MN}} - 1 \right) \times 100$ pourcentage de la composante apériodique

Figure 8 – Détermination des courants de court-circuit établi et coupé et du pourcentage de la composante apériodique

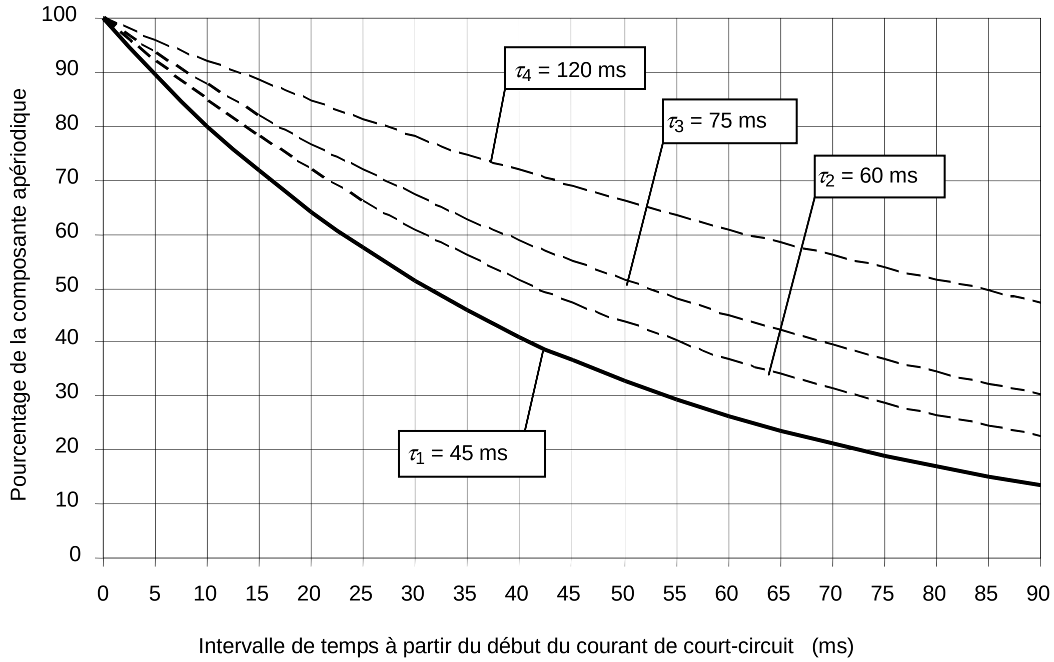


Figure 9 – Pourcentage de la composante apériodique en fonction de l'intervalle de temps à partir du début du courant de court-circuit pour ~~la~~ les différentes constantes de temps ~~normale τ_1 et pour les constantes de temps τ_2, τ_3 et τ_4 des applications particulières~~

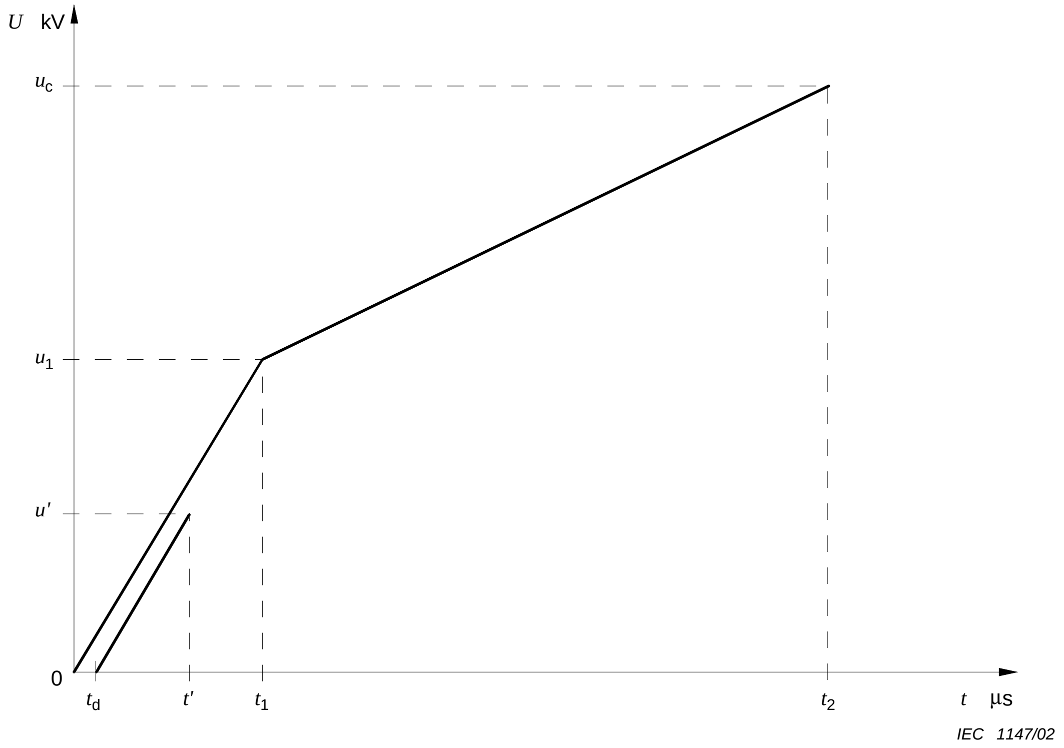


Figure 10 – Représentation d'une TTR spécifiée à quatre paramètres et d'un segment de droite définissant un retard pour les séquences d'essais T100, T60, de défaut proche en ligne et en discordance de phases

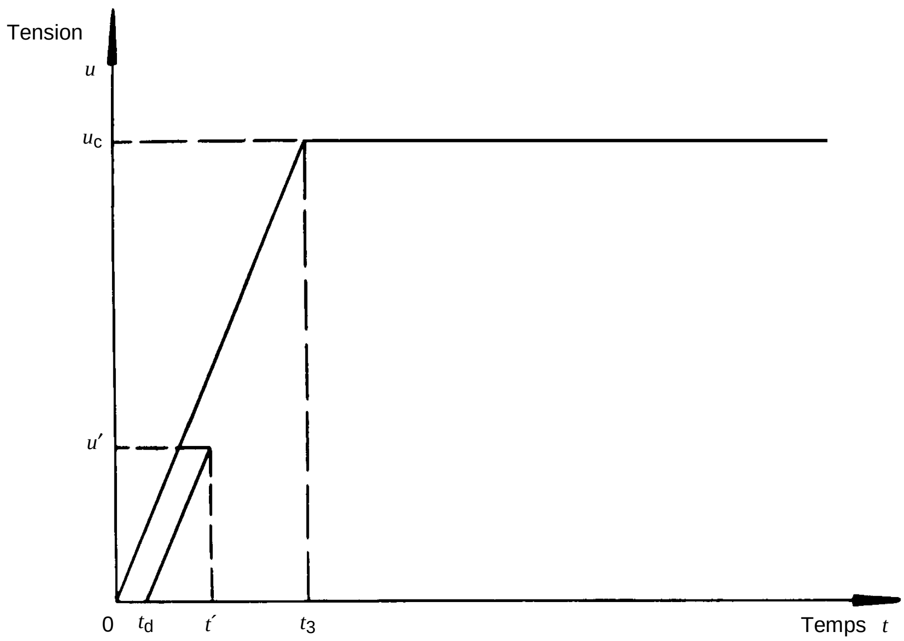
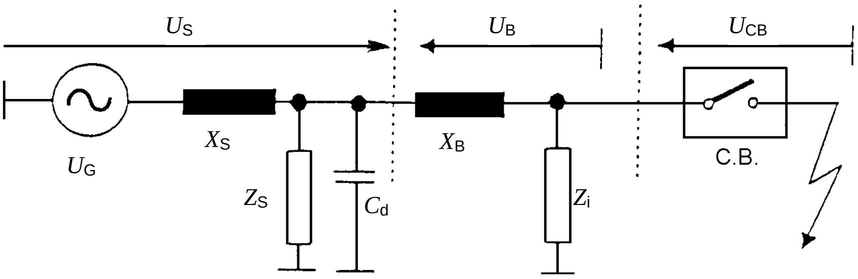


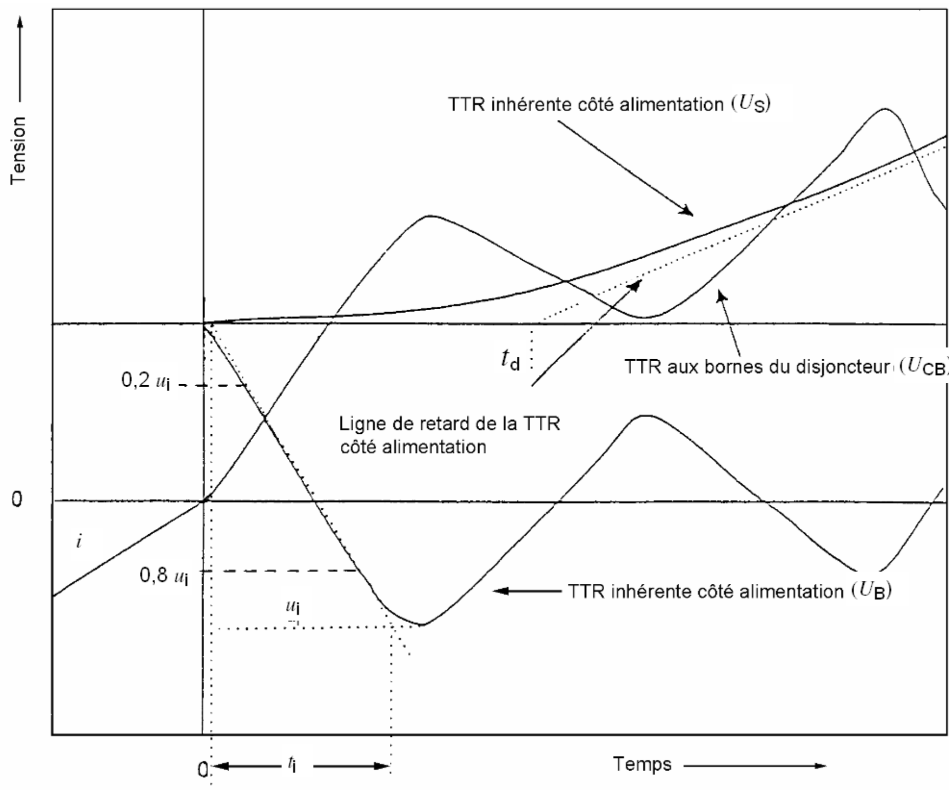
Figure 11 – Représentation d'une TTR spécifiée par un tracé de référence à deux paramètres et par un segment de droite définissant un retard



C.B.	disjoncteur	C_d	capacité de temps de retard côté alimentation
U_G	tension d'alimentation	Z_S	éléments de réglage de la TTR côté alimentation
U_B	tension aux bornes du jeu de barre	Z_i	éléments de réglage de la TTRI
U_{CB}	tension aux bornes du disjoncteur	X_S	réactance à fréquence industrielle côté alimentation
U_S	tension côté alimentation	X_B	réactance du jeu de barre à fréquence industrielle

NOTE Si une inductance concentrée est utilisée pour X_S, les éléments de réglage de la TTRI peuvent être connectés en parallèle à cette inductance.

Figure 12a – Circuit de base pour le défault aux bornes avec TTRI

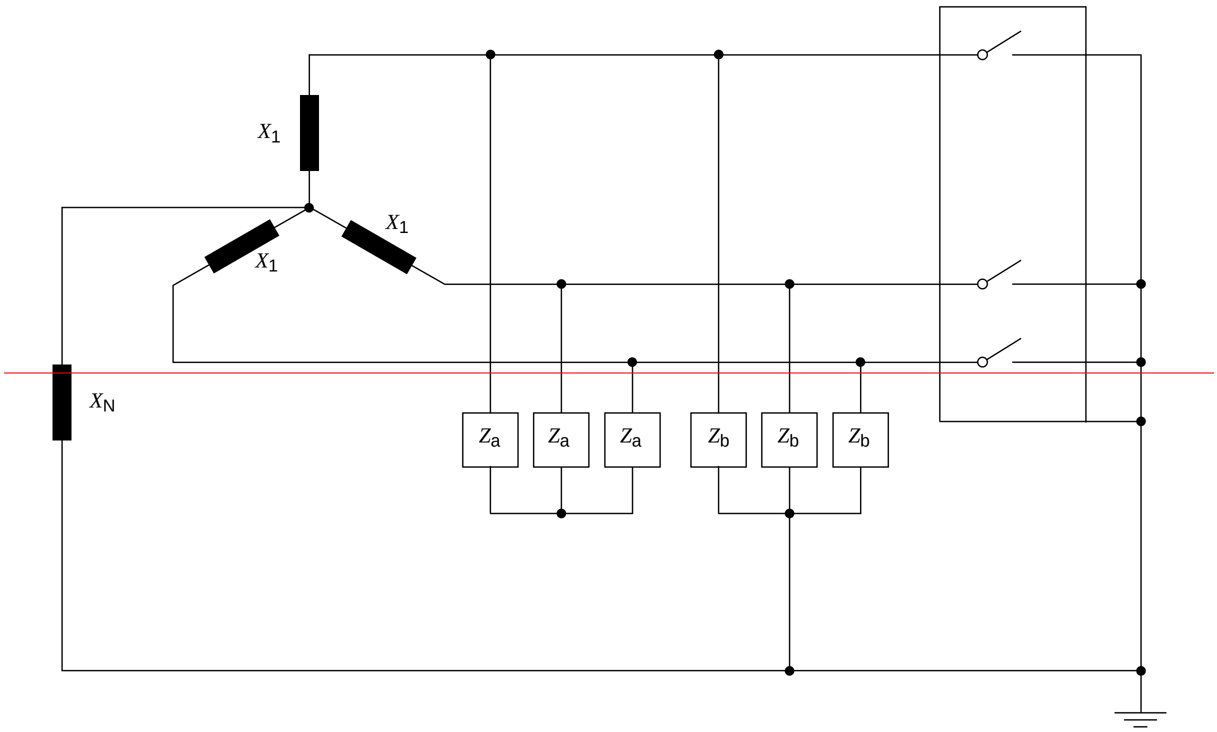


u_i tension crête de la TTRI

t_i paramètre temporel de la TTRI

Figure 12b – Représentation de la TTRI et de son influence sur la TTR

Figure 12 - Circuit de TTRI et représentation de la TTRI en relation avec la TTR



IEC 1187/06

~~**Légende**~~

~~X_N impédance de neutre de la source~~

~~X_1 composante directe de la réactance de court-circuit~~

~~Z_a impédance entre phases de court-circuit~~

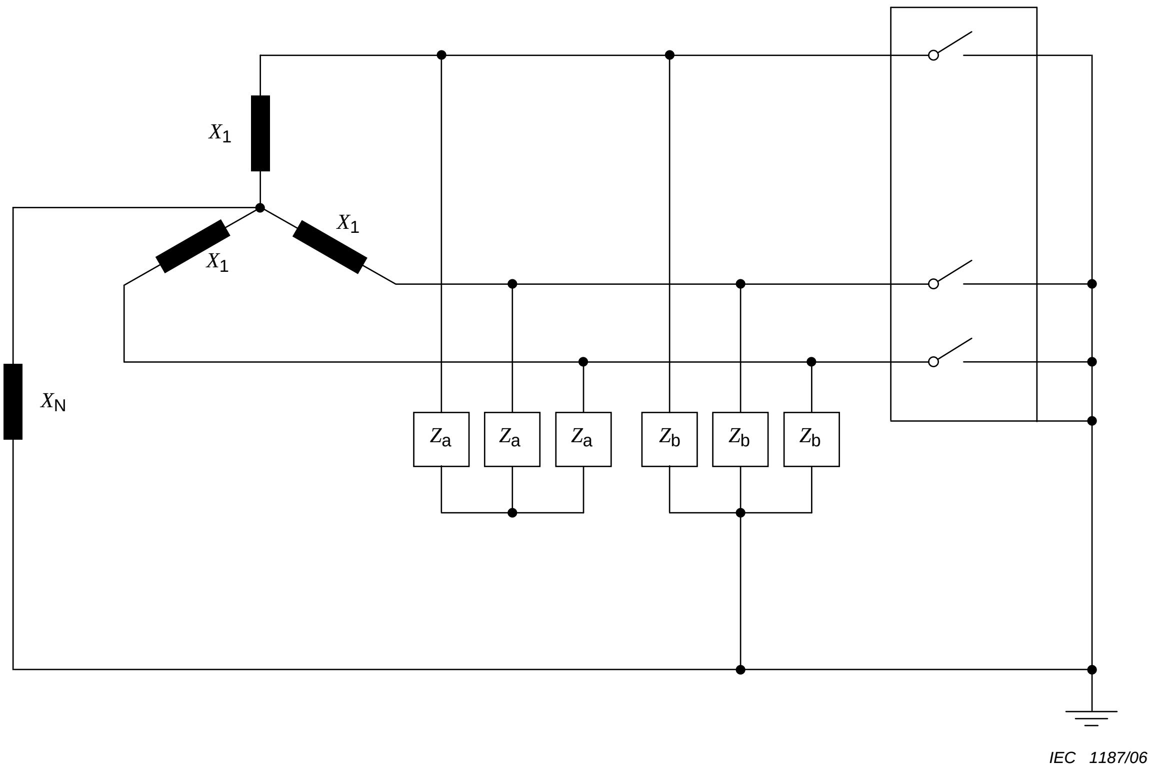
~~Z_b impédance phase-terre de court-circuit~~

~~X_N très supérieure à X_1 pour un facteur de 1er pôle égal à 1,5~~

~~X_N 0,75X_1 pour un facteur de 1er pôle égal à 1,3~~

~~Pour $Z_0/Z_1 \approx 2$: $Z_a = Z_b = 2Z_1$~~

~~avec Z_0 composante homopolaire de l'impédance de court-circuit du circuit d'alimentation~~



Légende

X_N impédance de neutre de la source

X_1 composante directe de la réactance de court-circuit

Z_a impédance entre phases du circuit de TTR

Z_b impédance phase-terre du circuit de TTR

X_N très supérieure à X_1 pour un facteur de 1er pôle égal à 1,5

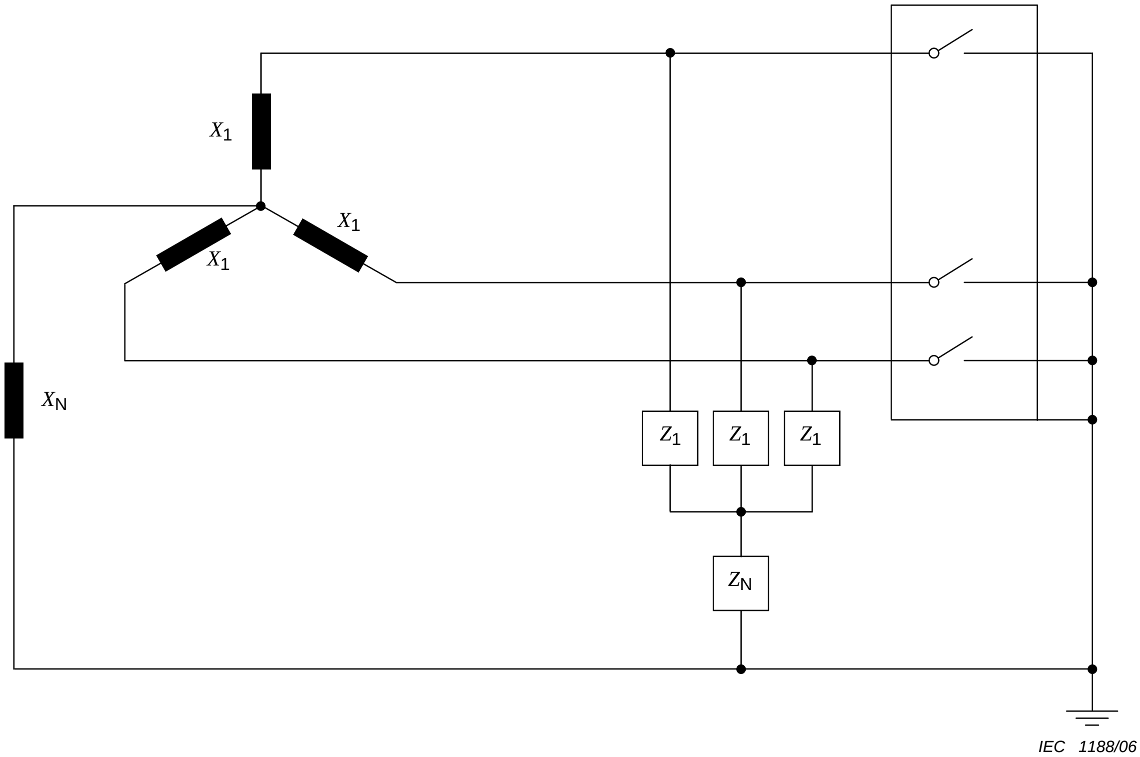
X_N 0,75 X_1 pour un facteur de 1er pôle égal à 1,3

X_N 0,33 X_1 pour un facteur de 1er pôle égal à 1,2

Pour $Z_0/Z_1 \approx 2$ (pour les valeurs exactes, voir la CEI 62271-306 [4]): $Z_a = Z_b = 2Z_1$

avec Z_0 composante homopolaire de l'impédance de court-circuit côté alimentation

Figure 13 – Représentation d'un court-circuit triphasé



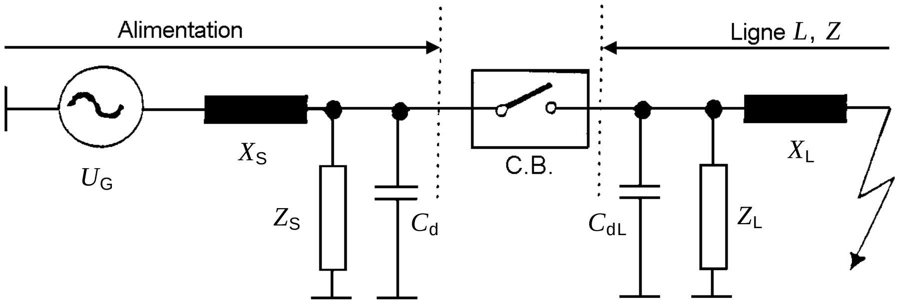
Légende

X_N	impédance de neutre de la source
X_1	composante directe de la réactance de court-circuit
Z_1	impédance phase-neutre du circuit de TTR
Z_N	impédance de neutre du circuit de TTR

Pour $\dfrac{Z_0}{Z_1} = 2 \qquad Z_N = \dfrac{Z_1}{3}$

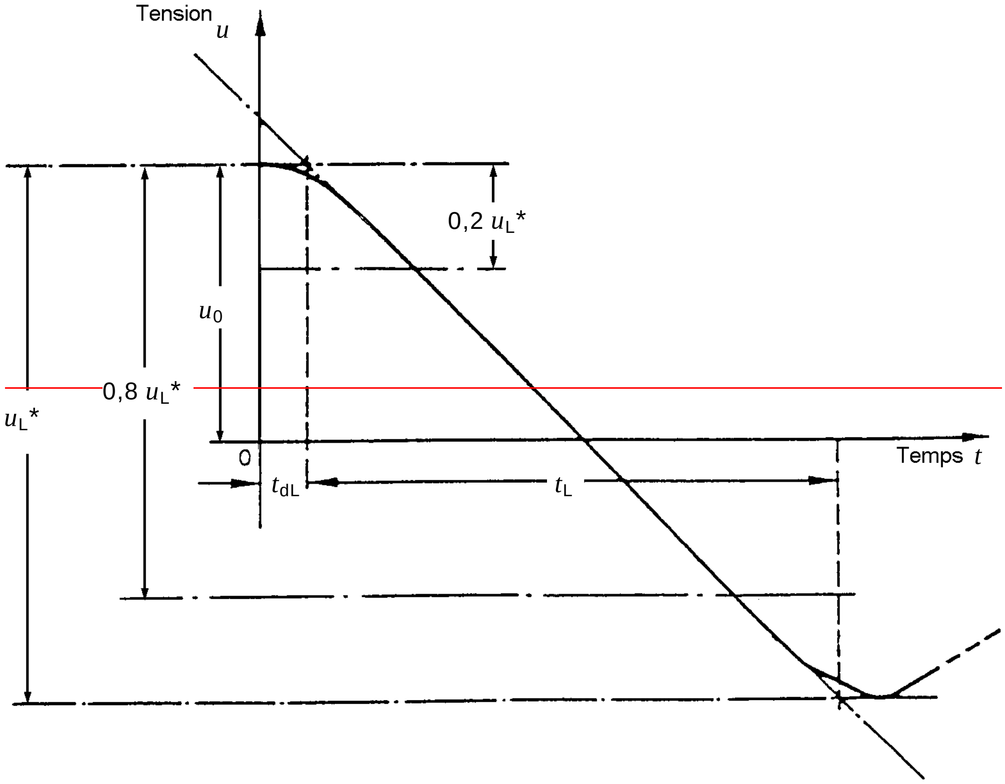
avec Z_0 composante homopolaire de l'impédance de court-circuit du circuit d'alimentation

Figure 14 – Représentation de variante à la Figure 13



U_G	tension d'alimentation, valeur phase-terre	X_L	réactance à fréquence industrielle côté ligne
X_s	réactance à fréquence industrielle côté alimentation	Z_L	éléments de réglage de la TTR côté ligne
Z_s	éléments de réglage de la TTR côté alimentation	C_{dL}	capacité de temps de retard côté ligne
C_d	capacité de temps de retard côté alimentation	Z	impédance d'onde de la ligne
C.B.	disjoncteur	L	longueur de ligne jusqu'au défaut

Figure 15 – Circuit de base de défaut proche en ligne



~~**Figure 16 – Exemple d'une tension transitoire côté ligne avec un retard et une crête arrondie la montrant construction à effectuer pour obtenir les valeurs u_L*, t_L et t_{dL}**~~

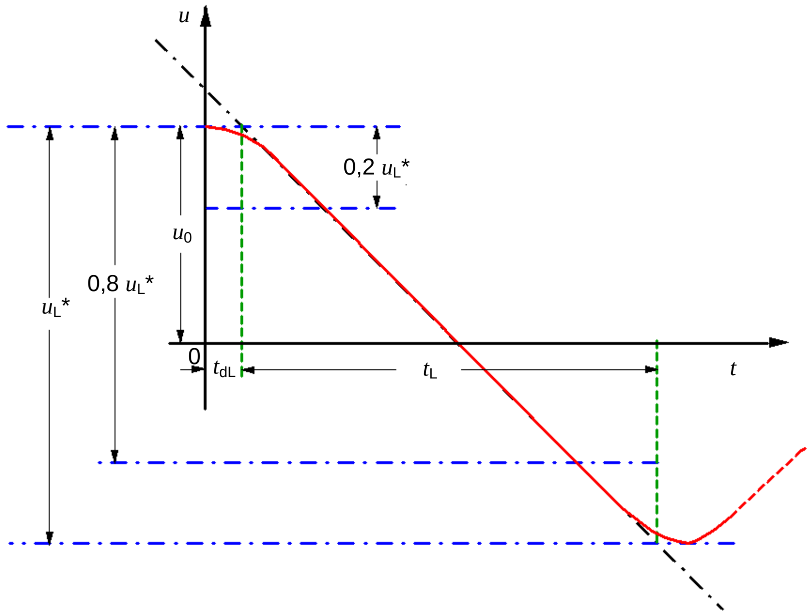


Figure 16a – Exemple d'une tension transitoire côté ligne avec un retard

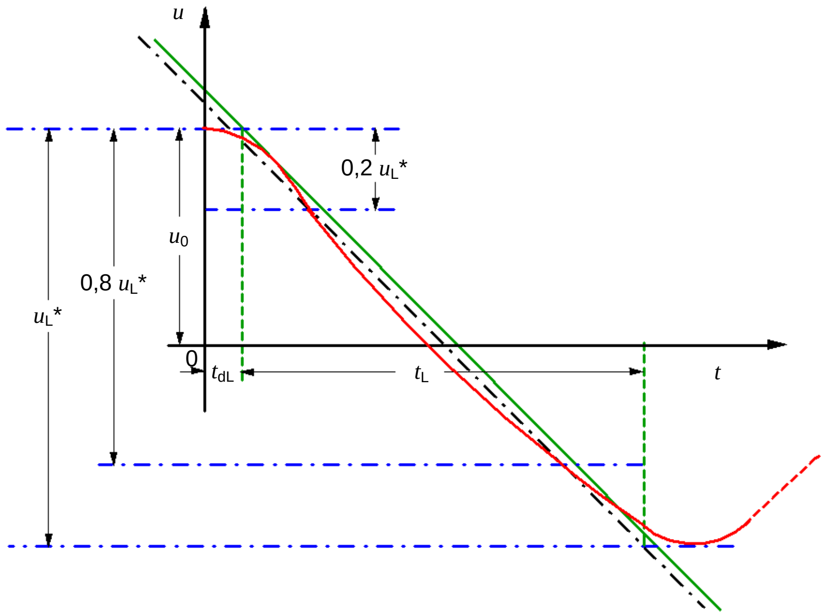
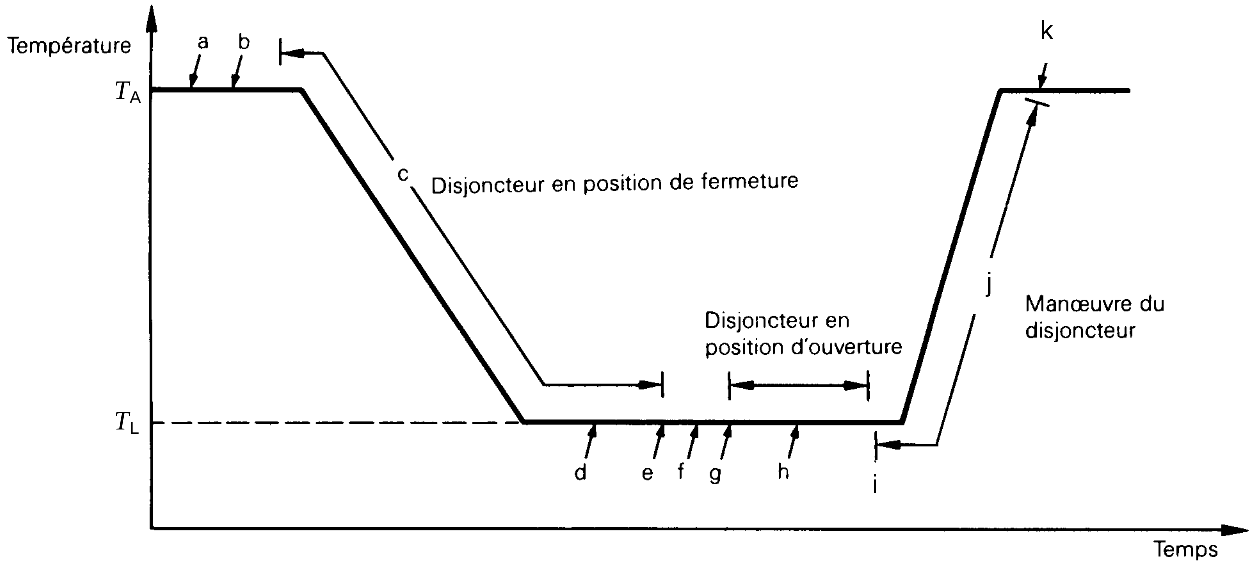
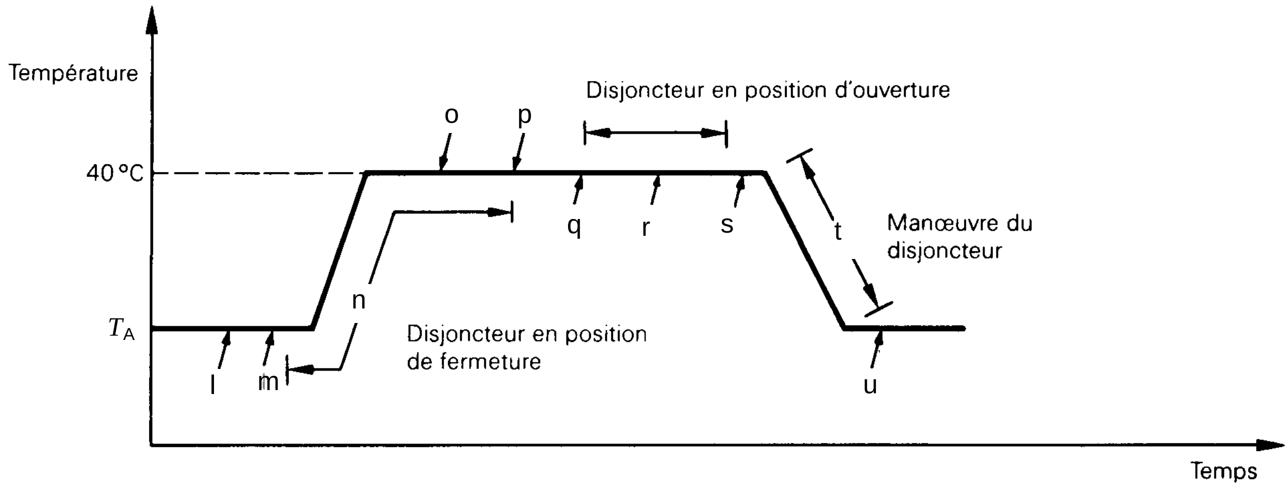


Figure 16b – Exemple d'une tension transitoire côté ligne avec un retard avec une vitesse d'accroissement non linéaire

Figure 16 – Exemples de tensions transitoires côté ligne



a) Essai à basse température



b) Essai à haute température

NOTE Les lettres a à u repèrent les points d'application des essais spécifiés en 6.101.3.3 et 6.101.3.4.

Figure 17 – Séquences d'essais pour les essais à basse et à haute température

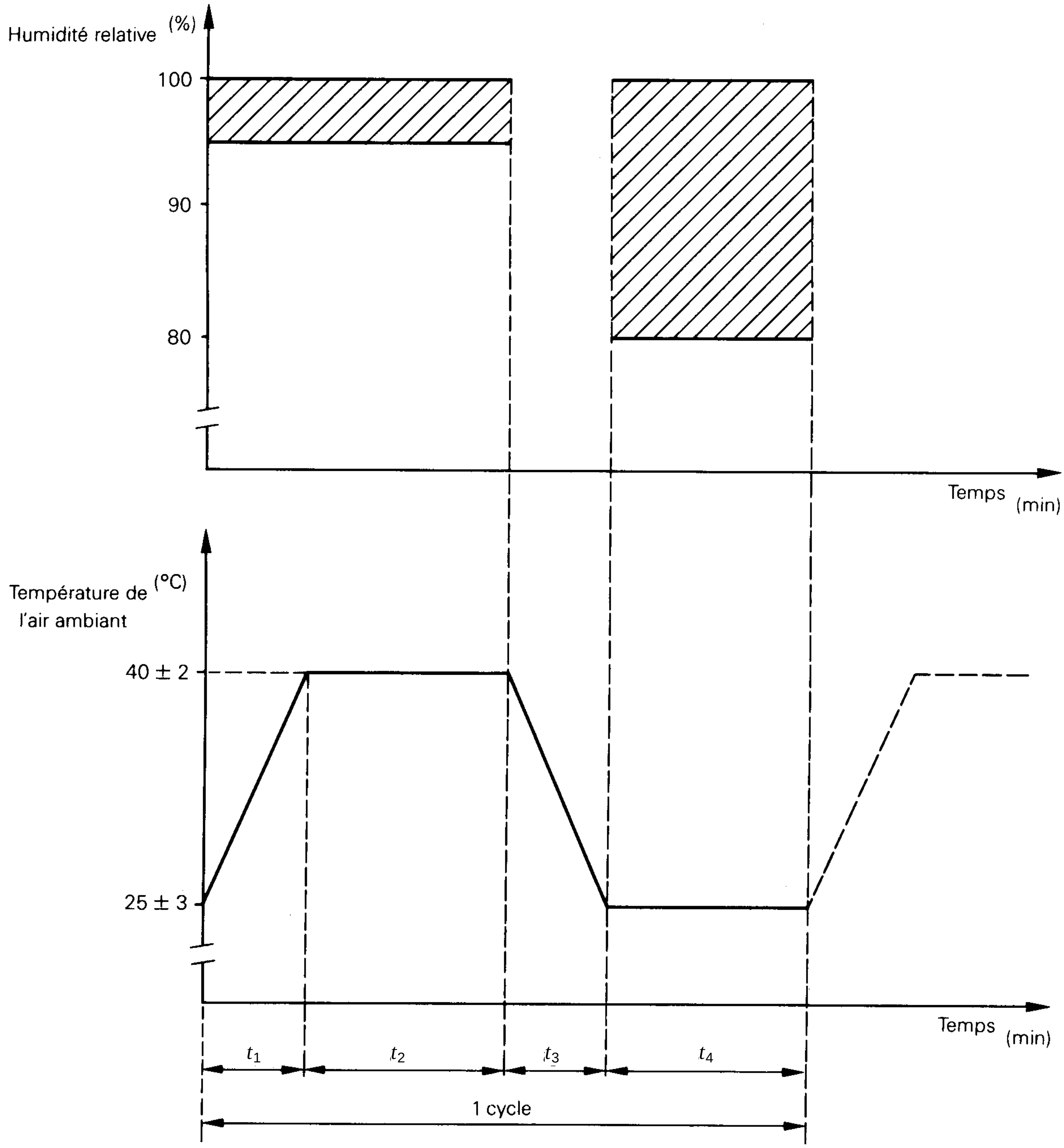
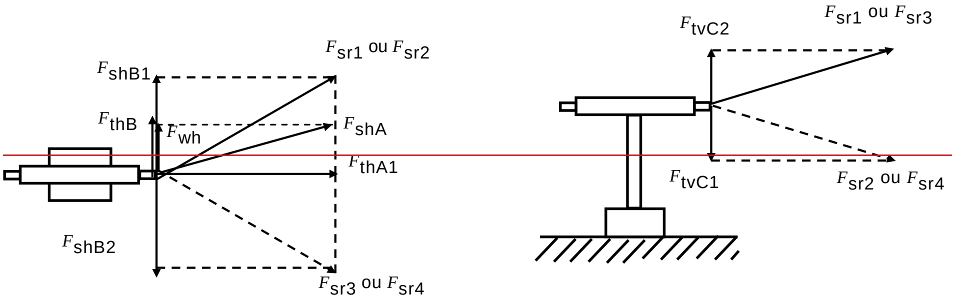


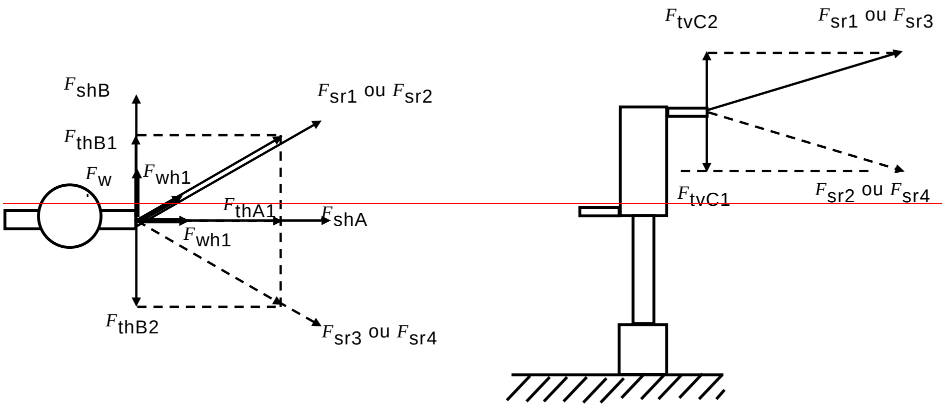
Figure 18 – Essai à l'humidité

~~**Disjoncteur avec plus d'un élément de coupure**~~



~~$F_{shB1} = F_{thB1} + F_{wh}$ et $F_{shB2} = F_{thB2} + F_{wh}$~~ ~~$F_{tv} = F_{sv}$ (voir 6.101.6.2)~~

~~**Disjoncteur avec un élément de coupure**~~



~~Essai selon le point a) de 6.101.6.2 : F_{wh} agit dans la direction de la résultante de F_{thB} et F_{thA}~~

~~Essai selon le point b) de 6.101.6.2: F_{wh} agit dans la direction de F_{thB} ou F_{thA}~~

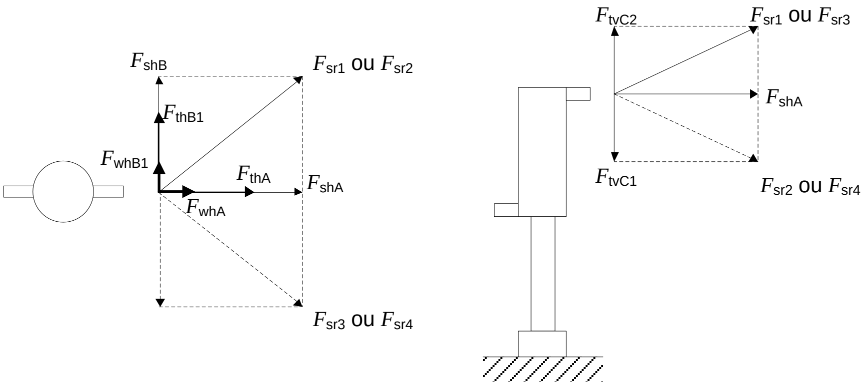
~~F_{thA}~~	~~effort horizontal de traction dû aux conducteurs raccordés (direction A)~~
~~F_{thB}~~	~~effort horizontal de traction dû aux conducteurs raccordés (direction B)~~
~~F_{tv}~~	~~effort vertical de traction dû aux conducteurs raccordés (direction C)~~
~~F_{wh}~~	~~effort horizontal sur le disjoncteur, dû à la pression du vent sur ce disjoncteur revêtu de glace~~
~~F_{shA}, F_{shB}~~	~~efforts horizontaux résultant de F_{thA}, F_{thB} et F_{wh}~~
~~F_{sr1}, F_{sr2}, F_{sr3}, F_{sr4}~~	~~efforts statiques assignés sur borne (efforts résultants)~~

~~NOTE 1 Voir la Figure 20 pour les directions A, B et C.~~

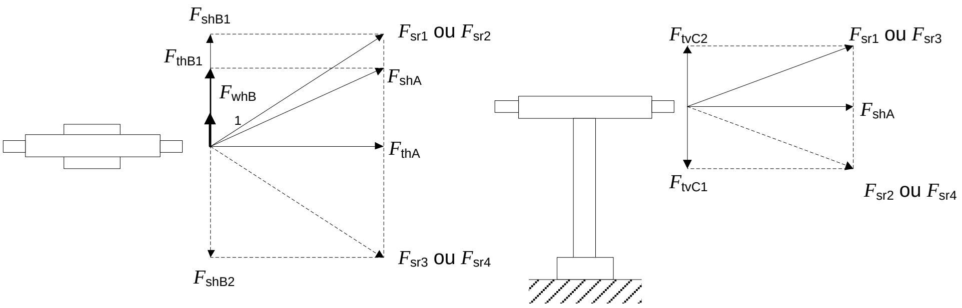
~~NOTE 2 La lettre index "s" caractérise les valeurs d'essais.~~

	~~**Horizontal**~~	~~**Vertical**~~	~~**Remarque**~~
~~Efforts dus au poids mort, au vent et à la glace sur le conducteur raccordé~~	~~F_{thA}, F_{thB}~~	~~F_{tv}~~	~~Conformément au Tableau 14~~
~~Efforts dus au vent et à la glace sur le disjoncteur*~~	~~F_{wh}~~	~~0~~	~~Calculés par le constructeur~~
~~* L'effort horizontal sur le disjoncteur, dû au vent, peut être déplacé depuis le centre de poussée vers la borne et son amplitude réduite proportionnellement à l'augmentation du bras de levier. (Il convient que le moment de flexion sur la partie la plus basse du disjoncteur soit le même.)~~			

Disjoncteur avec un élément de coupure



Disjoncteur avec plus d'un élément de coupure



$F_{shB1} = F_{thB1} + F_{whB1}$ et $F_{shB2} = F_{thB2} + F_{whB2}$ $F_{tv} = F_{sv}$ (voir 6.101.6.2)

Essai selon le point a) de 6.101.6.2:

– Pour un disjoncteur avec un élément de coupure, F_{wh} agit dans la direction de la résultante de F_{thB} et F_{thA}

– Pour un disjoncteur avec plus d'un élément de coupure, F_{wh} agit dans la direction de la résultante de F_{thB} pour obtenir la condition la plus rigoureuse de charge

Essai selon le point b) de 6.101.6.2: F_{wh} agit dans la direction de F_{thB} ou F_{thA}

F_{thA}	effort horizontal de traction dû aux conducteurs raccordés (direction A)
F_{thB}	effort horizontal de traction dû aux conducteurs raccordés (direction B)
F_{tv}	effort vertical de traction dû aux conducteurs raccordés (direction C)
F_{wh}	effort horizontal sur le disjoncteur, dû à la pression du vent sur ce disjoncteur revêtu de glace
F_{shA}, F_{shB}	efforts horizontaux résultant de F_{thA}, F_{thB} et F_{wh}
F_{sr1}, F_{sr2}, F_{sr3}, F_{sr4}	efforts statiques assignés sur borne (efforts résultants)

NOTE 1 Voir la Figure 20 pour les directions A, B et C.

NOTE 2 La lettre index « s » caractérise les valeurs d'essais.

	Horizontal	Vertical	Remarque
Efforts dus au poids mort, au vent et à la glace sur le conducteur raccordé	F_{thA}, F_{thB}	F_{tv}	Conformément au Tableau 14
Efforts dus au vent et à la glace sur le disjoncteur*	F_{wh}	O	Calculés par le constructeur

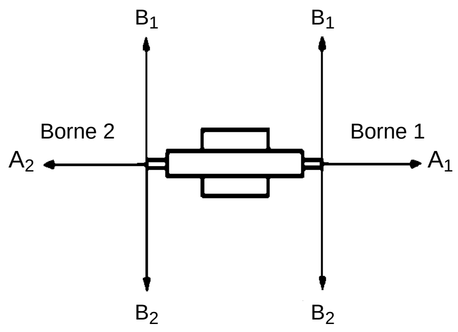
* L'effort horizontal sur le disjoncteur, dû au vent, peut être déplacé depuis le centre de poussée vers la borne et son amplitude réduite proportionnellement à l'augmentation du bras de levier. (Il convient que le moment de flexion sur la partie la plus basse du disjoncteur soit le même.)

Figure 19 – Efforts statiques sur les bornes

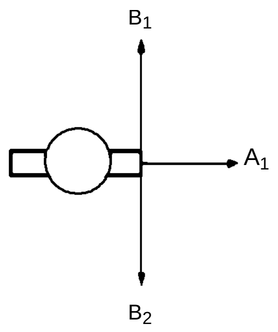
Disjoncteur avec plus d'un élément de coupure

Disjoncteur avec un élément de coupure

Efforts horizontaux



Efforts horizontaux

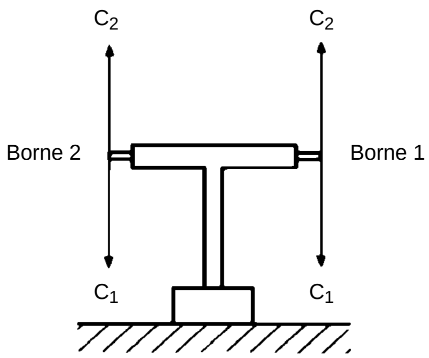


Direction des efforts: A_1, B_1, B_2 pour la borne 1

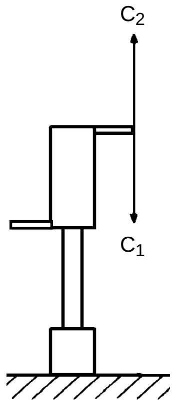
Direction des efforts: A_2, B_1, B_2 pour la borne 2

Efforts horizontaux d'essais: F_{shA} et F_{shB} (voir Figure 19)

Efforts verticaux



Efforts verticaux



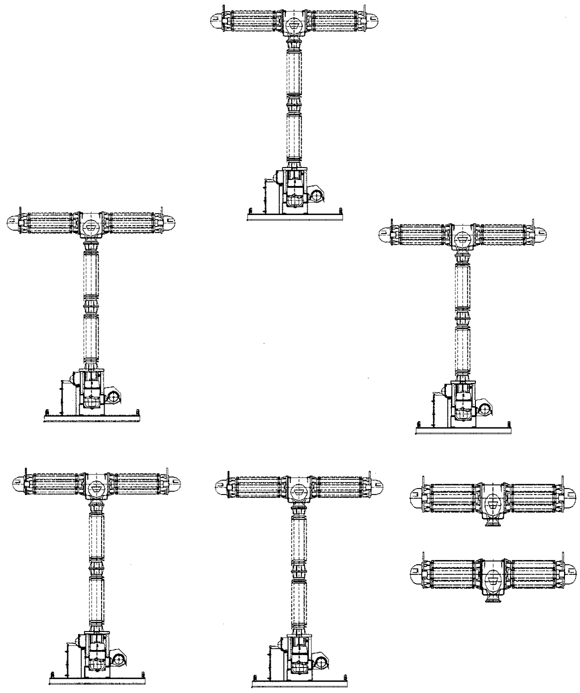
Direction des efforts: C_1, C_2, pour la borne 1

Direction des efforts: C_1, C_2, pour la borne 2

Efforts verticaux d'essais (dans les deux directions): F_{sv} (voir Figure 19)

NOTE Il suffit d'essayer une seule borne des disjoncteurs s'ils sont symétriques par rapport à l'axe vertical central du pôle.

Figure 20 – Directions pour les essais d'efforts statiques sur les bornes



Recommandé — 1 spécimen

Plusieurs séquences d'essai pendant une campagne d'essais en laboratoire — 2 spécimens

Un organe de manœuvre par pôle, essais monophasés — 2 spécimens + chambres de coupure à 2 pôles

Figure 21 – Nombre permis de spécimens pour les essais d'établissement et de coupure, illustration des spécifications de 6.102.2

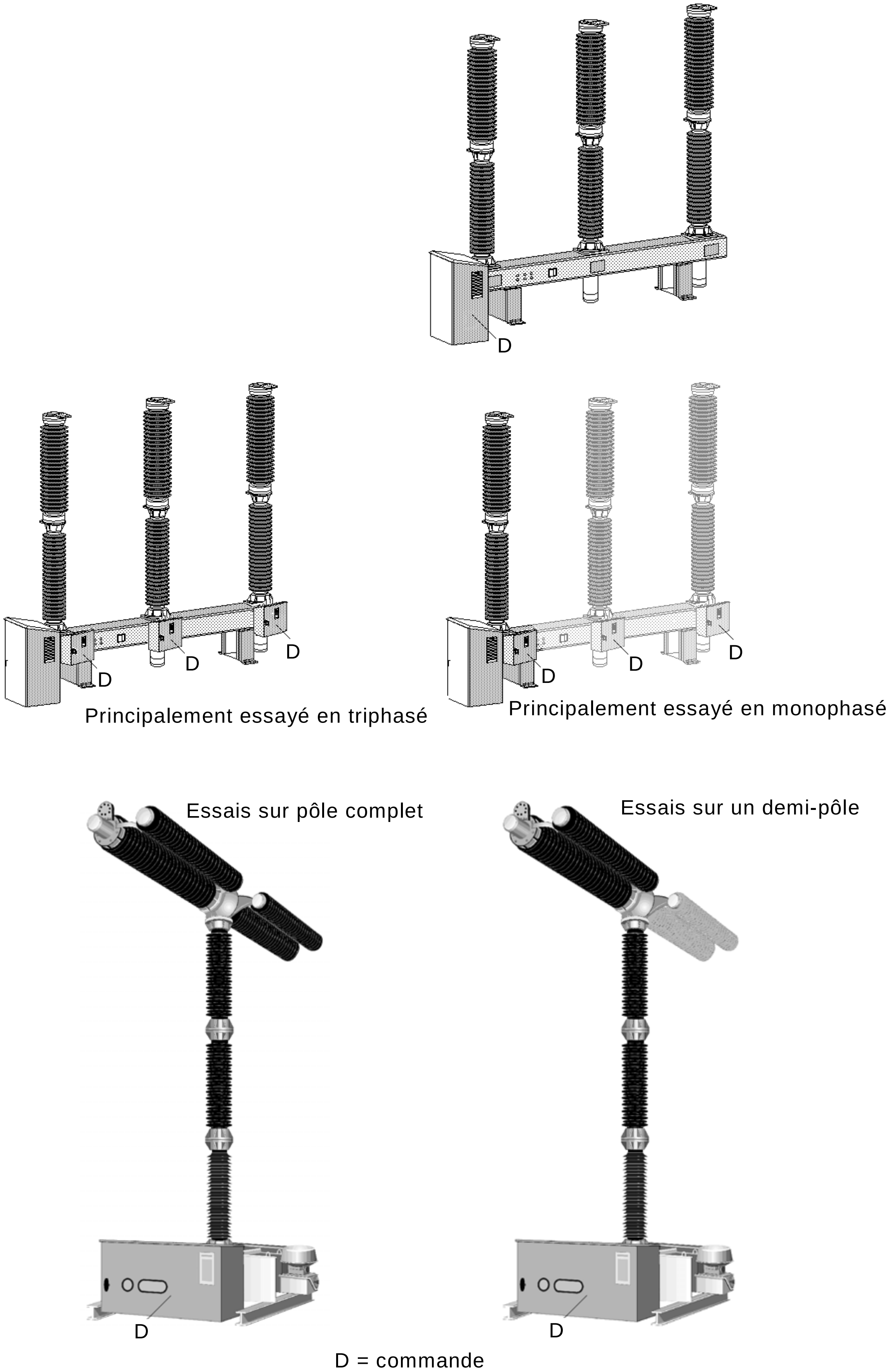


Figure 22 – Définition d'un essai conformément à 3.2.2 de la CEI 62271-1

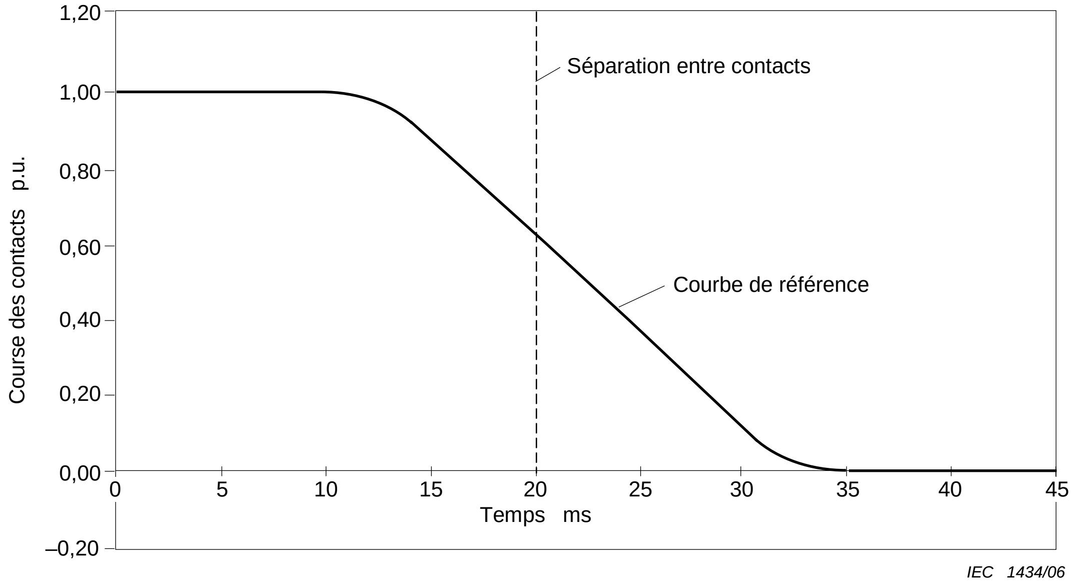


Figure 23a – Caractéristique mécanique de référence (courbe idéalisée)

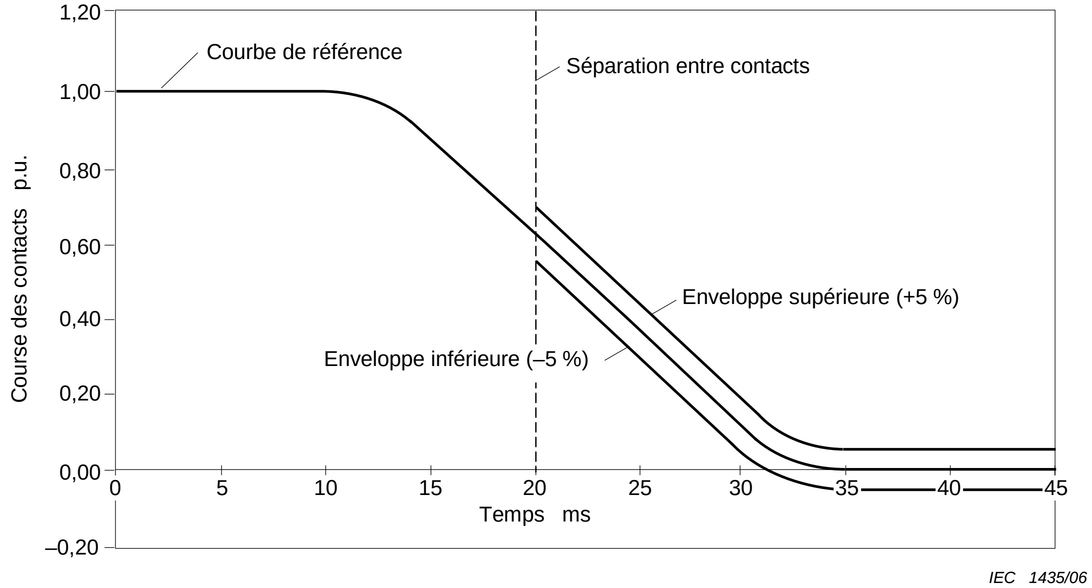


Figure 23b – Caractéristique mécanique de référence (courbe idéalisée) avec l'enveloppe exigée centrée autour de la courbe de référence (+5 %, –5 %), dans cet exemple la séparation des contacts a lieu à *t* = 20 ms

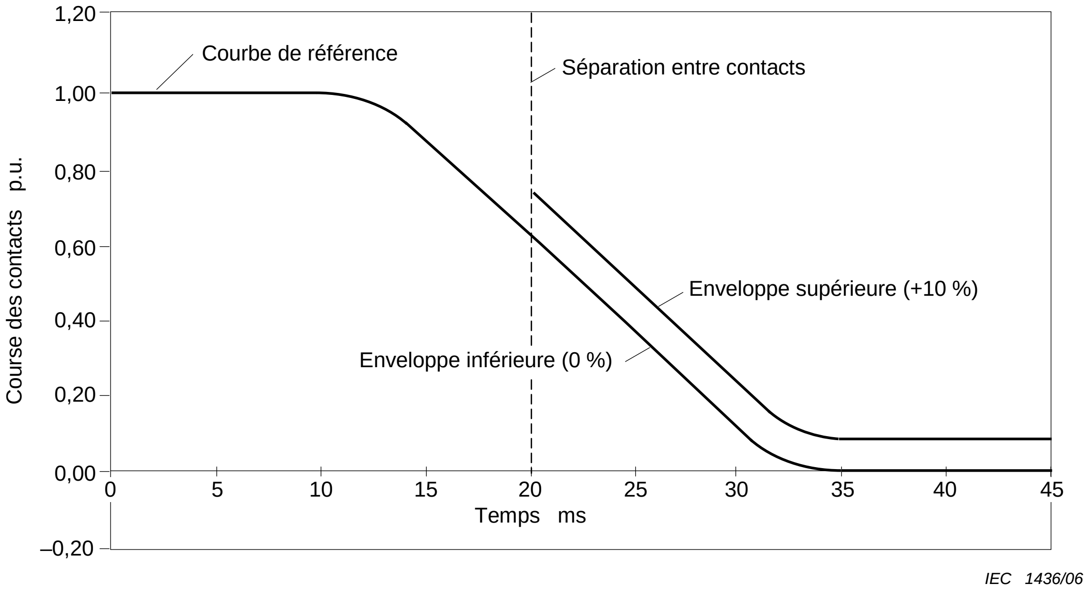


Figure 23c – Caractéristique mécanique de référence (courbe idéalisée) avec l'enveloppe exigée déplacée totalement vers le haut par rapport à la courbe de référence (+10 %, –0 %), dans cet exemple la séparation des contacts a lieu à *t* = 20 ms

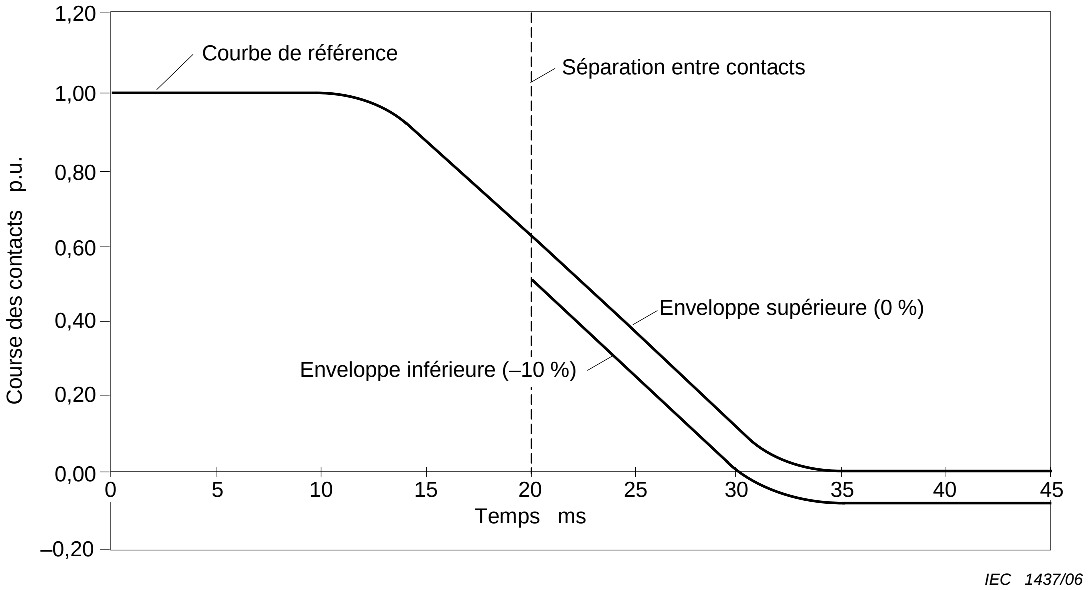
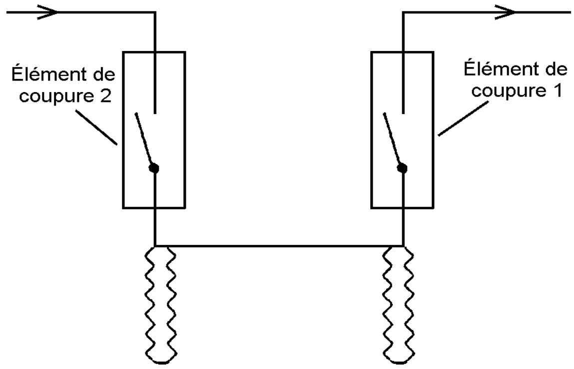


Figure 23d – Caractéristique mécanique de référence (courbe idéalisée) avec l'enveloppe exigée déplacée totalement vers le haut par rapport à la courbe de référence (+0 %, –10 %), dans cet exemple la séparation des contacts a lieu à *t* = 20 ms

Pôle de disjoncteur avec deux chambres de coupure séparées en série



Montage d’essai équivalent pour des essais sur éléments séparés; le second élément de coupure est remplacé par un conducteur de forme équivalente

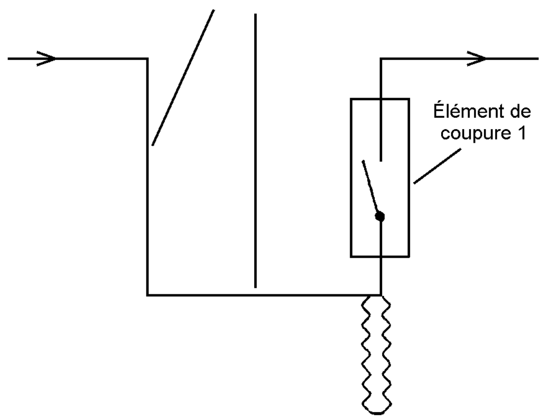


Figure 24 – Montage d’essai équivalent pour les essais sur éléments séparés d'un disjoncteur ayant plus d’un élément de coupure

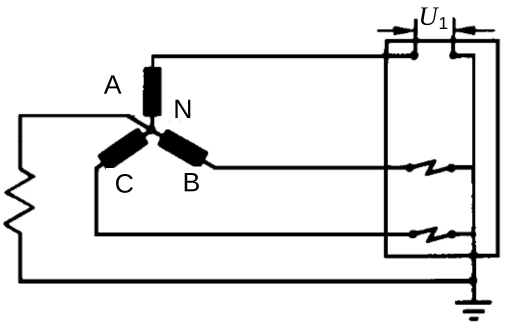


Figure 25a – Circuit préféré

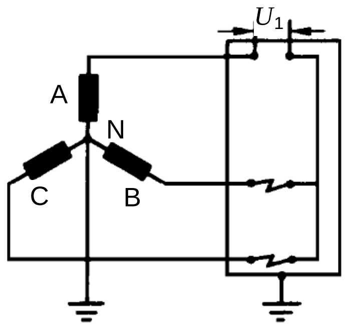
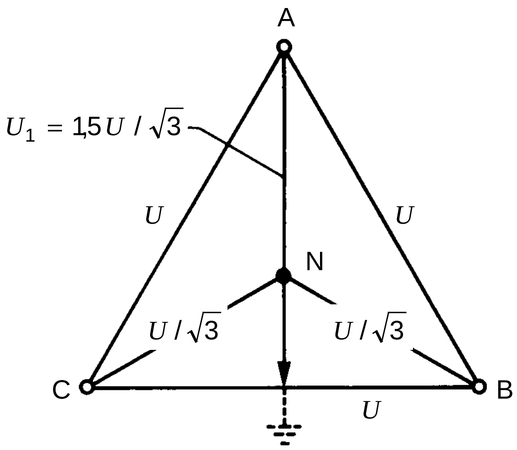


Figure 25b – Circuit utilisé en variante



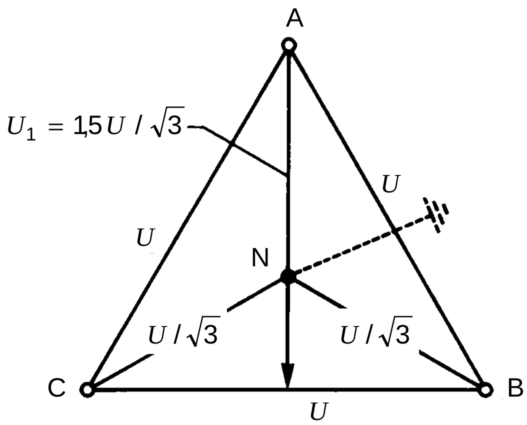


Figure 25 – Mise à la terre des circuits d'essais pour des essais triphasés en court-circuit, facteur de premier pôle 1,5

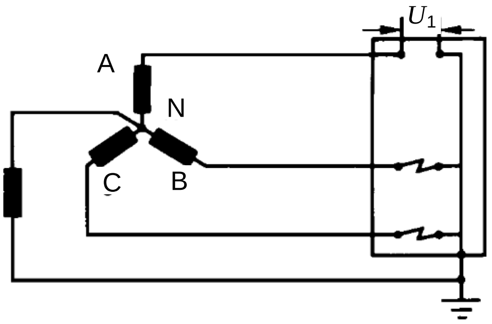


Figure 26a – Circuit préféré

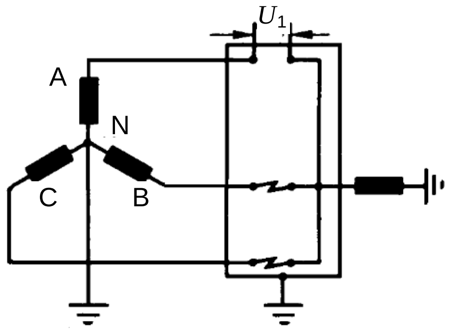


Figure 26b – Circuit utilisé en variante

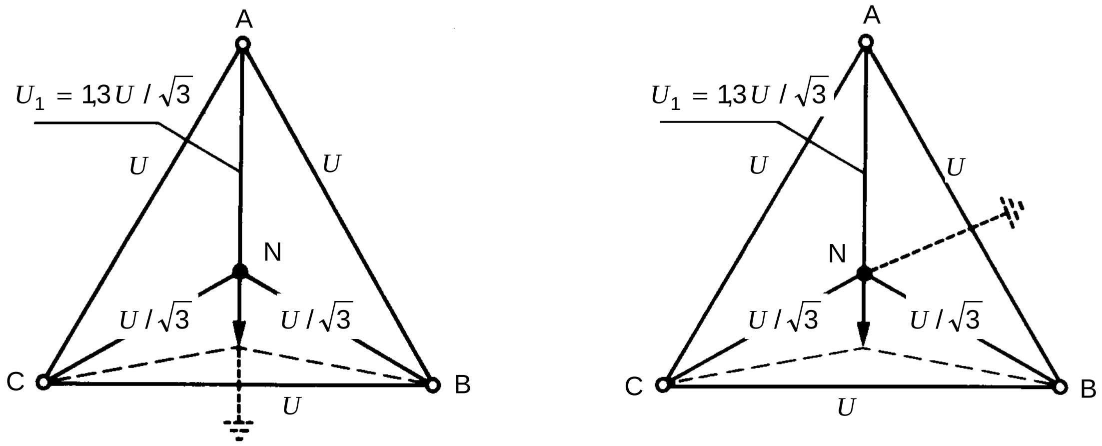


Figure 26 – Mise à la terre des circuits d'essais pour des essais triphasés en court-circuit, facteur de premier pôle 1,3

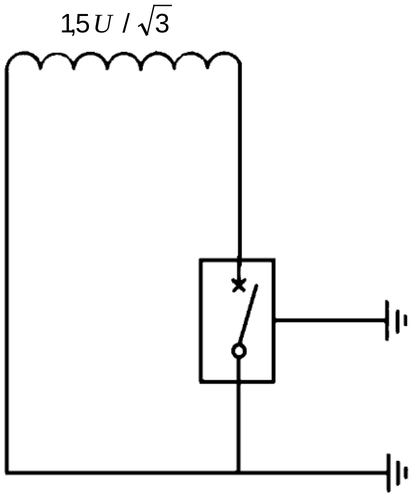


Figure 27a – Circuit préféré

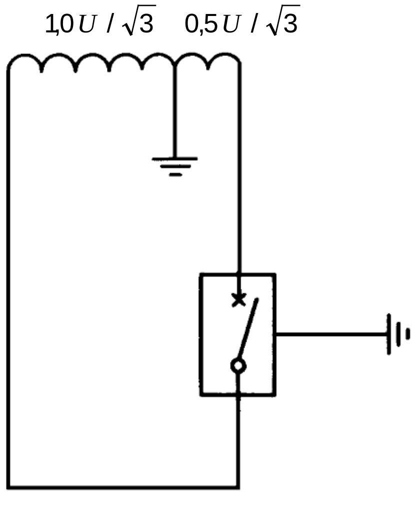


Figure 27b – Circuit utilisé en variante, n'est pas applicable aux disjoncteurs dont l'isolement entre phases et/ou à la terre est critique (par exemple GIS ou disjoncteurs *dead tank*)

Figure 27 – Mise à la terre des circuits d'essais pour des essais monophasés en court-circuit, facteur de premier pôle 1,5

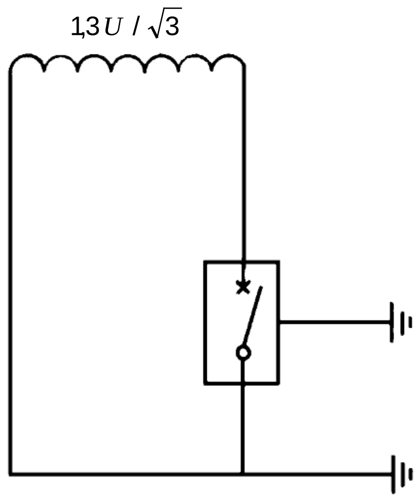


Figure 28a – Circuit préféré

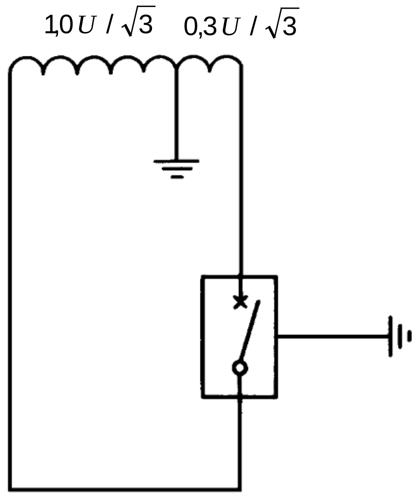


Figure 28b – Circuit utilisé en variante, n'est pas applicable aux disjoncteurs dont l'isolement entre phases et/ou à la terre est critique (par exemple GIS ou disjoncteurs *dead tank*)

Figure 28 – Mise à la terre des circuits d'essais pour des essais monophasés en court-circuit, facteur de premier pôle 1,3

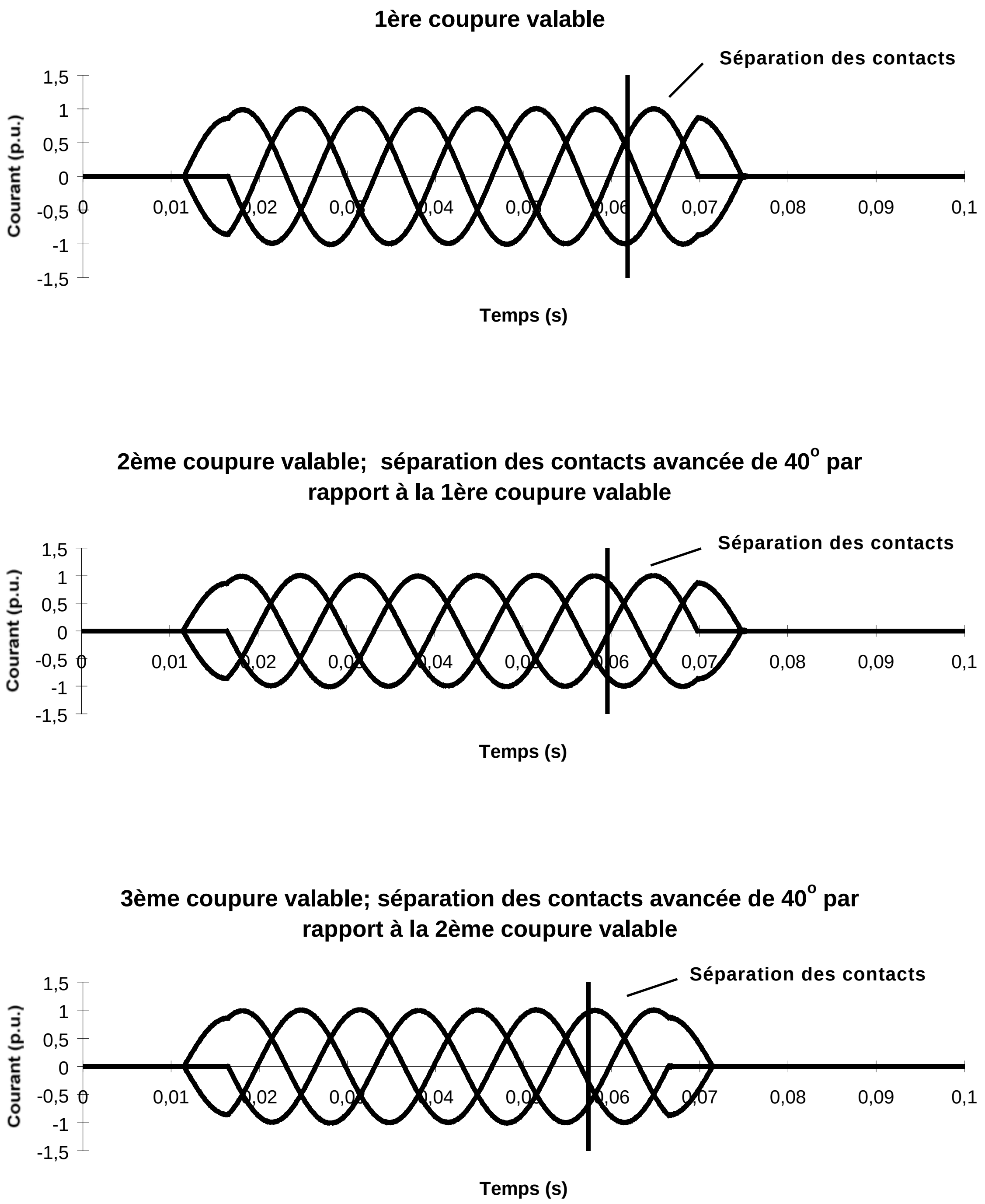
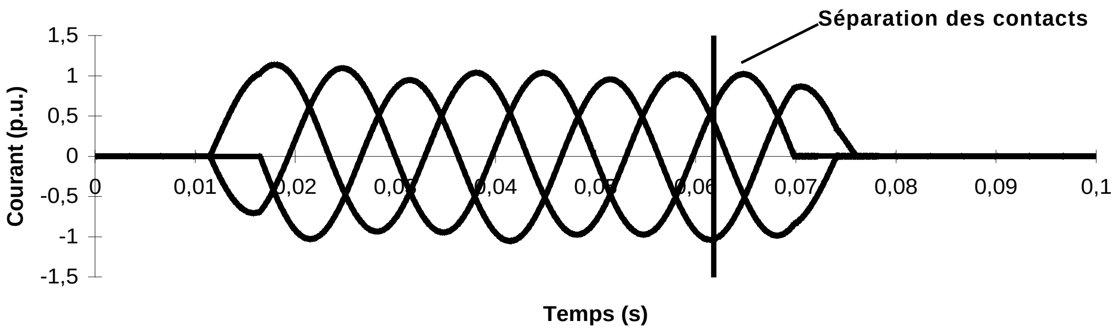
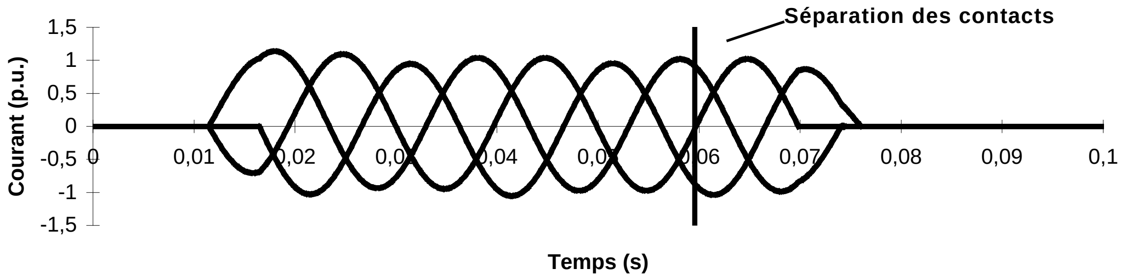


Figure 29 – Exemple de représentation graphique des trois coupures valables sur courants symétriques lors d'essais effectués en triphasé pour un réseau à neutre non effectivement à la terre (facteur de premier pôle 1,5)

1ère coupure valable



2ème coupure valable; séparation des contacts avancée de 40° par rapport à la 1ère coupure valable



3ème coupure valable; séparation des contacts avancée de 40° par rapport à la 2ème coupure valable

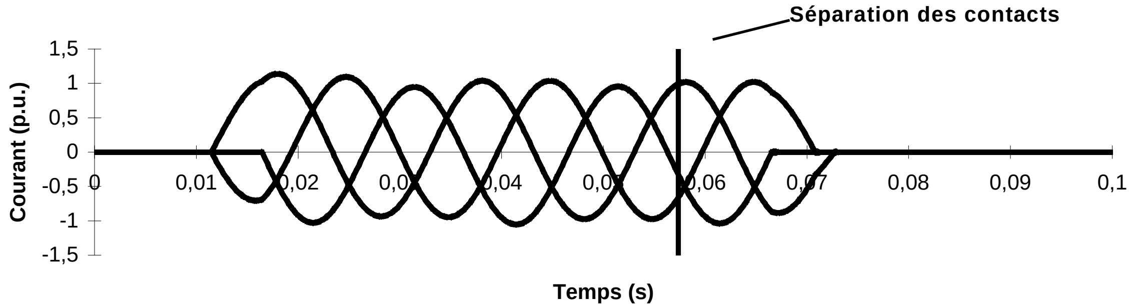
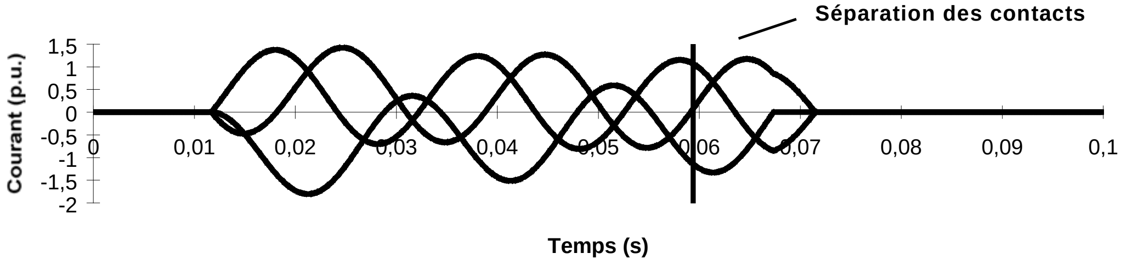
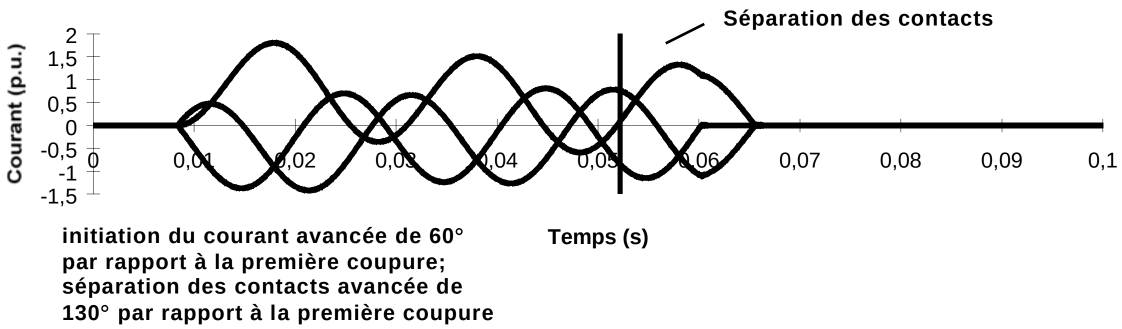


Figure 30 – Exemple de représentation graphique des trois coupures valables sur courants symétriques lors d'essais effectués en triphasé pour un réseau à neutre ~~mis~~ effectivement à la terre (facteur de premier pôle 1,3)

1ère coupure valable; premier pôle qui coupe sur une grande alternance avec le niveau de c.c. requis à la séparation des contacts



2ème coupure valable; un des derniers pôles qui coupe sur une grande alternance allongée avec le niveau de c.c. requis à la séparation des contacts



3ème coupure valable; premier pôle qui coupe sur une grande alternance avec le niveau de c.c. requis à la séparation des contacts

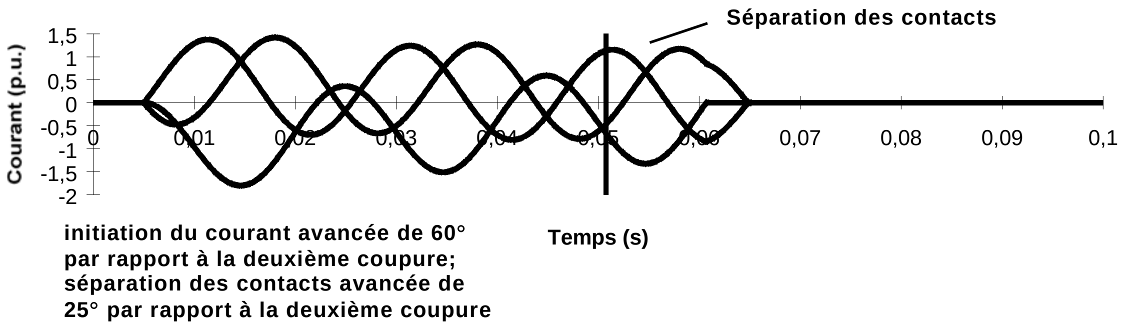
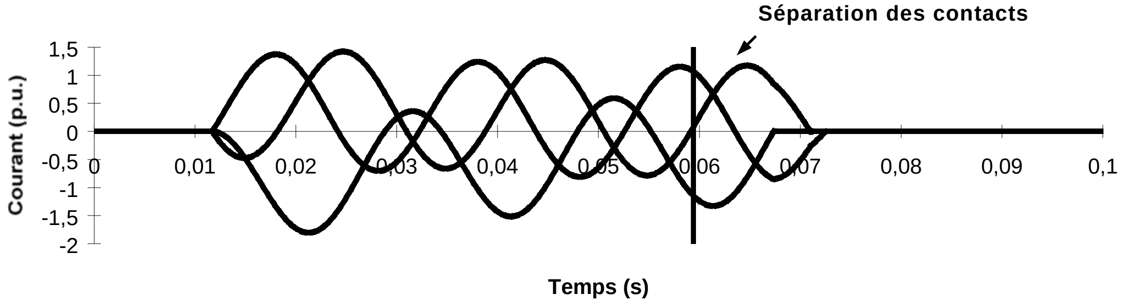
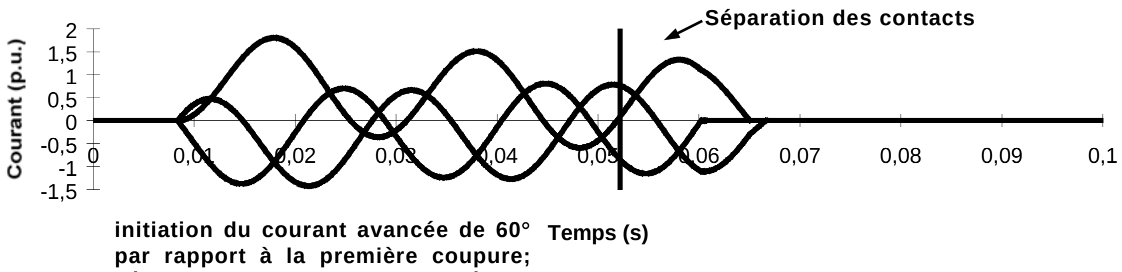


Figure 31 – Représentation graphique des trois coupures valables sur courants asymétriques lors d'essais effectués en triphasé pour un réseau à neutre non effectivement à la terre (facteur de premier pôle 1,5)

1ère coupure valable; premier pôle qui coupe sur une grande alternance avec le niveau de c.c. requis à la séparation des contacts

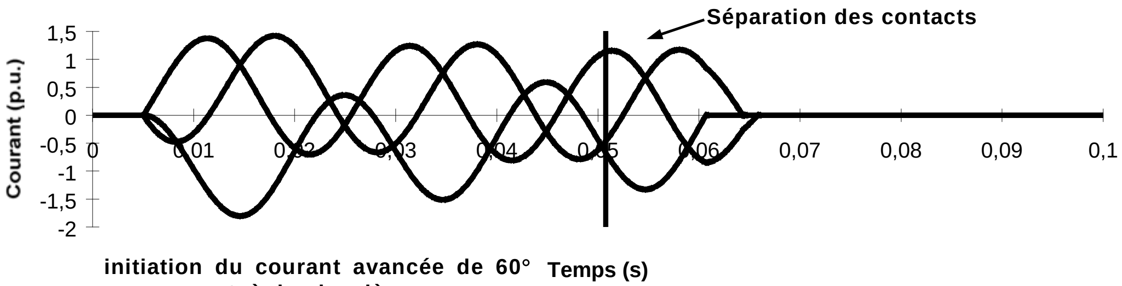


2ème coupure valable; deuxième pôle qui coupe après une grande alternance allongée avec le niveau de c.c. requis à la séparation des contacts



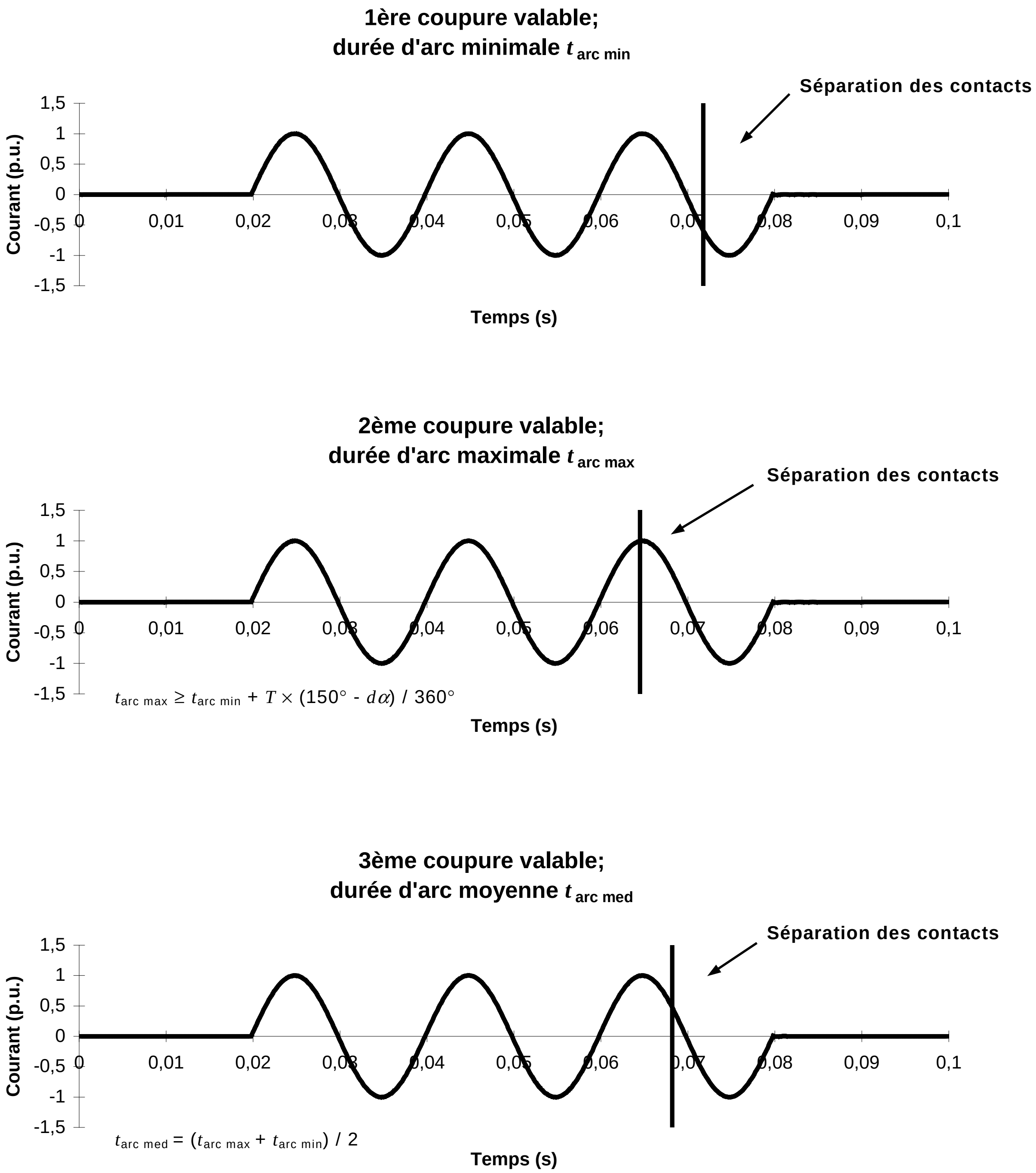
initiation du courant avancée de 60° par rapport à la première coupure; séparation des contacts avancée de 130° par rapport à la première coupure.

3ème coupure valable; premier pôle qui coupe après une grande alternance avec le niveau de c.c. requis à la séparation des contacts



initiation du courant avancée de 60° par rapport à la deuxième coupure; séparation des contacts avancée de 25° par rapport à la deuxième coupure

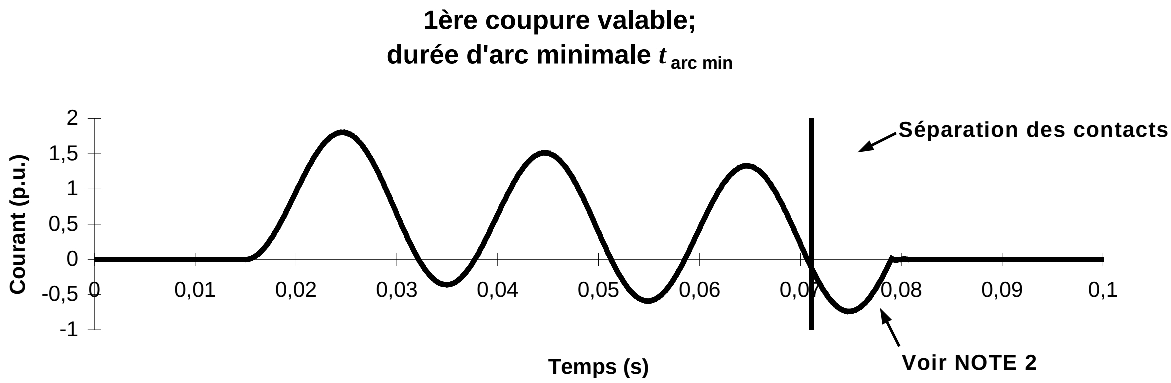
Figure 32 – Représentation graphique des trois coupures valables sur courants asymétriques lors d'essais effectués en triphasé pour un réseau à neutre mis effectivement à la terre (facteur de premier pôle 1,3)

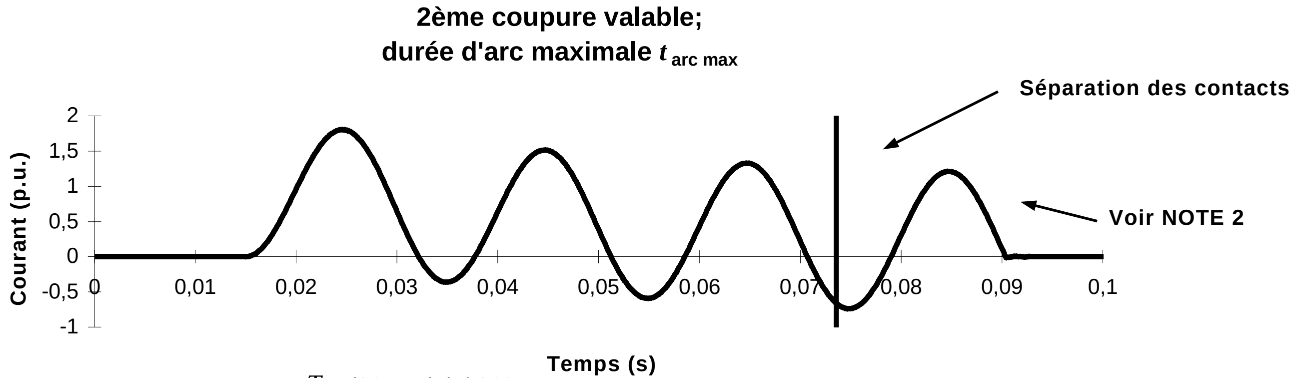


$d\alpha = 18°$

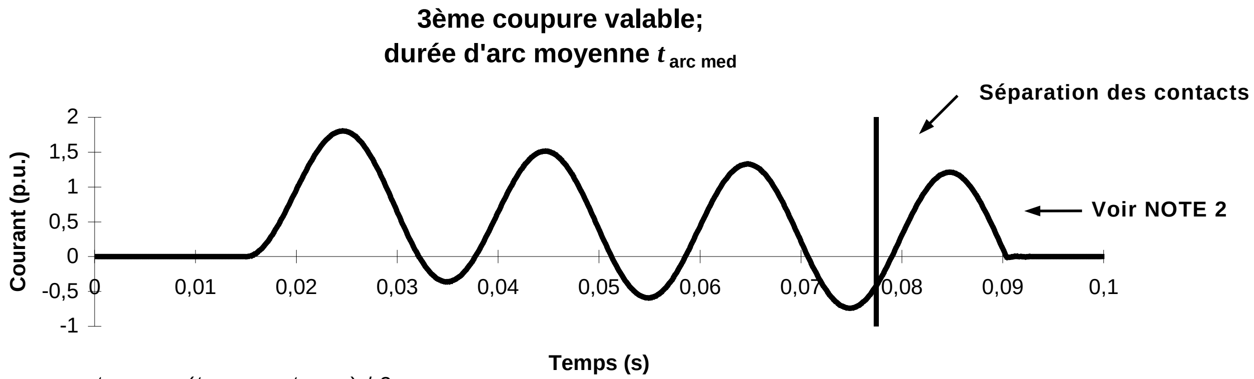
NOTE La polarité du courant peut être inversée.

Figure 33 – Représentation graphique des trois coupures valables sur courants symétriques lors d'essais en monophasé effectués en remplacement des conditions triphasées dans un réseau à neutre non effectivement à la terre (facteur de premier pôle 1,5)





$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times (30° + \mathrm{d}\alpha) / 360°$



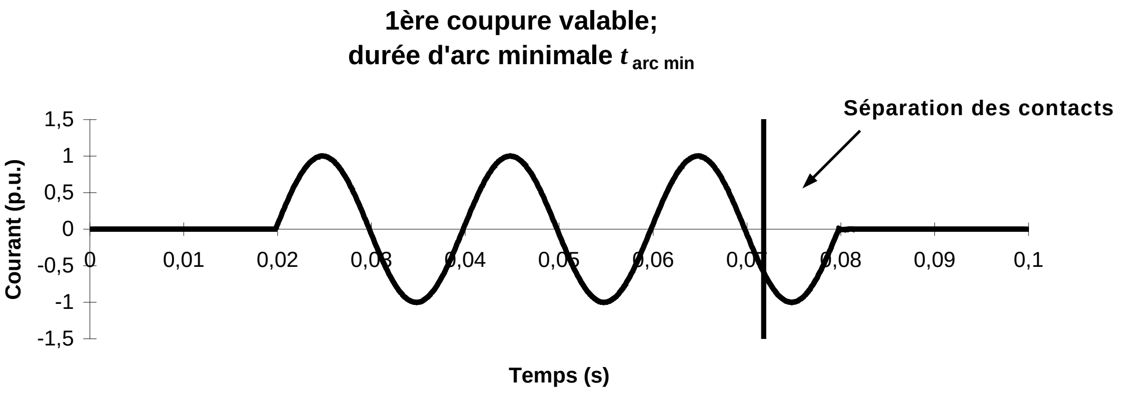
$t_{\text{arc med}}. = (t_{\text{arc max}} + t_{\text{arc min}}) / 2$

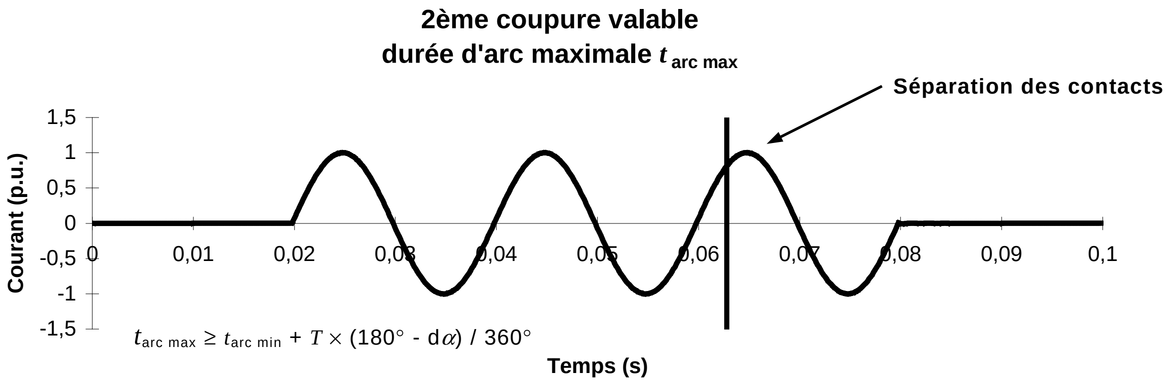
$\mathrm{d}\alpha = 18°$

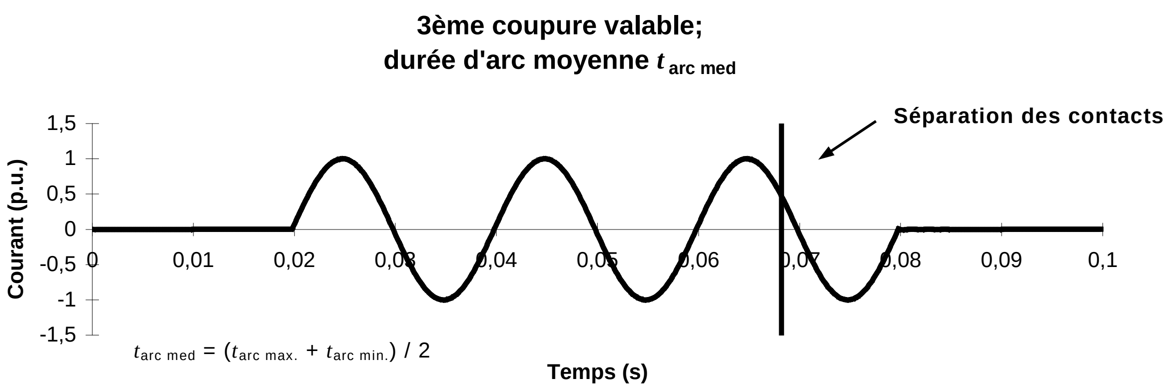
NOTE 1 La polarité du courant peut être inversée.

NOTE 2 Il faut que l'amplitude et la durée de la dernière demi-alternance de courant rencontrent les critères énoncés en 6.102.10.

Figure 34 – Représentation graphique des trois coupures valables sur courants asymétriques lors d'essais en monophasé effectués en remplacement des conditions triphasées dans un réseau à neutre non effectivement à la terre (facteur de premier pôle 1,5)



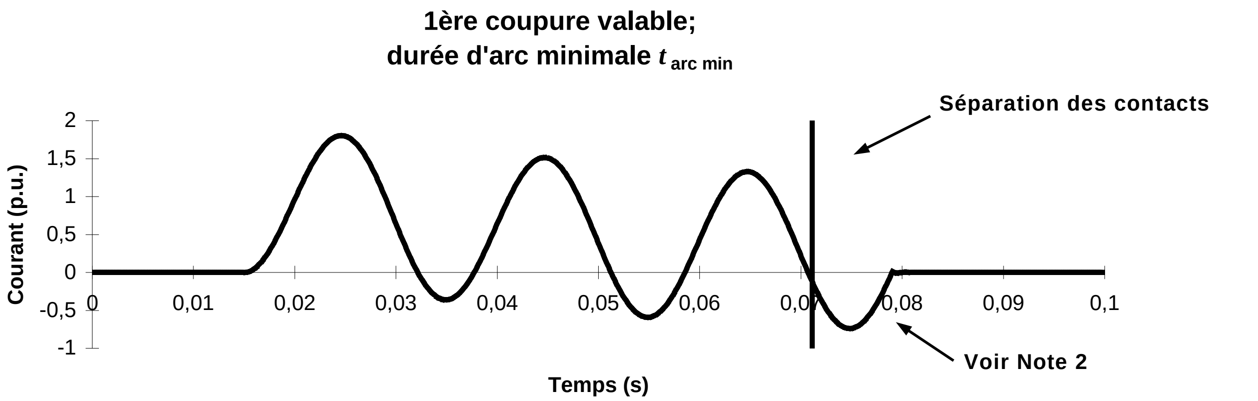


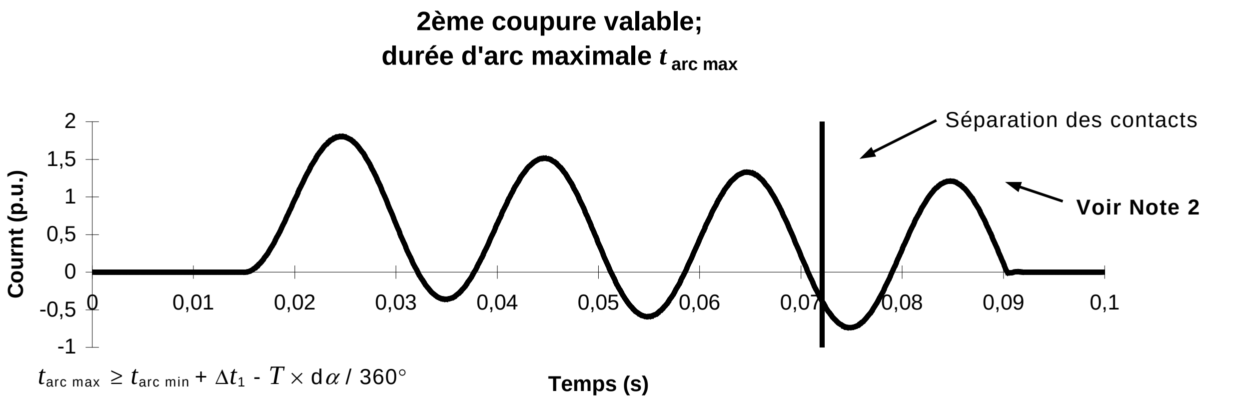


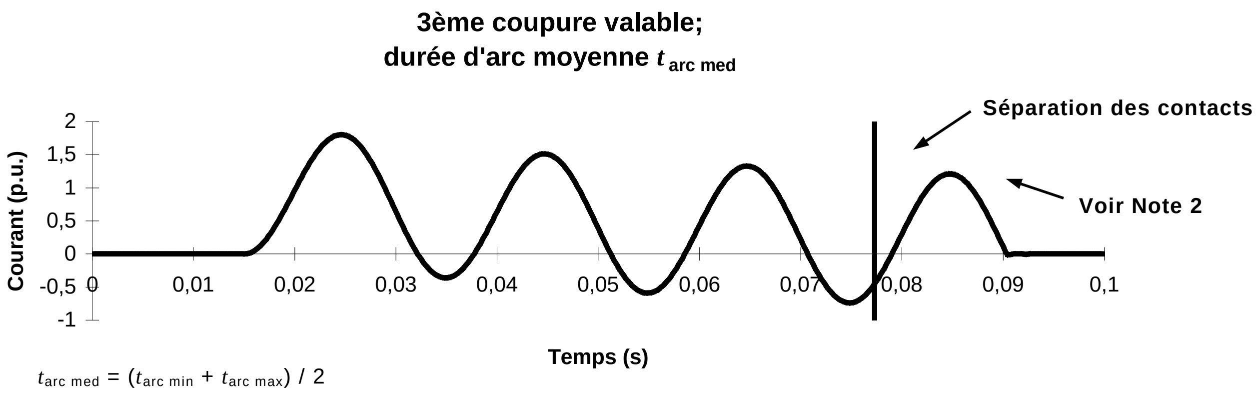
$d\alpha = 18°$

NOTE La polarité du courant peut être inversée.

Figure 35 – Représentation graphique des trois coupures valables sur courants symétriques lors d'essais en monophasé effectués en remplacement des conditions triphasées dans un réseau à neutre mis effectivement à la terre (facteur de premier pôle 1,2 ou 1,3)







$\mathrm{d}\alpha = 18°$

NOTE 1 La polarité du courant peut être inversée.

NOTE 2 Il faut que l'amplitude et la durée de la dernière demi-alternance de courant rencontrent les critères énoncés en 6.102.10.

Figure 36 – Représentation graphique des trois coupures valables sur courants asymétriques lors d'essais en monophasé effectués en remplacement des conditions triphasées dans un réseau à neutre mis effectivement à la terre (facteur de premier pôle 1,2 ou 1,3)

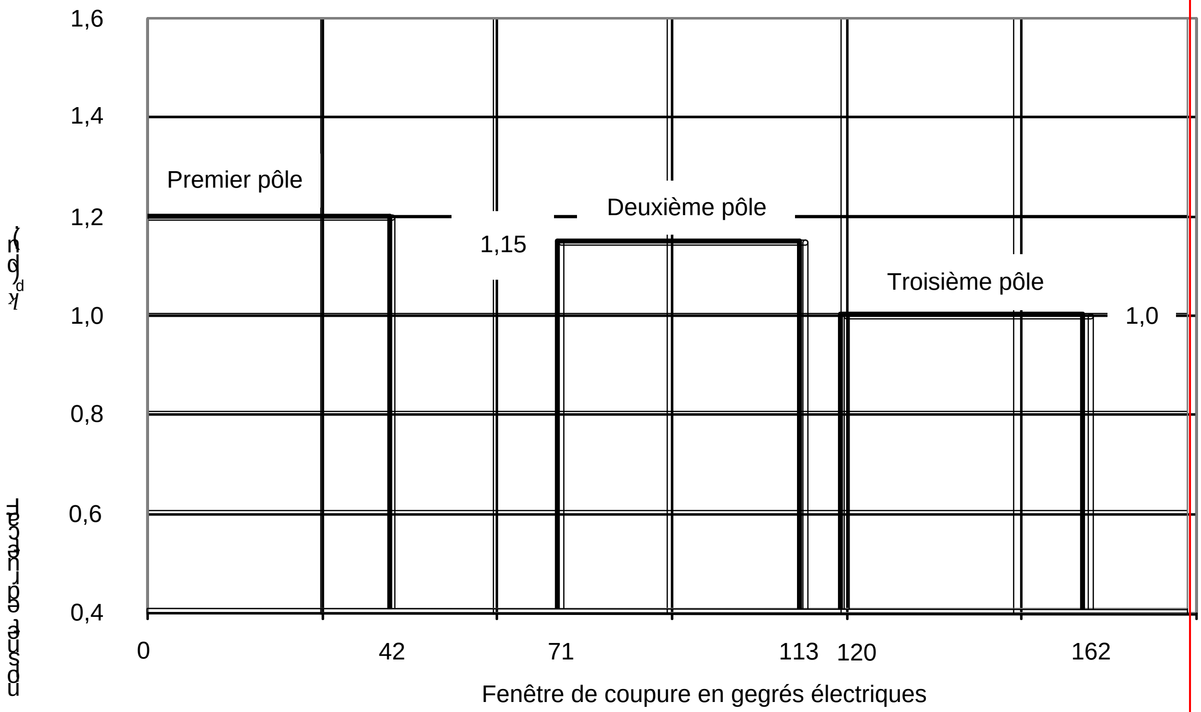


Figure 58 – Représentation graphique de la fenêtre de coupure et du facteur de tension k_p qui détermine la TTR de chaque pôle, pour des réseaux avec un facteur premier pôle égal à 1,2

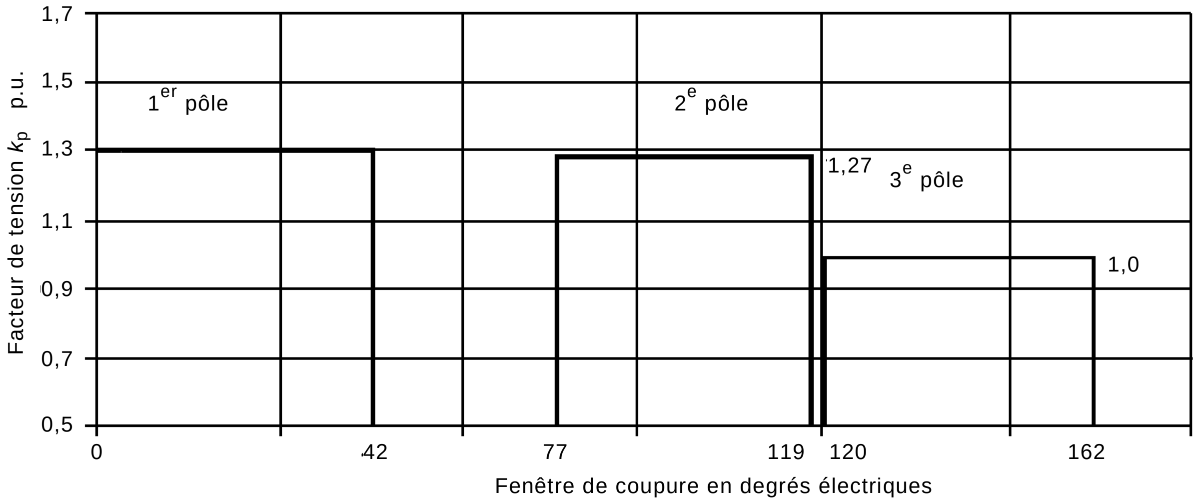


Figure 37 – Représentation graphique de la fenêtre de coupure et du facteur de tension k_p qui détermine la TTR de chaque pôle, pour des réseaux avec un facteur de premier pôle égal à 1,3

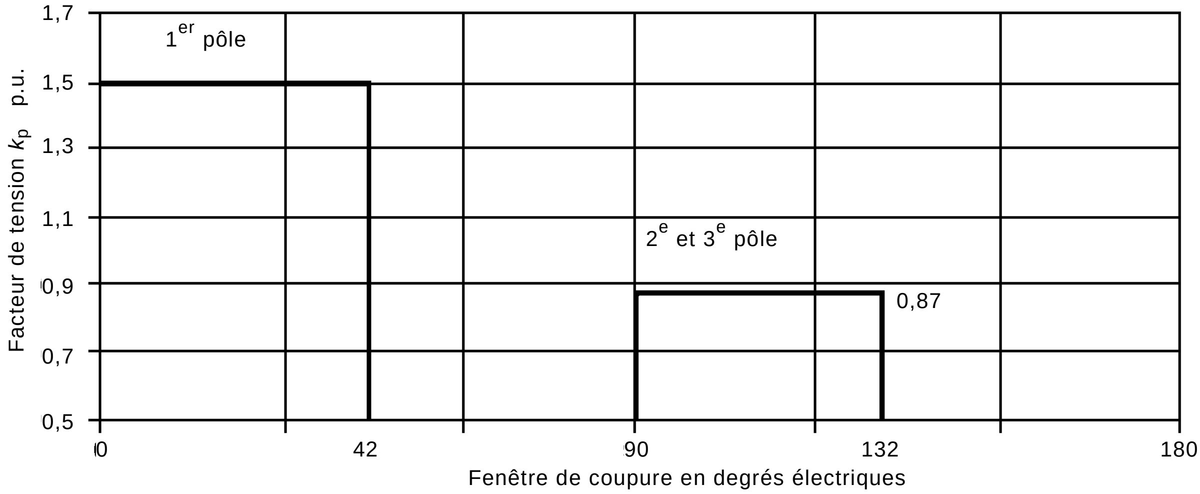


Figure 38 – Représentation graphique de la fenêtre de coupure et du facteur de tension k_p qui détermine la TTR de chaque pôle, pour des réseaux avec un facteur premier pôle égal à 1,5

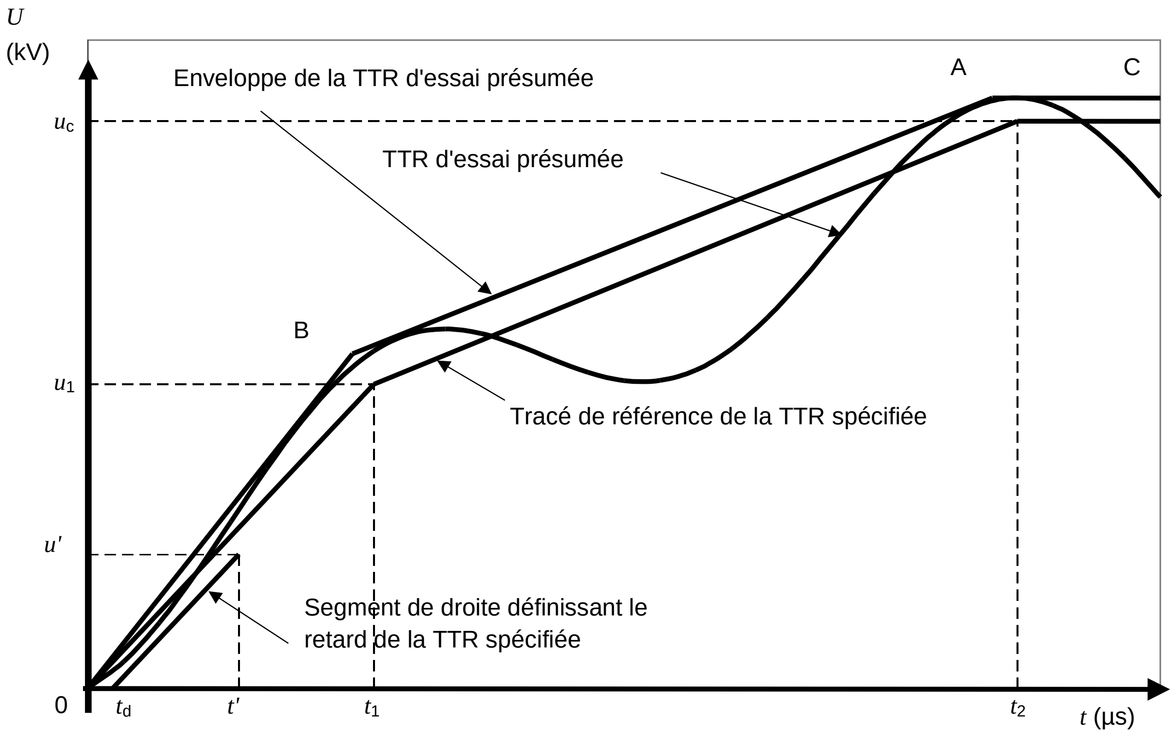


Figure 39 – Exemple d'une TTR d'essai présumée comportant une enveloppe à quatre paramètres et répondant aux conditions imposées pour l'essai de type – Cas de la TTR spécifiée comportant un tracé de référence à quatre paramètres

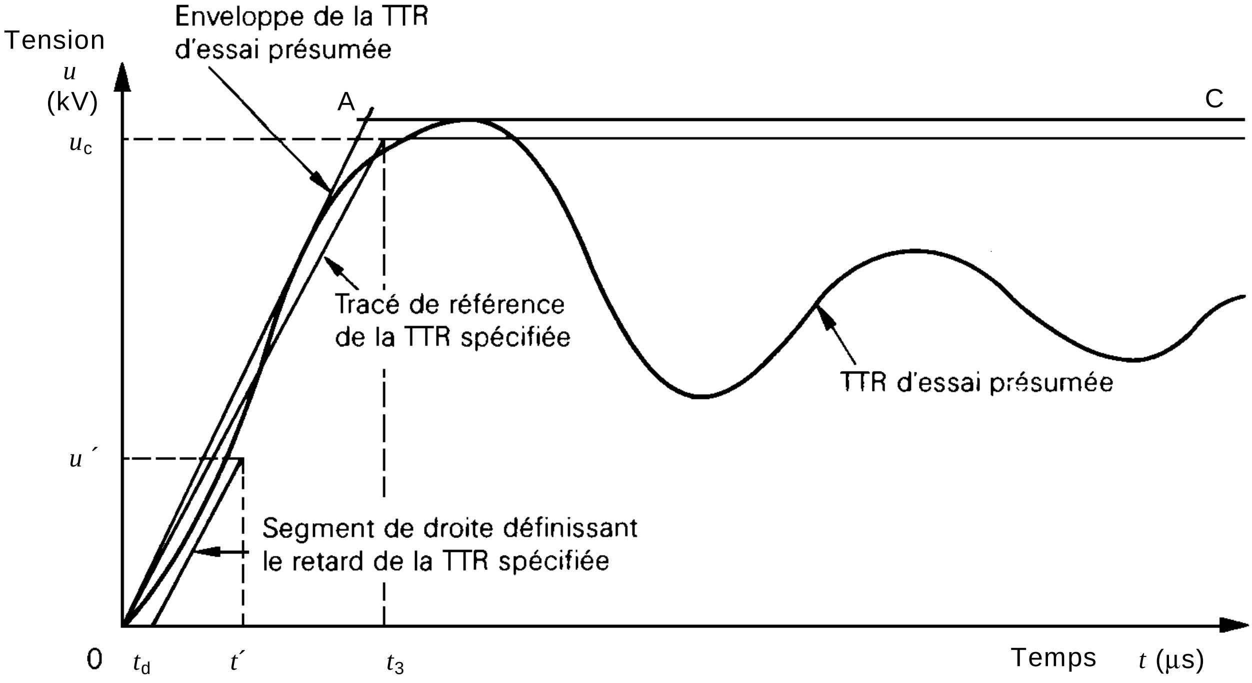


Figure 40 – Exemple d'une TTR d'essai présumée comportant une enveloppe à deux paramètres et répondant aux conditions imposées pour l'essai de type: cas de la TTR spécifiée comportant un tracé de référence à deux paramètres

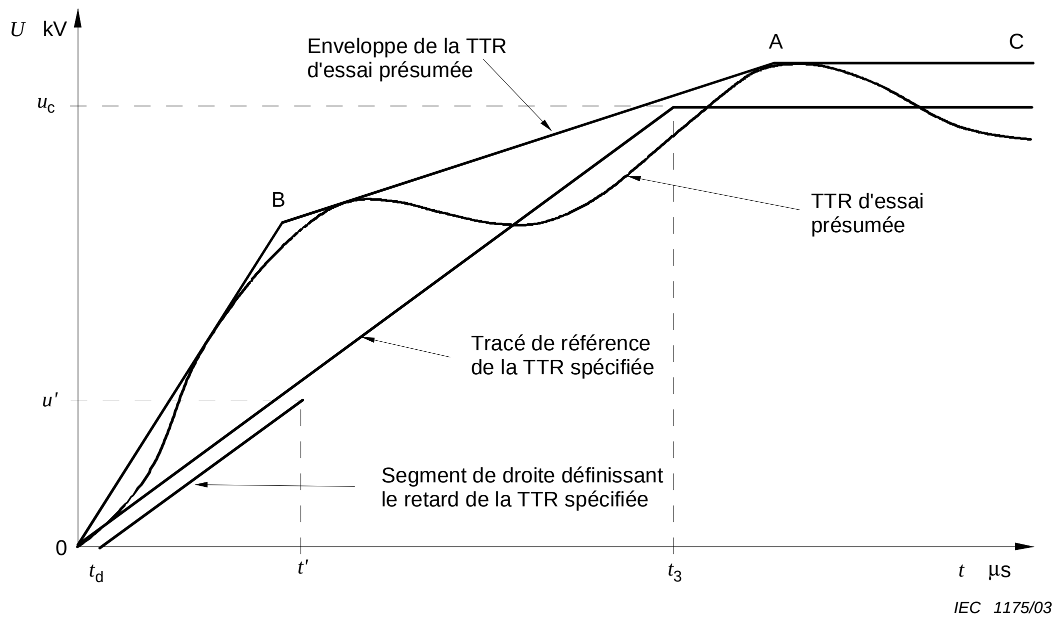


Figure 41 – Exemple d'une TTR d'essai présumée comportant une enveloppe à quatre paramètres répondant aux conditions imposées pour l'essai de type – Cas de la TTR spécifiée comportant un tracé de référence à deux paramètres

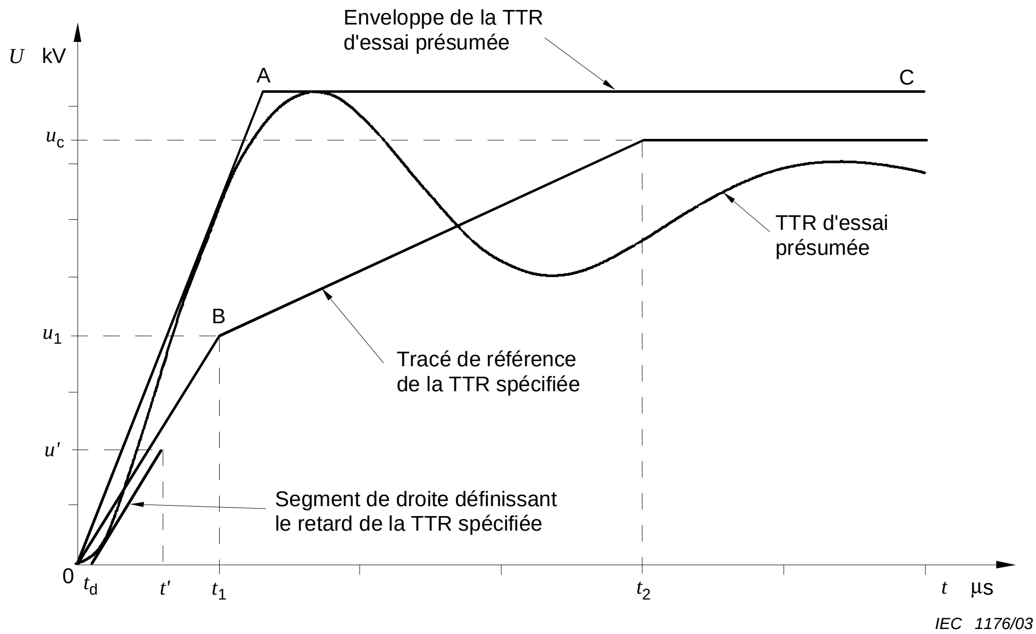
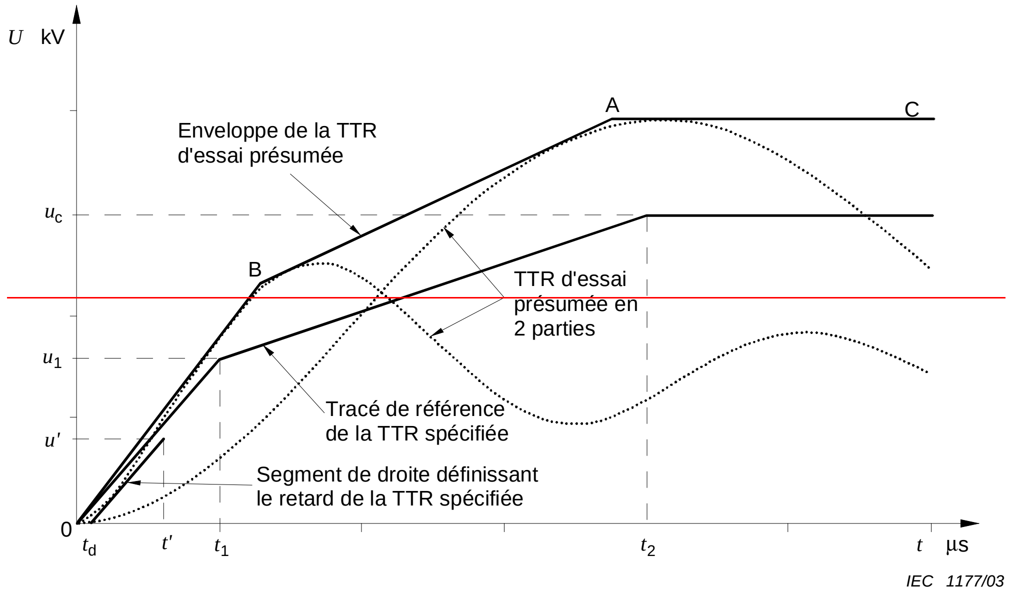
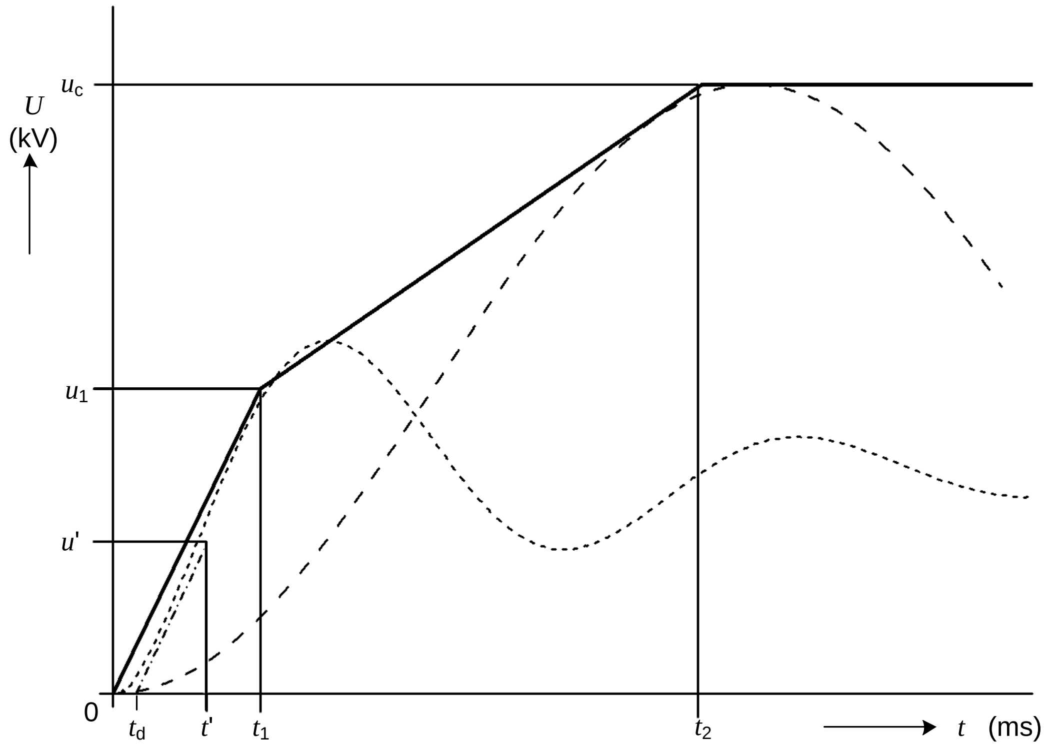


Figure 42 – Exemple d'une TTR d'essai présumée comportant une enveloppe à deux paramètres répondant aux conditions imposées pour l'essai de type – Cas de la TTR spécifiée comportant un tracé de référence à quatre paramètres

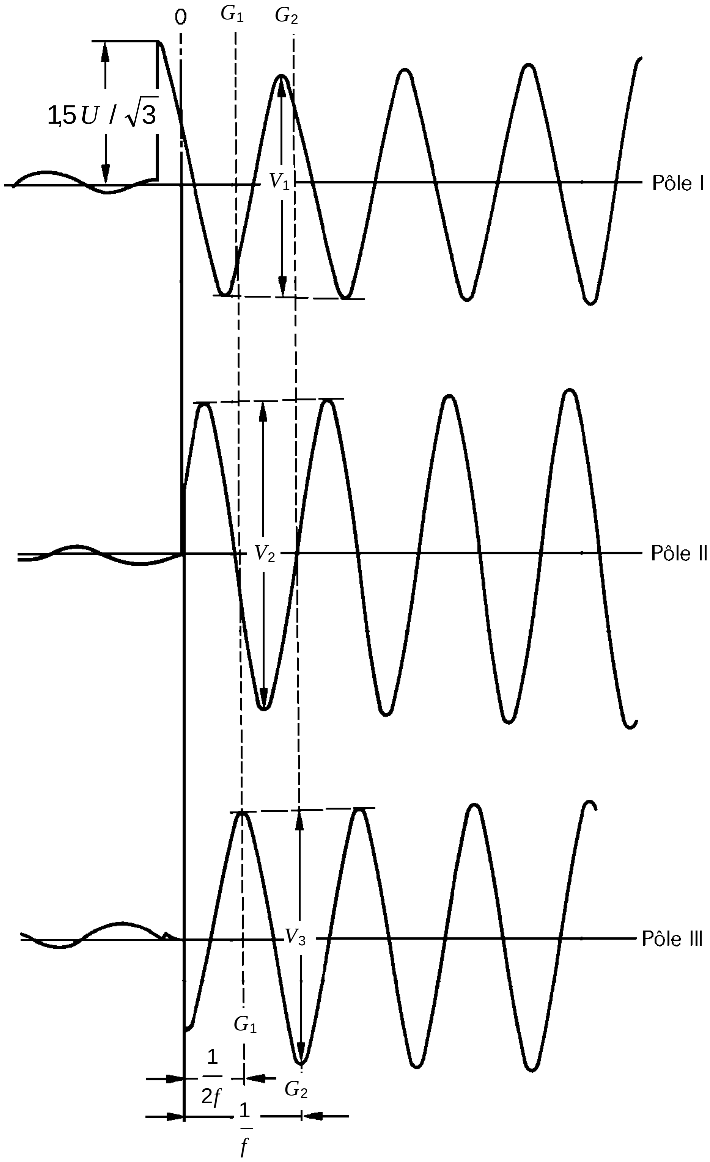




Légende

(trait plein)	Enveloppe à 4 paramètres requise
(tirets courts)	TTR d'essai partie 1
(tirets longs)	TTR d'essai partie 2
(trait mixte)	Segment définissant le retard

Figure 43 – Exemple d'ondes de TTR d'essai présumée et de l'enveloppe de l'ensemble pour des essais en deux parties



Pole I = premier pôle qui coupe

OO = instant de l'extinction finale de l'arc sur toutes les phases

G_1G_1 = instant $\frac{1}{2f}$ depuis OO

G_2G_2 = instant $\frac{1}{f}$ depuis OO

f = fréquence de l'essai

$\frac{V_1}{2\sqrt{2}}$ = valeur de la tension de rétablissement à fréquence industrielle du pôle I

$\frac{V_2}{2\sqrt{2}}$ = valeur de la tension de rétablissement à fréquence industrielle du pôle II

$\frac{V_3}{2\sqrt{2}}$ = valeur de la tension de rétablissement à fréquence industrielle du pôle III

Sur le pôle III, une crête de tension se produit exactement à l'instant G_1G_1. Dans un tel cas, on effectue la mesure à l'instant G_2G_2 qui suit.

Valeur moyenne des tensions de rétablissement à fréquence industrielle des pôles I, II et III

$$= \frac{\frac{V_1}{2\sqrt{2}} + \frac{V_2}{2\sqrt{2}} + \frac{V_3}{2\sqrt{2}}}{3}$$

L’exemple montre les trois tensions obtenues pendant un essai sur un disjoncteur tripolaire dans un circuit d’essai triphasé ayant un de ses points neutres isolé (voir Figure 25a ou 25b, et par conséquent produisant sur le premier pôle qui coupe un accroissement momentané de 50 % de la tension de rétablissement, comme cela est indiqué sur le pôle I.

Figure 44 – Détermination de la tension de rétablissement à fréquence industrielle

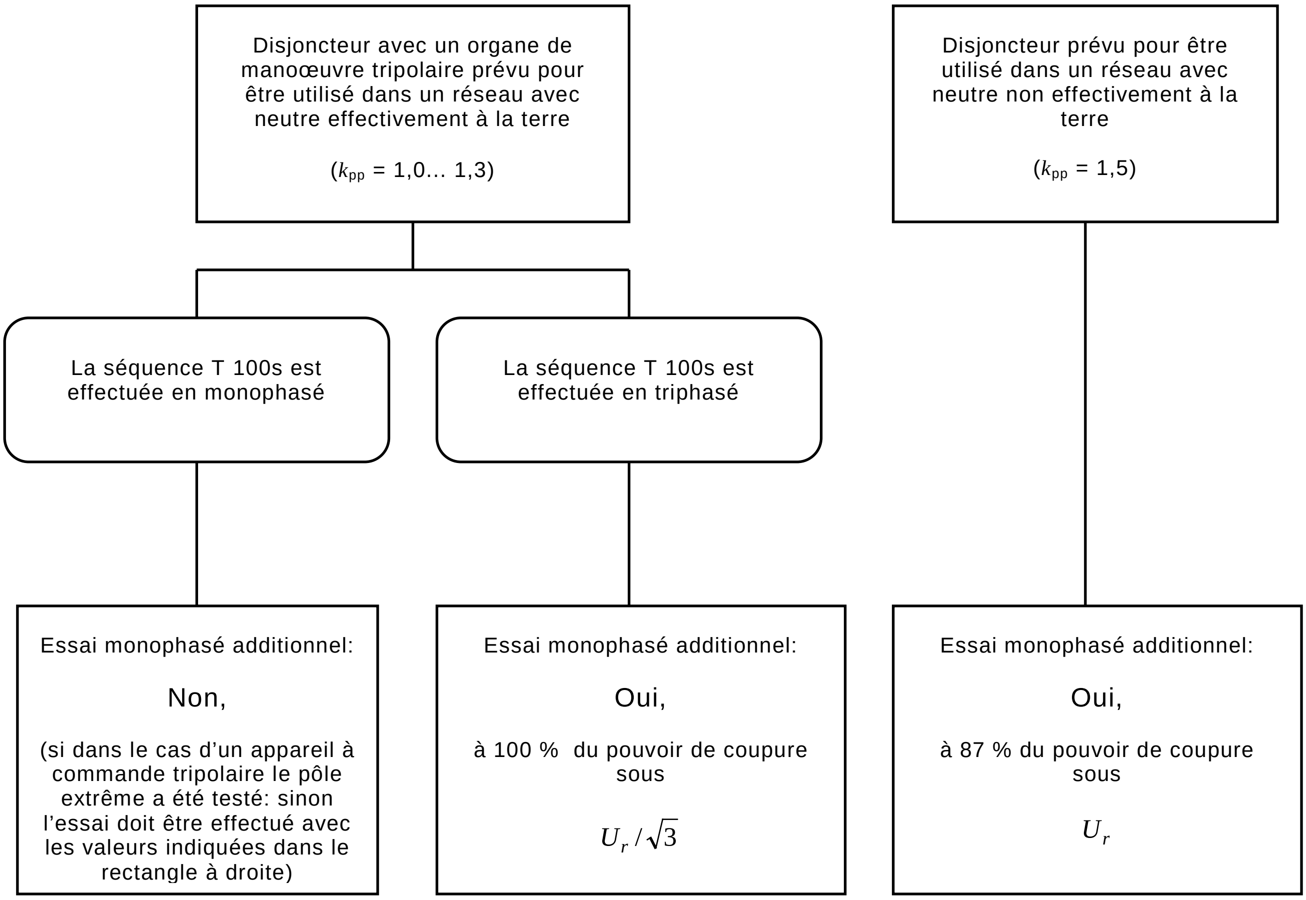
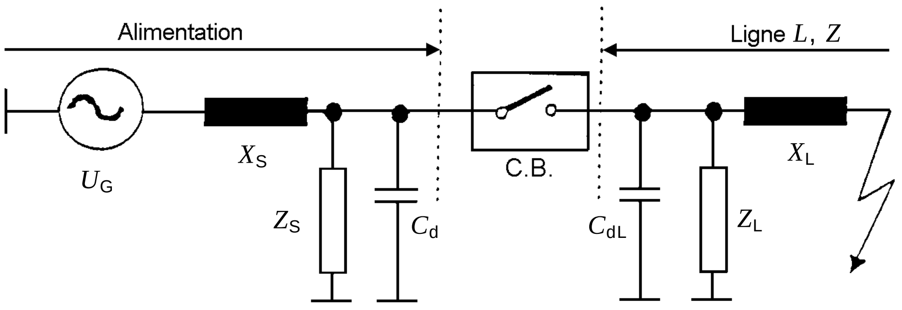
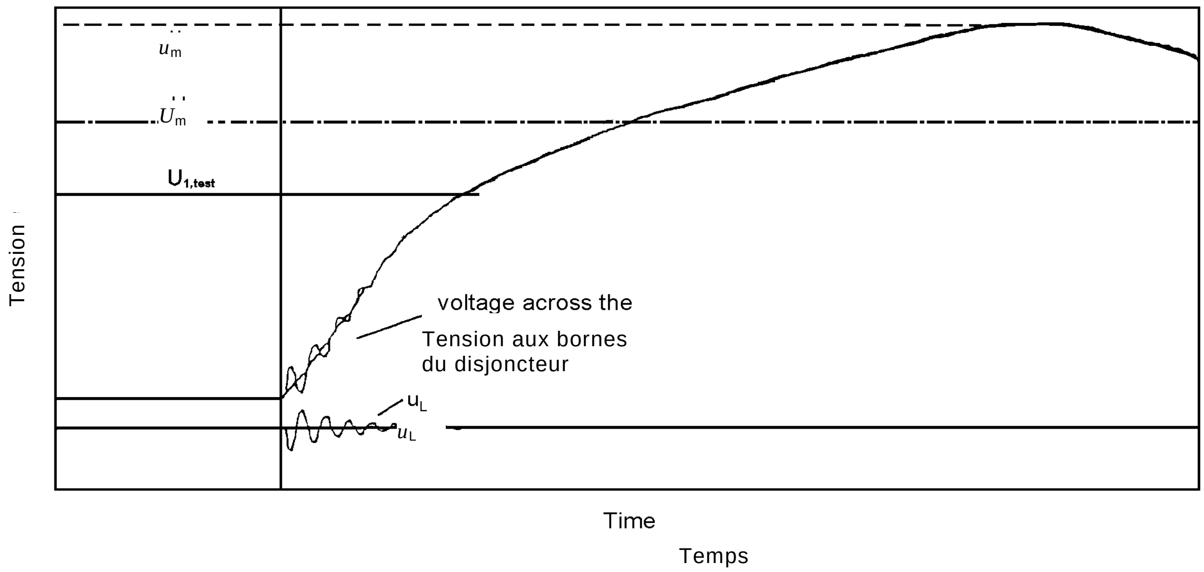


Figure 45 – Nécessité d'essais additionnels monophasés et exigences d'essais



U_G Tension d'alimentation, valeur phase terre
X_S Réactance à fréquence industrielle côté alimentation
Z_S Éléments de réglage de la TTR côté alimentation
C_d Capacité de retard côté alimentation
C.B. Disjoncteur
X_L Réactance à fréquence industrielle, côté ligne
Z_L Éléments de réglage de la TTR côté ligne
C_{dL} Capacité de retard, côté ligne
Z Impédance d'onde de la ligne
L Longueur de ligne en défaut



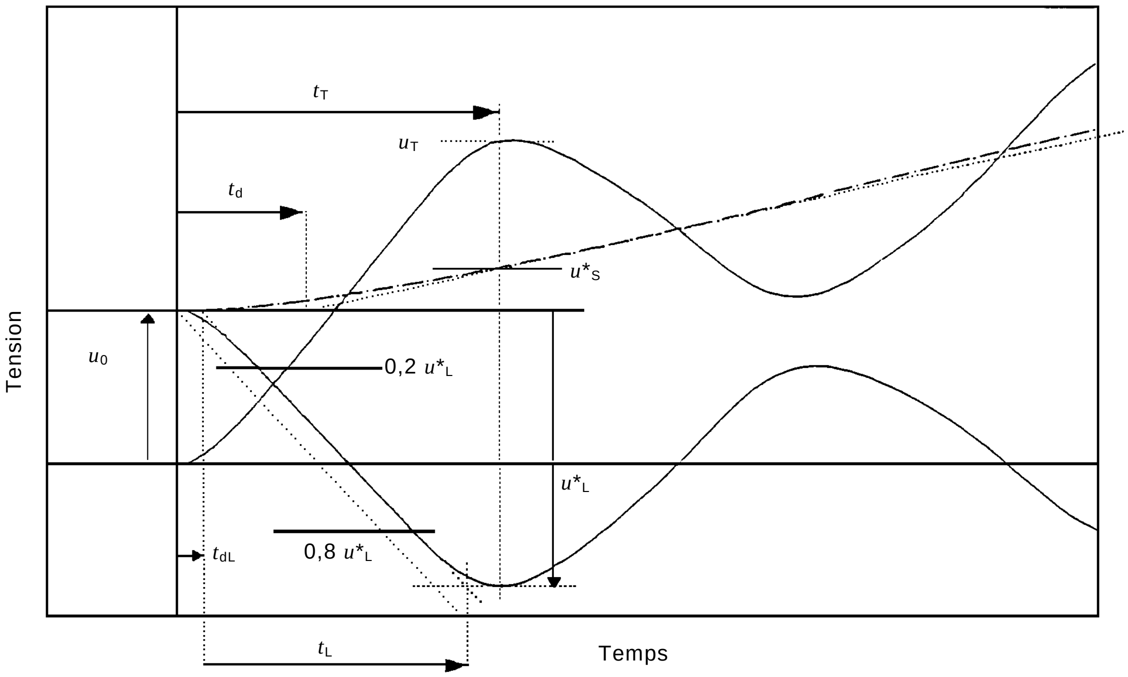
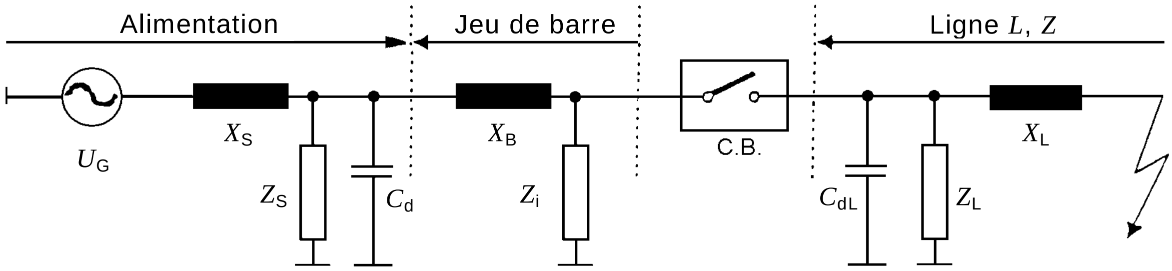
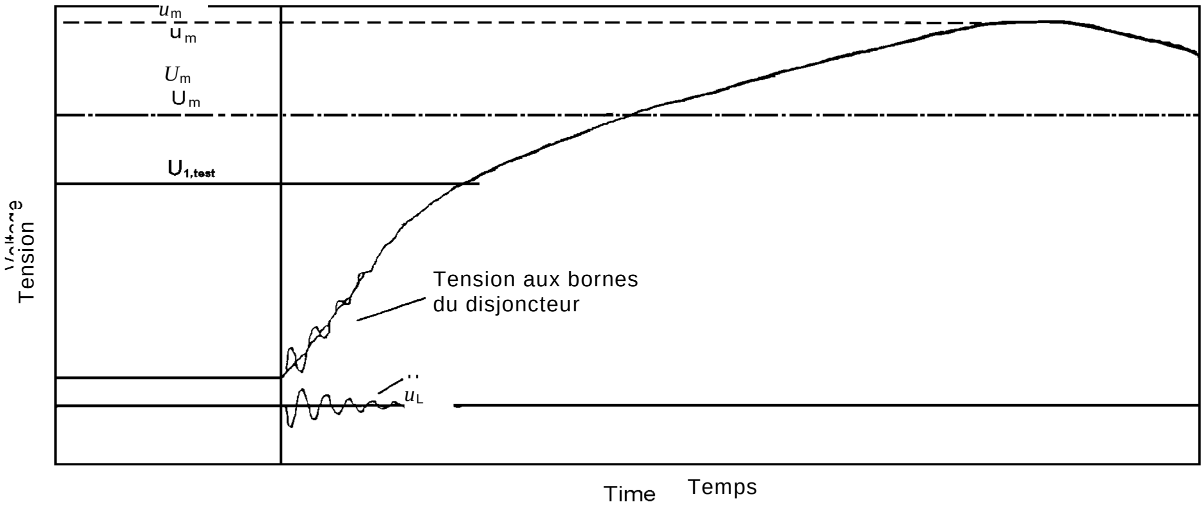


Figure 46 – Circuit de base pour les essais de défaut proche en ligne – TTR présumée du circuit type a) selon 6.109.3: côté alimentation et côté ligne avec temps de retard



U_G	Tension d'alimentation, valeur phase terre	Z_i	Élements de réglage de la TTR
X_S	Réactance à fréquence industrielle côté alimentation	X_L	Réactance à fréquence industrielle, côté ligne
Z_S	Éléments de réglage de la TTR côté alimentation	Z_L	Éléments de réglage de la TTR côté ligne
C_d	Capacité de retard côté alimentation	C_{dL}	Capacité de retard côté ligne
C.B.	Disjoncteur	Z	Impédance d'onde de la ligne
X_B	Réactance à fréquence industrielle du jeu de barre	L	Longueur de ligne en défaut



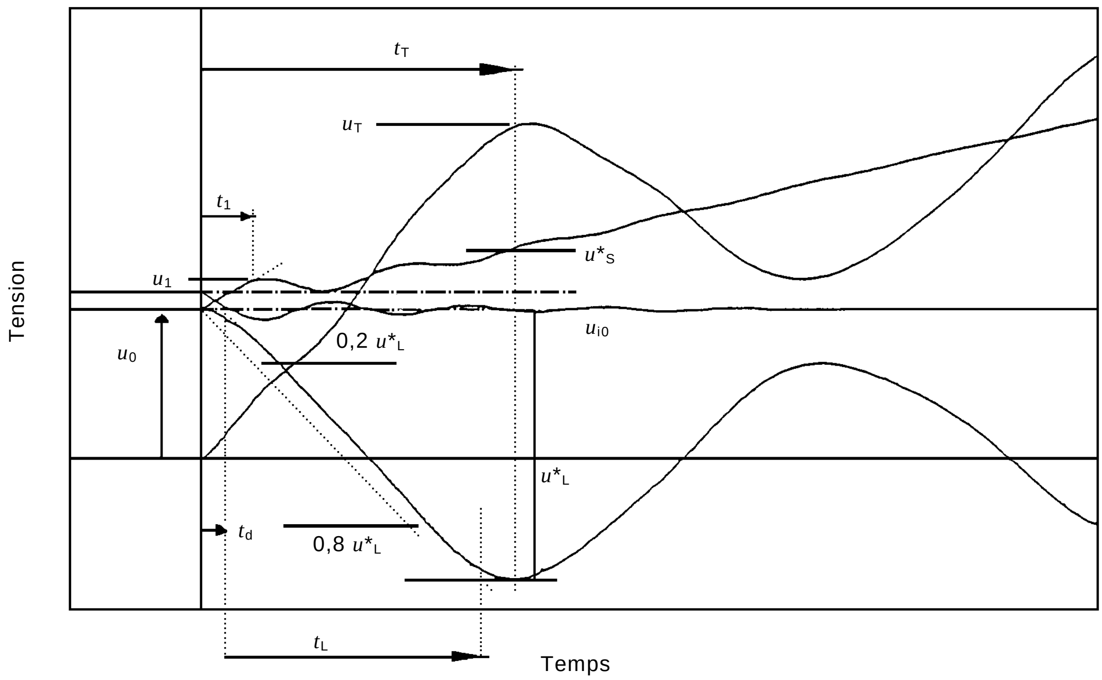
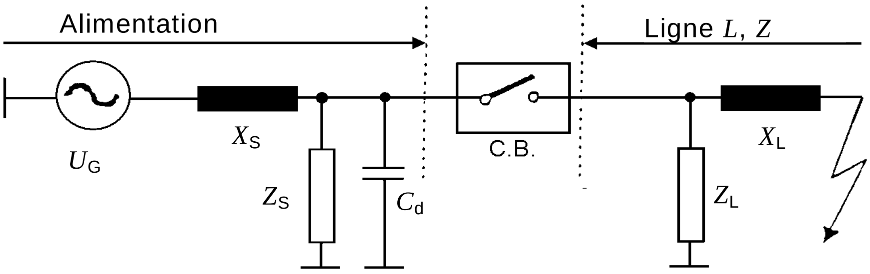
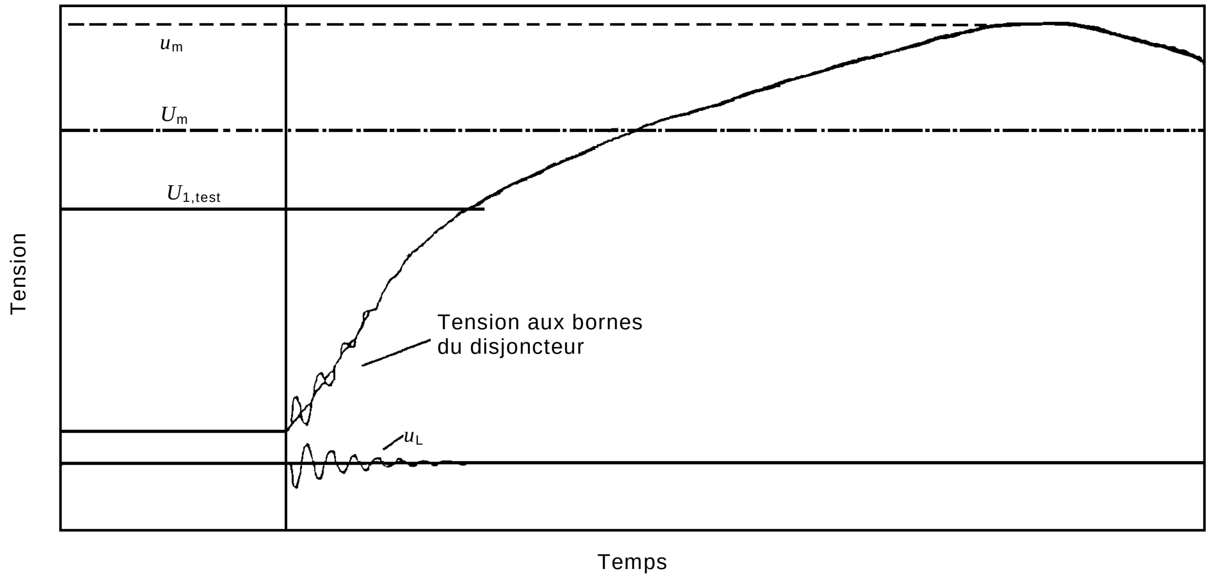


Figure 47 – Circuit de base pour les essais de défaut proche en ligne – circuit type b1) selon 6.109.3: côté alimentation avec TTRI et côté ligne avec temps de retard



U_G	Tension d'alimentation, valeur phase terre	X_L	Réactance à fréquence industrielle côté ligne
X_S	Réactance à fréquence industrielle côté alimentation	Z_L	Éléments de réglage de la TTR côté ligne
Z_S	Éléments de réglage de la TTR côté alimentation	Z	Impédance d'onde de la ligne
C_d	Capacité de retard côté alimentation	L	Longueur de ligne en défaut
C.B.	Disjoncteur		



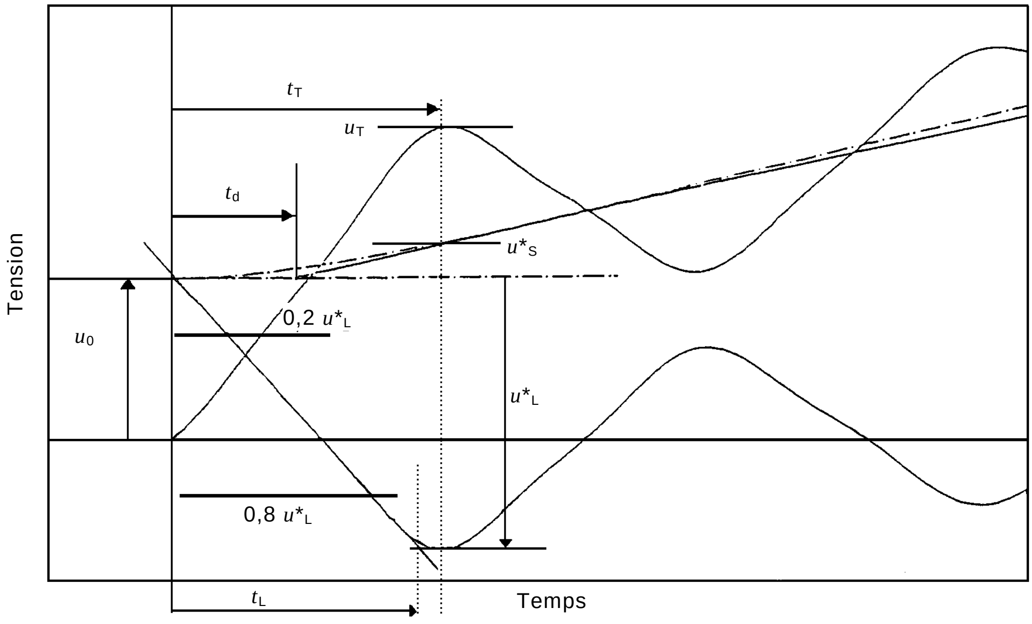


Figure 48 – Circuit de base pour les essais de défaut proche en ligne – circuit type b2) selon 6.109.3: côté alimentation avec temps de retard et côté ligne sans temps de retard

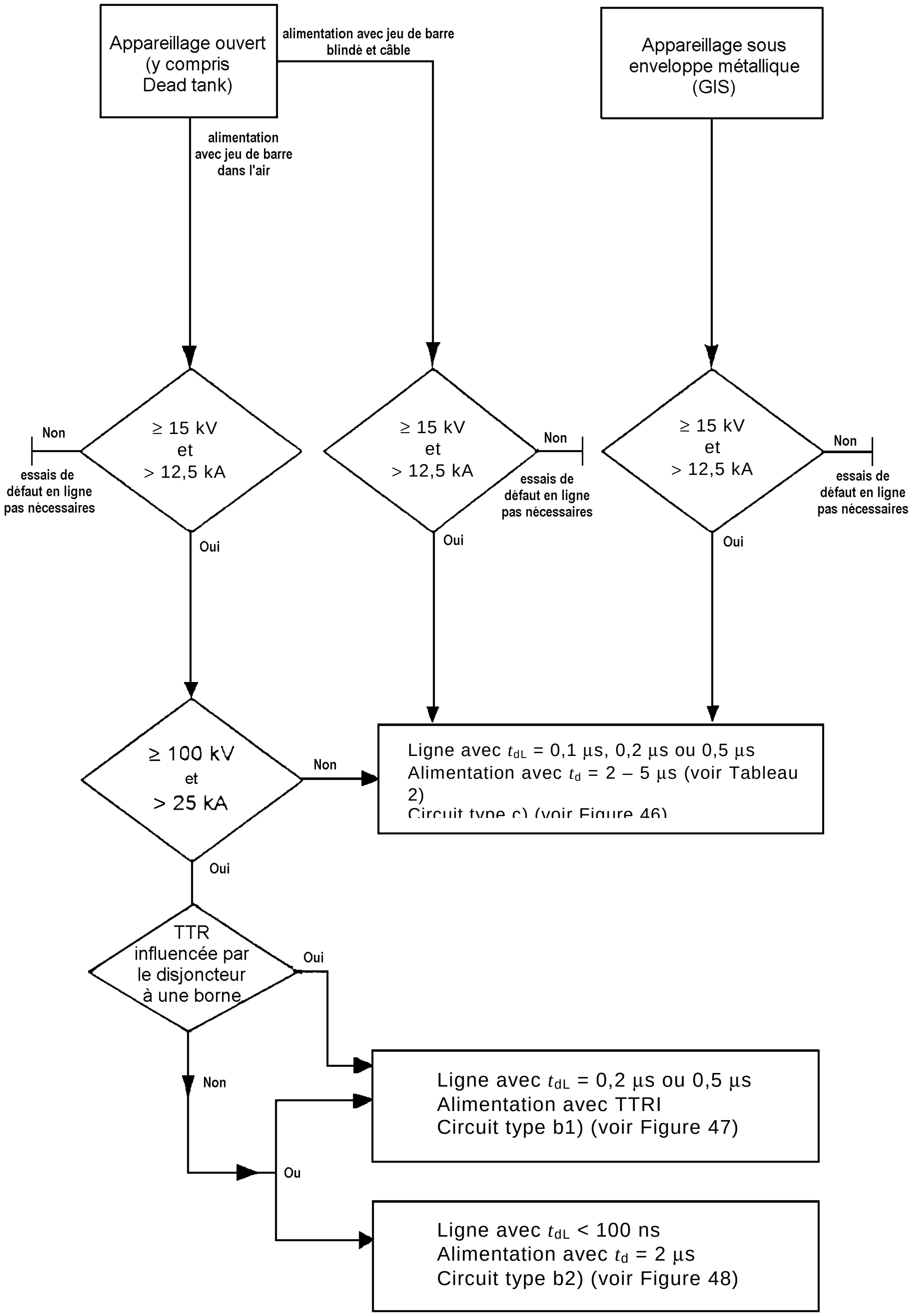


Figure 49 – Diagramme de décision pour le choix des circuits d'essais de défaut proche en ligne pour les disjoncteurs de classe S2 et pour les disjoncteurs de tensions assignées supérieures ou égales à 100 kV

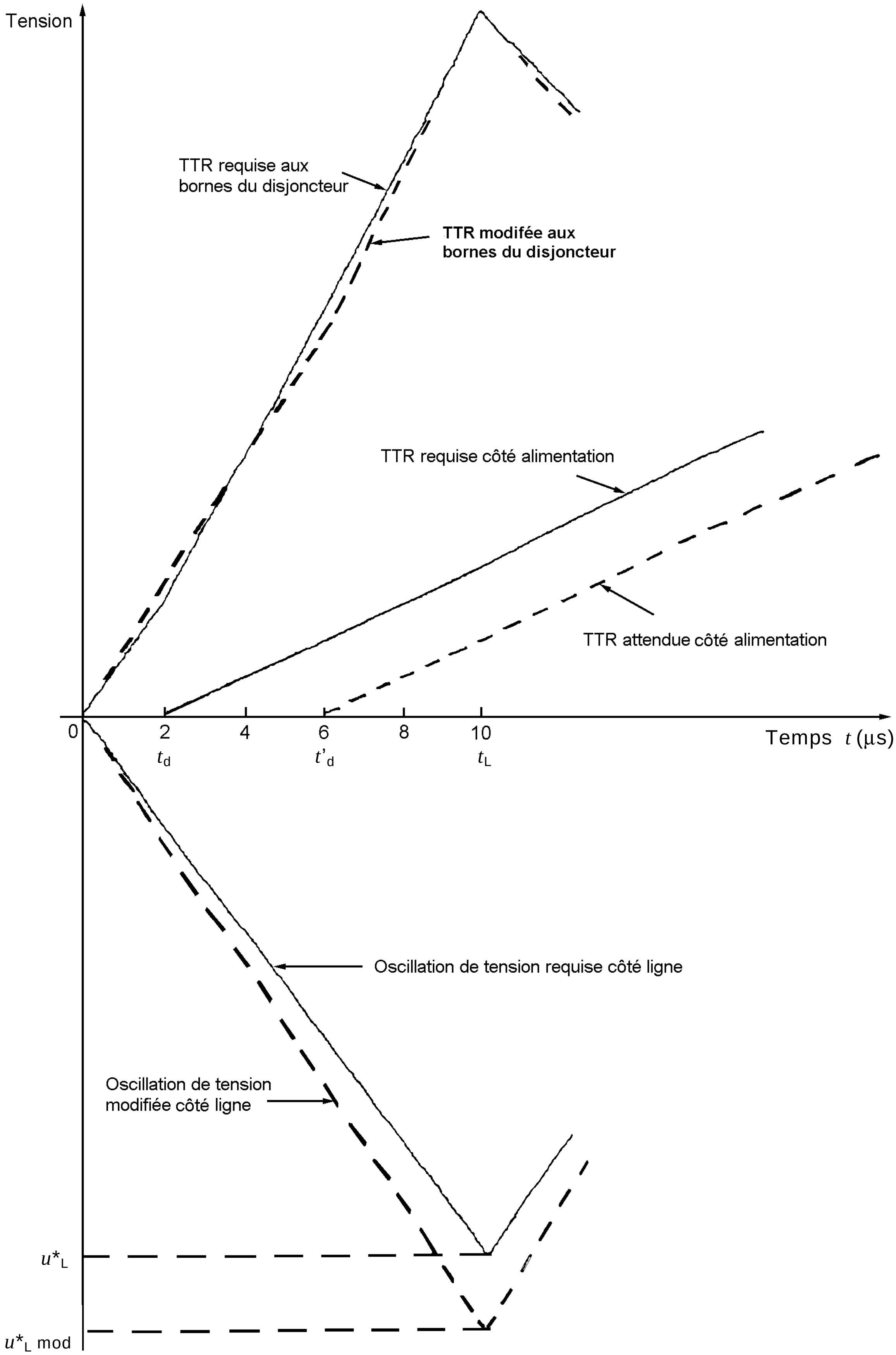
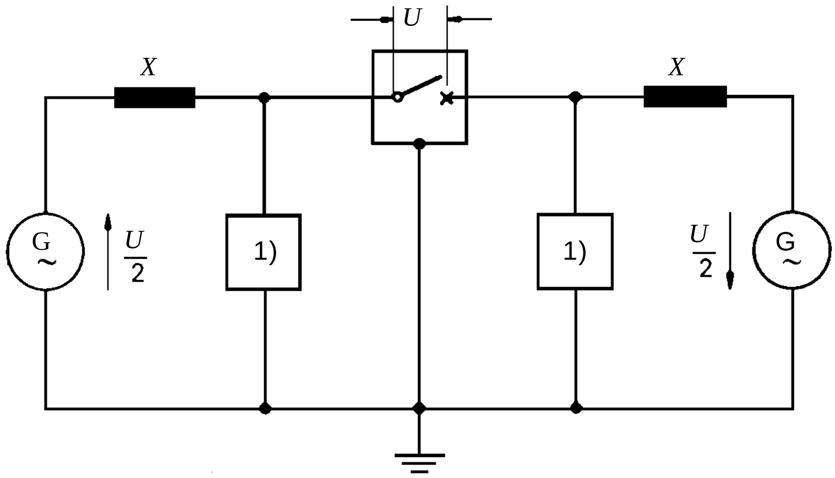
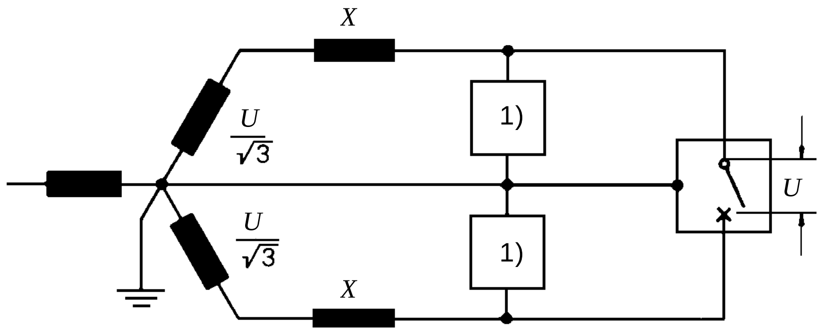


Figure 50 – Compensation d'un défaut du temps de retard côté alimentation par une augmentation de l'amplitude de la tension côté ligne



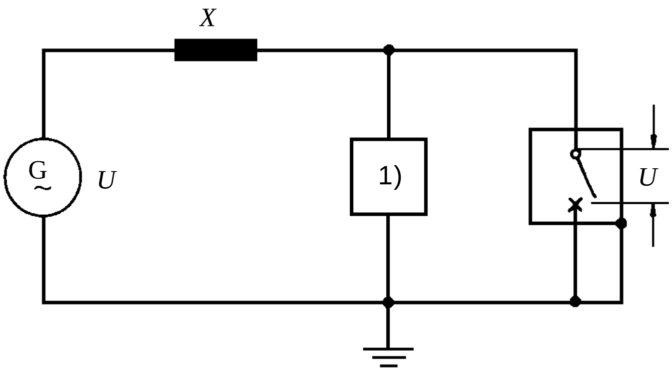
1) Les carrés représentent des combinaisons de capacités et de résistances.

Figure 51 – Circuit d'essais pour les essais monophasés en discordance de phases



1) Les carrés représentent des combinaisons de capacités et de résistances.

Figure 52 – Circuit d'essais avec deux tensions décalées de 120 degrés électriques pour les essais en discordance de phases



1) Le carré représente des combinaisons de capacités et de résistances.

Figure 53 – Circuit d'essais avec une borne du disjoncteur à la terre pour les essais en discordance de phases (sous réserve de l'accord du constructeur)

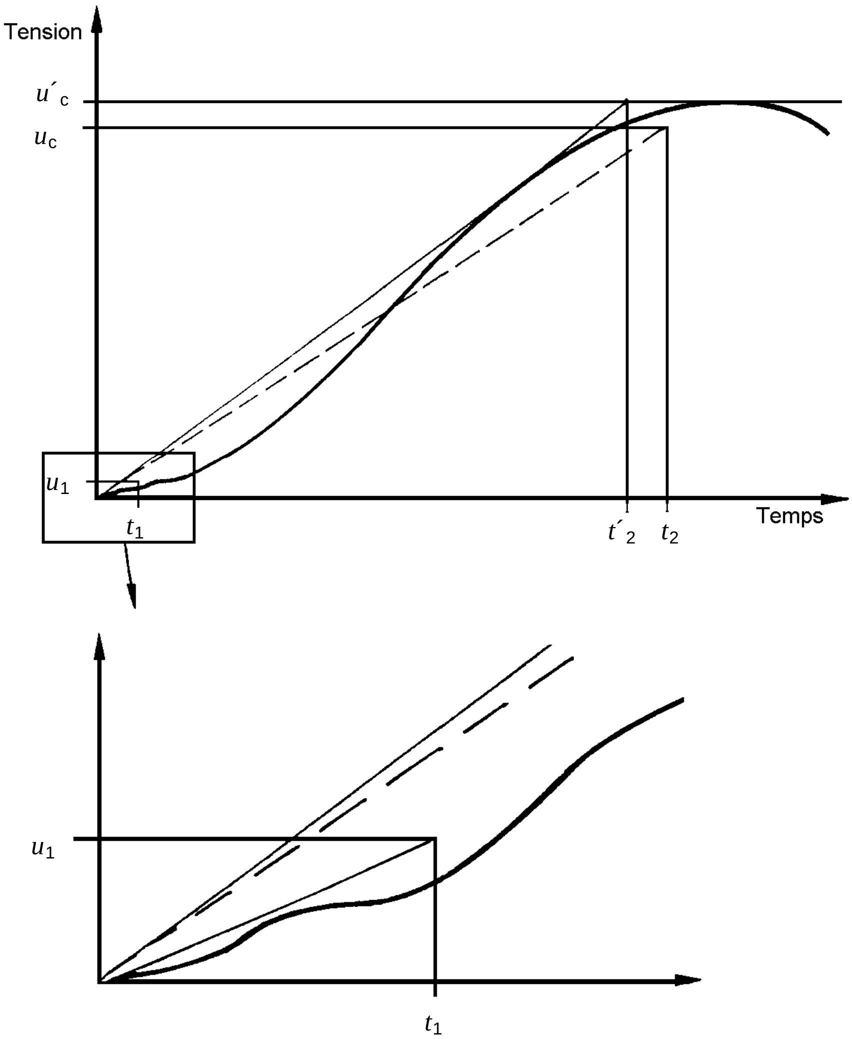
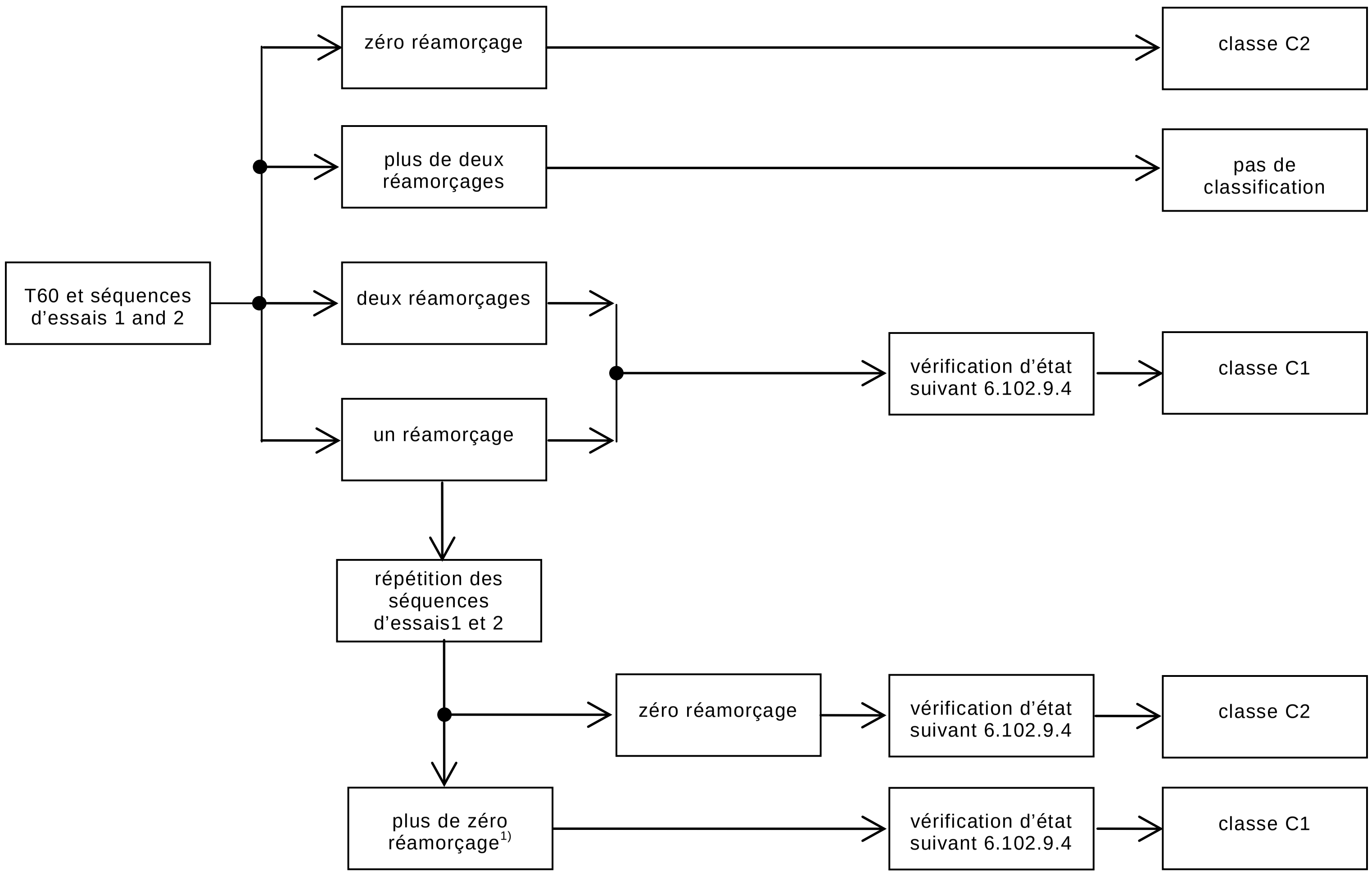
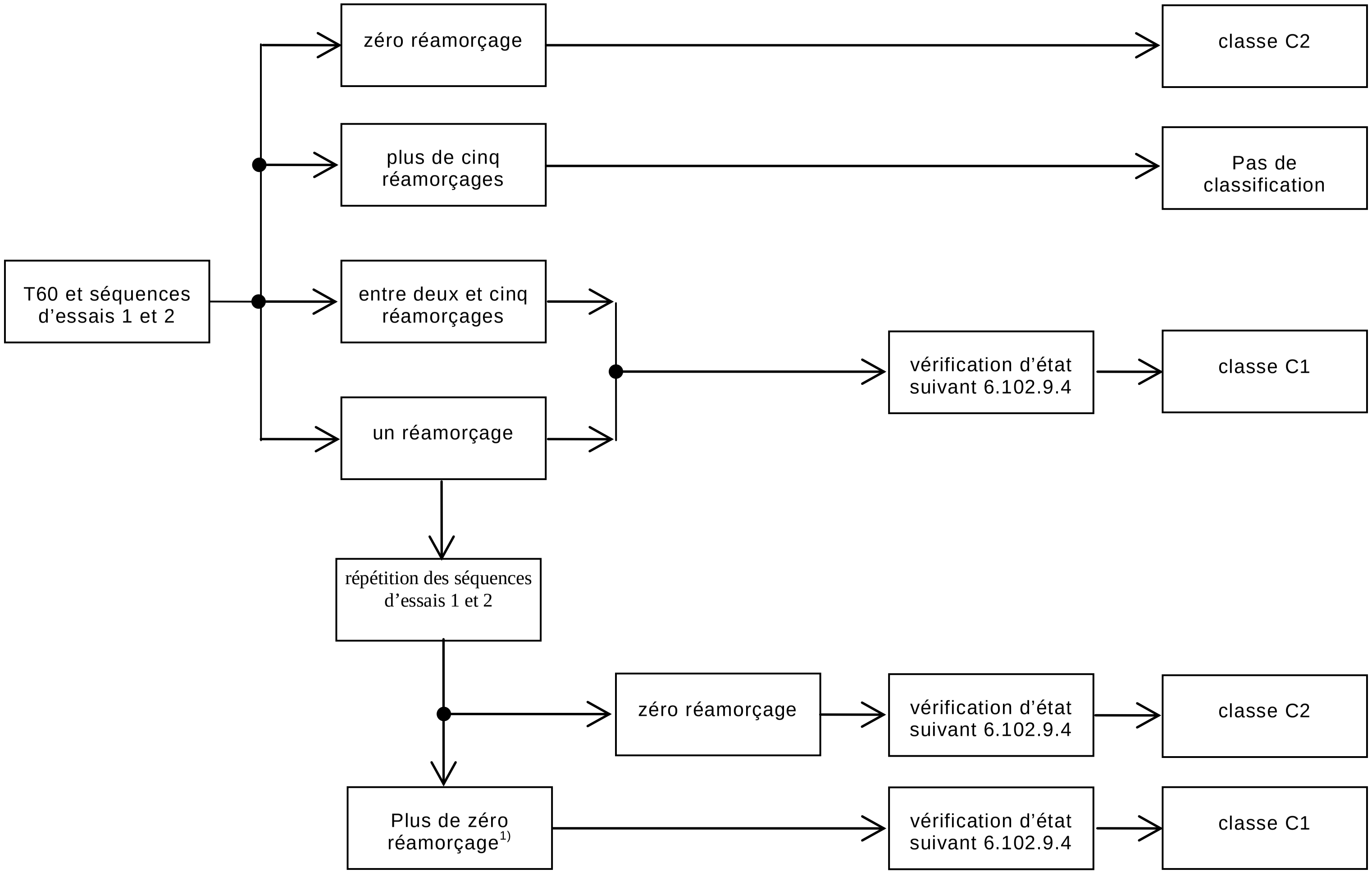


Figure 54 – Tension de rétablissement pour les essais de coupure de courants capacitifs



[1] Les essais peuvent être arrêtés après un réamorçage au cours de la répétition.

Figure 55 – Procédure de re-classification pour les essais d'établissement et de coupure de courants de lignes à vide et de câbles à vide



[1)] Les essais peuvent être arrêtés après un réamorçage au cours de la répétition.

Figure 56 – Procédure de re-classification pour les essais d'établissement et de coupure de courants de batteries de condensateurs

Annexe A
(normative)

Calcul des tensions transitoires de rétablissement pour les défauts proches en ligne à partir des caractéristiques assignées

A.1 Approche de base

Pour les caractéristiques assignées et les essais, il a été décidé de considérer seulement le cas d'un défaut proche en ligne monophasé, à la terre, sur un réseau à neutre relié à la terre et avec un facteur de premier pôle de 1,0, ce cas correspondant à une sévérité suffisante pour couvrir d'autres cas, à l'exception de cas particuliers où les paramètres du réseau peuvent être plus sévères que les valeurs normalisées.

Le circuit monophasé simplifié peut alors être représenté comme l’indiquent les Figures 46, 47 et 48.

Pendant le court-circuit, la tension d'alimentation U_G est

$$U_G = U_r / \sqrt{3} \qquad \text{(A.1)}$$

où U_r est la tension assignée du disjoncteur.

Cette tension U_G engendre un courant I_L dans un circuit comprenant les réactances X_S, X_B (si tel est le cas) et X_L en série.

Les réactances sont définies comme suit:

– X_S réactance du côté alimentation;
– X_B réactance des jeux de barres du côté alimentation;
– X_L réactance du côté ligne.

Les inductances correspondantes sont

$$L_S = X_S/\omega \qquad \text{(A.2a)}$$

$$L_B = X_B/\omega \qquad \text{(A.2b)}$$

$$L_L = X_L/\omega \qquad \text{(A.2c)}$$

La valeur efficace de la chute de tension du côté alimentation, en ne considérant pas X_B à cause de sa contribution négligeable, est

$$U_S = I_L \times X_S = U_G \frac{I_L}{I_{sc}} \qquad \text{(A.3)}$$

où

I_{sc} est le pouvoir de coupure assigné en court-circuit;

I_L est le courant de défauts proches en ligne.

La valeur efficace de la chute de tension le long de la ligne est

$$U_L = I_L \times X_L = U_G \left(1 - \frac{I_L}{I_{sc}}\right) \qquad \text{(A.4)}$$

A l'instant où le courant est interrompu, la chute de tension induite aux bornes de l'inductance du côté ligne est:

$$u_0 = U_L \sqrt{2} = L_L \frac{di}{dt} \quad \text{(A.5a)}$$

et pour un courant symétrique:

$$u_0 = \omega \times L_L \times I_L \sqrt{2} \quad \text{(A.5b)}$$

Cette chute de tension revient à zéro par l'intermédiaire d'un régime transitoire comportant des ondes mobiles qui se réfléchissent le long de la ligne entre le disjoncteur et l'endroit du défaut, générant ainsi une tension transitoire côté ligne ayant la forme d'une oscillation amortie en dents de scie [2)].

A l'instant où le courant est interrompu, la chute de tension induite aux bornes de l'inductance du côté alimentation est:

$$u_X = U_X \sqrt{2} = L_S \frac{di}{dt} \quad \text{(A.6a)}$$

et pour un courant symétrique:

$$u_X = \omega \times L_S \times I_L \sqrt{2} \quad \text{(A.6b)}$$

Cette chute de tension revient à zéro par l'intermédiaire d'une série d'oscillations. Elle est superposée à la tension d'alimentation, les deux formant la tension du côté alimentation u_S du disjoncteur.

La valeur crête de la tension induite totale U_m à l'instant de l'interruption du courant est

$$U_m = u_0 + u_x = (L_L + L_S) \frac{di}{dt} \quad \text{(A.7a)}$$

et pour un courant symétrique:

$$U_m = \omega (L_L + L_S) I_L \sqrt{2} = U_G \sqrt{2} = U_r \sqrt{2} / \sqrt{3} \quad \text{(A.7b)}$$

La tension du côté alimentation du disjoncteur est la différence entre la tension d'alimentation et la chute de tension dans la réactance X_S. La tension transitoire de rétablissement assignée résultante pour les défauts proches en ligne apparaissant aux bornes du disjoncteur est la différence entre la tension transitoire du côté alimentation u_S et la tension transitoire du côté ligne u_L telle que montrée à la Figure A.1.

Le rapport entre la tension u_0 à l'instant de l'interruption et la valeur crête U_m de la tension d'alimentation est déterminé par le rapport des chutes de tension au travers de l'inductance du côté ligne et de l'inductance du côté alimentation, donc

$$u_0 / U_m = u_0 / (u_0 + u_x) = L_L / (L_L + L_S) = 1 - I_L / I_{SC} \quad \text{(A.8)}$$

Cette équation est montrée au Tableau A.1 pour les valeurs normales des rapports de courants pour les défauts proches en ligne.

[2)] En pratique, la forme d'onde en dents de scie est modifiée jusqu'à un certain point par un retard dû aux capacités concentrées présentes aux bornes du disjoncteur (capacités des transformateurs de tension, transformateurs de courant, etc.); de plus, la partie supérieure de l'oscillation est légèrement arrondie.

Tableau A.1 – Rapport des chutes de tension et de TTR côté alimentation

U_r	I_L/I_{SC}	u_0/U_m	u_m/U_m	$u_{1,test}$ / u_1
< 100 kV	0,90	0,10	1,49	-
	0,75	0,25	1,41	-
	0,60	0,40	1,32	-
≥ 100 kV	0,90	0,10	1,36	1,033
	0,75	0,25	1,30	1,083
	0,60	0,40	1,24	1,133

A.2 Tension transitoire côté ligne

La valeur crête u_L* de la première crête de la tension transitoire de la ligne est obtenue en multipliant la valeur u_0 par le facteur de crête k.

$$u_L^* = ku_0 = kL_L \frac{di}{dt} \tag{A.9}$$

Le temps t_L est obtenu à partir de la vitesse d'accroissement du_L/dt de la tension transitoire u_L de la ligne et de la valeur crête u_L* de la tension transitoire de la ligne:

$$\frac{du_L}{dt} = sI_L = Z\frac{di}{dt} \tag{A.10}$$

donc

$$t_L = \frac{u_L^*}{\frac{du_L}{dt}} = \frac{u_L^*}{sI_L} = k\frac{L_L}{Z} \tag{A.11}$$

où

s est le facteur de VATR (kV/µs/kA);

Z est l'impédance d'onde de la ligne;

f est la fréquence assignée.

Les caractéristiques assignées de la ligne Z, k *et* s sont données au Tableau 8 (voir 4.105).

NOTE La longueur approximative de la ligne, correspondant à un défaut en ligne donné, peut être obtenue par la formule suivante:

$$L = c \times t_L/2 \tag{A.12}$$

où c est la vitesse de propagation des ondes mobiles qui est supposée être égale à: c = 0,3 km/µs.

A.3 Tension transitoire côté alimentation

A.3.1 Tensions assignées supérieures ou égales à 100 kV

La courbe de la tension transitoire côté alimentation, depuis la valeur initiale u_0 jusqu'à la valeur de crête u_m, peut être obtenue à partir des Tableaux 3, 4 et 5. On peut utiliser directement les coordonnées de temps t_1, t_2, t_3 et t_d données dans ces tableaux. La tension u_1 des Tableaux 3, 4 et 5, qui est égale à 0,75 fois la tension U_m, valeur instantanée de la tension source à l'instant de l'interruption du courant, entraîne une valeur plus élevée $u_{1,test}$:

$$u_{1,test} = u_1 \times (1 + \frac{1}{3} \times (1 - \frac{I_L}{I_{sc}})) \tag{A.13}$$

Les valeurs réelles du rapport $u_{1,\mathrm{test}}$ / u_1 sont données au Tableau A.1.

La valeur de crête u_c de la TTR entraîne une valeur plus faible u_m:

$$u_\mathrm{m} = u_0 + k_\mathrm{af} u_\mathrm{x} \tag{A.14}$$

alors

$$u_\mathrm{m} / U_\mathrm{m} = (u_0 + k_\mathrm{af} u_\mathrm{x}) / U_\mathrm{m} \tag{A.14a}$$

et en utilisant l'Equation (A.8)

$$u_\mathrm{m} / U_\mathrm{m} = 1 + (k_\mathrm{af} - 1) I_\mathrm{L} / I_\mathrm{sc} \tag{A.14b}$$

comme donné au Tableau A.1.

La vitesse d'accroissement réelle de la TTR du/dt_SLF du côté alimentation est réduite par rapport à la valeur normalisée pour le défaut proche en ligne du/d$t_\mathrm{SLF,\ stand}$ donnée aux Tableaux 1, 2, 3 et 4.

$$\left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_\mathrm{SLF} = \left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_\mathrm{SLF,\,stand} \times \frac{I_\mathrm{L}}{I_\mathrm{sc}} \tag{A.15}$$

La durée pour atteindre le niveau de tension U_m est

$$t_\mathrm{m} = t_1 \times \frac{k_\mathrm{af}}{k_\mathrm{af} - 3/4} \tag{A.16}$$

La valeur de crête u_m de la tension transitoire de rétablissement du côté alimentation est également la valeur crête de la tension transitoire de rétablissement aux bornes du disjoncteur, à condition que l'oscillation de la tension de la ligne soit amortie à zéro au temps t_2 (ou t_3), ce qui est généralement le cas. La courbe résultante de la TTR du côté alimentation est représentée à la Figure A.3.

La partie la plus importante de la tension transitoire de rétablissement résultante se situe jusqu'à la première crête u_L* de la tension transitoire du côté ligne qui est atteinte après le temps t_T:

– côté ligne avec temps de retard (voir Figures 46 et 47): $t_\mathrm{T} = 2t_\mathrm{dL} + t_\mathrm{L}$ (A.17a)

– côté ligne ~~sans temps de retard significatif~~ avec retard inférieur à 100 ns (voir Figure 48): $t_\mathrm{T} = t_\mathrm{dL} + t_\mathrm{L}$ avec t_dL = 0,1 µs. (A.17b)

NOTE Contrairement à la procédure habituelle utilisée pour définir les tensions transitoires de rétablissement par leurs enveloppes, la forme réelle de l'onde est utilisée pour évaluer la tension totale aux bornes du disjoncteur à l'instant où la tension du côté ligne atteint sa valeur crête u_L*. Cette procédure modifiée est utilisée parce que la méthode des enveloppes conduirait à une valeur de tension intermédiaire dans la pente ascendante de la TTR légèrement avant la crête et non pas à la crête réelle de la TTR de la tension totale aux bornes du disjoncteur, laquelle est pertinente pour l'évaluation des conditions d'essai. La méthode des enveloppes est relativement satisfaisante à condition que les TTR ne soient pas formées par la superposition de deux ou plusieurs composantes. Cependant, dans le cas présent, lorsque la TTR totale est évaluée aux bornes du disjoncteur, la somme des trois différentes composantes est considérée: la TTR du côté alimentation, la TTRI du côté alimentation et la TTR du côté ligne.

Pour le calcul de la contribution du côté alimentation u_s* au temps t_T, deux cas différents doivent être distingués:

– sans exigence de TTRI (voir Figure A.1)

$$u_S^* = \left(\frac{du}{dt}\right)_{SLF} \times (t_T - t_d) \tag{A.18}$$

et

$$u_T = u_L^* + u_S^* \tag{A.19}$$

– avec exigences de TTRI (voir Figure A.2)

$$u_S^* = u_{i0} + \left(\frac{du}{dt}\right)_{SLF} \times (t_T - t_d) \tag{A.20}$$

et encore

$$u_T = u_L^* + u_S^* \tag{A.21}$$

Pour les exigences de TTRI (comme données au Tableau 11), les équations suivantes s'appliquent:

$$u_i = f_i I_L = k_i L_B \frac{di}{dt} \tag{A.22}$$

où

k_i = 1,4 (facteur crête);

f_i est le facteur multiplicatif du Tableau 11.

Donc, la chute de tension du jeu de barres u_{i0} devient

$$u_{i0} = u_i / k_i \tag{A.23}$$

et l'inductance du jeu de barres est

$$L_B = u_{i0} / (di/dt) \tag{A.24}$$

A.3.2 Tensions assignées supérieures ou égales à 15 kV et inférieures à 100 kV

Le paragraphe A.3.1 s'applique à l'exception de ce qui suit:

La courbe de la tension transitoire côté alimentation, depuis la valeur initiale u_0 jusqu'à la valeur de crête u_m, peut être obtenue à partir du Tableau 25. On utilise directement les temps t_3 *et* t_d donnés dans ce tableau. La valeur de crête u_c de la TTR résulte en une valeur plus faible u_m:

$$u_m = u_0 + k_{af} u_x \tag{A.25}$$

donc

$$u_m / U_m = (u_0 + k_{af} u_x) / U_m \tag{A.26}$$

A.4 Exemples de calculs

Comme exemples de calculs, trois cas typiques de circuits d'essais (voir 6.109.3) sont calculés. Les résultats sont donnés de A.4.1 à A.4.3:

– côté alimentation et côté ligne avec retard (A.4.1);
– côté alimentation avec TTRI et côté ligne avec retard (A.4.2);
– côté alimentation avec retard et côté ligne sans retard (A.4.3).

A.4.1 Côté alimentation et côté ligne avec retard (L_{90} et L_{75} pour 245 kV, 50 kA, 50 Hz)

Paramètres	Équation	Paramètres d'essai		
		Unité	L_{90}	L_{75}
Côté alimentation; fréquence industrielle				
Tension assignée U_r	---	kV	245	245
Pouvoir assigné en court-circuit I_{sc}	---	kA	50	50
Fréquence assignée f_r	---	Hz	50	50
Tension d'alimentation U_G	A.1	kV	141,5	141,5
Réactance du côté alimentation X_S	---	Ω	2,83	2,83
Inductance du côté alimentation L_S	A.2a	mH	9,01	9,01
Côté ligne; fréquence industrielle				
Ligne spécifiée	---	%	90	75
Pouvoir de coupure de défauts proches en ligne I_L	---	kA	45	37,5
di/dt à l'interruption du courant	---	A/µs	20	16,7
Tension du côté ligne U_L	A.4	kV	14,2	35,4
Réactance du côté ligne X_L	---	Ω	0,316	0,944
Inductance du côté alimentation L_L	A.2c	mH	1,0	3,0
Paramètres de la TTR du côté ligne				
Tension à l'interruption du courant u_0	A.8	kV	20	50
Facteur de crête k	---	p.u.	1,6	1,6
Valeur de la première crête de la TTR du côté ligne u_l*	A.9	kV	32	80
Retard t_{dL}	---	µs	0,5	0,5
Vitesse d'accroissement de la TTR du côté ligne du_L/dt	A.10	kV/µs	9	7,5
Impédance d'onde spécifiée de la ligne Z	---	Ω	450	450
Temps de montée t_L	A.11	µs	3,56	10,7
Paramètres de la TTR du côté alimentation				
Retard t_d	---	µs	2	2
Vitesse d'accroissement au pouvoir de coupure assigné en court-circuit I_{sc} $(\mathrm{d}u/\mathrm{d}t)_{TF}$	---	kV/µs	2	2
Vitesse d'accroissement au pouvoir de coupure de défaut proche en ligne I_L $(\mathrm{d}u/\mathrm{d}t)_{SLF}$	A.15	kV/µs	1,8	1,5
Tension à l'interruption du courant u_x	A.7 a	kV	180	150
Tension $u_{1,test}$ au temps t_1	A.13	kV	155	162,5
Temps t_m pour atteindre la tension U_m	A.16	µs	162	162
Tension transitoire crête u_m	A.14	kV	272	260
Facteur transitoire u_m/U_m	A.14a	p.u.	1,36	1,3
Première crête totale aux bornes du disjoncteur				
Coordonnée de temps de la première crête t_T	A.17a	µs	4,56	11,7
Contribution du côté alimentation u_s* à la TTR au temps t_T	A.18	kV	4,6	14,6
Tension de la première crête u_T	A.19	kV	36,6	94,6

A.4.2 Côté alimentation avec TTRI et côté ligne avec retard (L_{90} pour 245 kV, 50 kA, 50 Hz)

Paramètres	Equation	Paramètres d'essai	
		Unité	L_{90}
Côté alimentation; fréquence industrielle	Même que dans A.4.1		
Côté ligne; fréquence industrielle	Même que dans A.4.1		
Paramètres de la TTR du côté ligne	Même que dans A.4.1		
Paramètres de la TTR du côté alimentation	Même que dans A.4.1		
Paramètres de la TTRI du côté alimentation			
Coordonnée de temps t_i	Tableau 7	µs	0,6
Facteur multiplicatif f_i	Tableau 7	kV/kA	0,069
Tension crête initiale u_i	A.22	kV	3,1
Chute de tension dans le jeu de barres u_{i0}	A.23	kV	2,21
Inductance du jeu de barres L_B	A.24	µH	111
Première crête totale aux bornes du disjoncteur			
Coordonnée de temps de la première crête t_T	A.17a	µs	4,56
Contribution du côté alimentation u_s* à la TTR au temps t_T	A.20	kV	6,8
Tension de la première crête u_T	A.21	kV	38,8

A.4.3 Côté alimentation avec retard et côté ligne sans retard (L_{90} pour 245 kV, 50 kA, 50 Hz) – Calculs effectués en utilisant une méthode simplifiée

~~Paramètres~~	~~Equation~~	~~Paramètres d'essai~~	
		~~Unité~~	~~L_{90}~~
~~**Côté alimentation; fréquence industrielle (l'inductance du jeu de barre est négligée)**~~	~~Même que dans A.4.1~~		
~~**Côté ligne; fréquence industrielle**~~	~~Même que dans A.4.1~~		
~~**Paramètres de la TTR du côté ligne**~~	~~Même que dans A.4.1~~		
~~**Paramètres de la TTR du côté alimentation**~~	~~Même que dans A.4.1~~		
~~**Première crête totale aux bornes du disjoncteur**~~			
~~Coordonnée de temps de la première crête t_T~~	~~A.17b~~	~~µs~~	~~3,66~~
~~Contribution du côté alimentation u_S* à la TTR au temps t_T~~	~~A.18~~	~~kV~~	~~3,0~~
~~Tension de la première crête u_T~~	~~A.19~~	~~kV~~	~~35,0~~

Paramètres	Équation	Paramètres d'essai	
		Unité	L_{90}
Côté alimentation; fréquence industrielle (l'inductance du jeu de barre est négligée)	Même que dans A.4.1		
Côté ligne; fréquence industrielle	Même que dans A.4.1		
Paramètres de la TTR du côté ligne	Même que dans A.4.1 sauf pour la valeur donnée t_{dL}		
Retard t_{dL}	---	µs	< 0,1
Paramètres de la TTR du côté alimentation	Même que dans A.4.1		
Première crête totale aux bornes du disjoncteur			
Coordonnée de temps de la première crête t_T	A.17b	µs	3,66
Contribution du côté alimentation u_S^* à la TTR au temps t_T	A.18	kV	3,0
Tension de la première crête u_T	A.19	kV	35,0

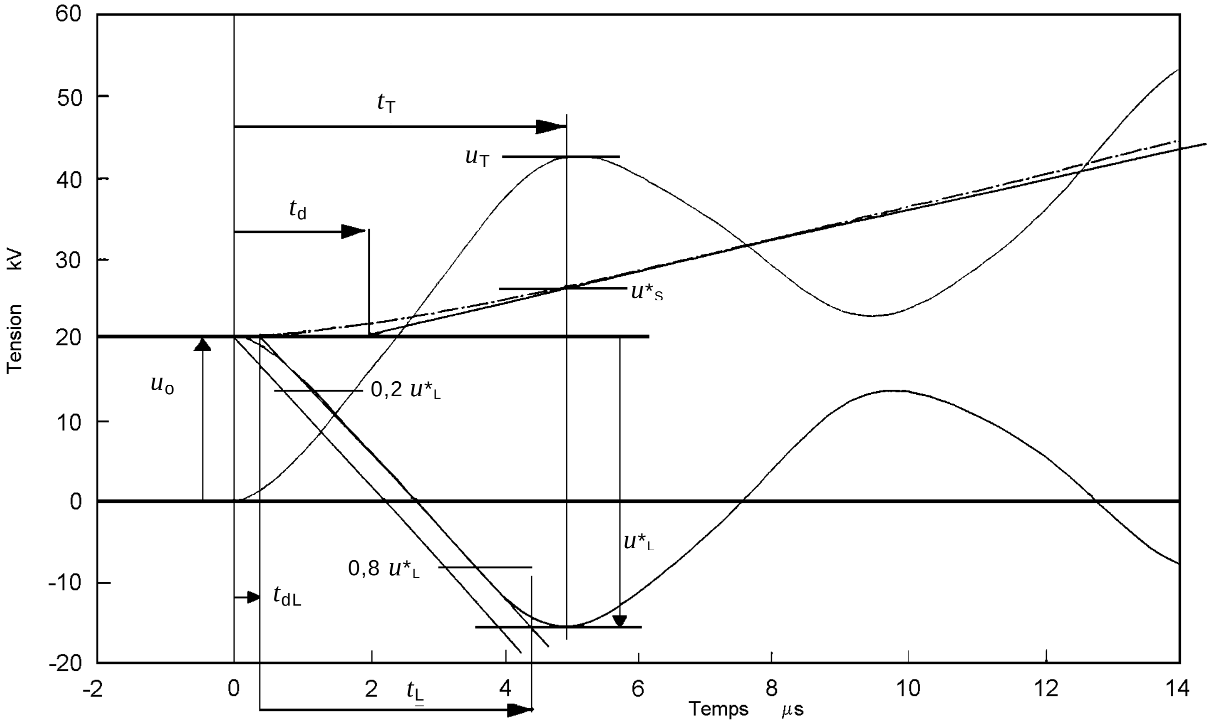


Figure A.1 – Graphique typique montrant des paramètres de TTR côté ligne et alimentation – Les TTR côté ligne et alimentation ont un temps de retard

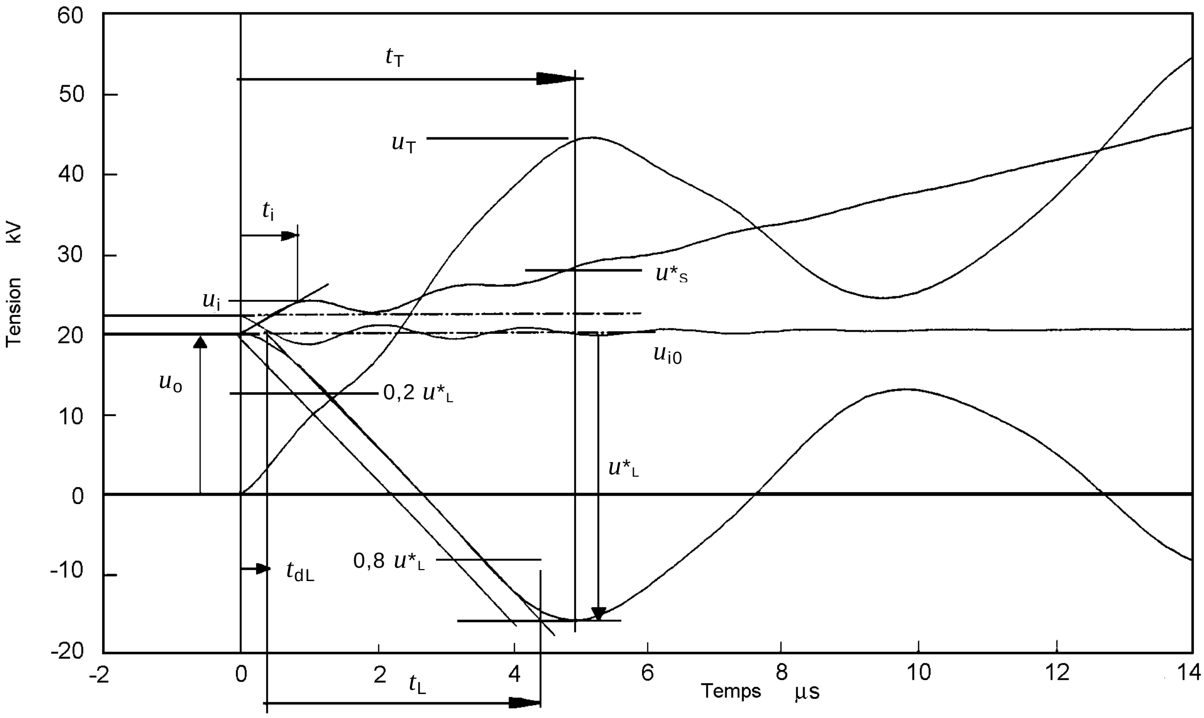


Figure A.2 – Graphique typique montrant les paramètres de TTR côté ligne et alimentation – Les TTR côté ligne et alimentation ont un temps de retard, la TTR côté alimentation a une TTRI

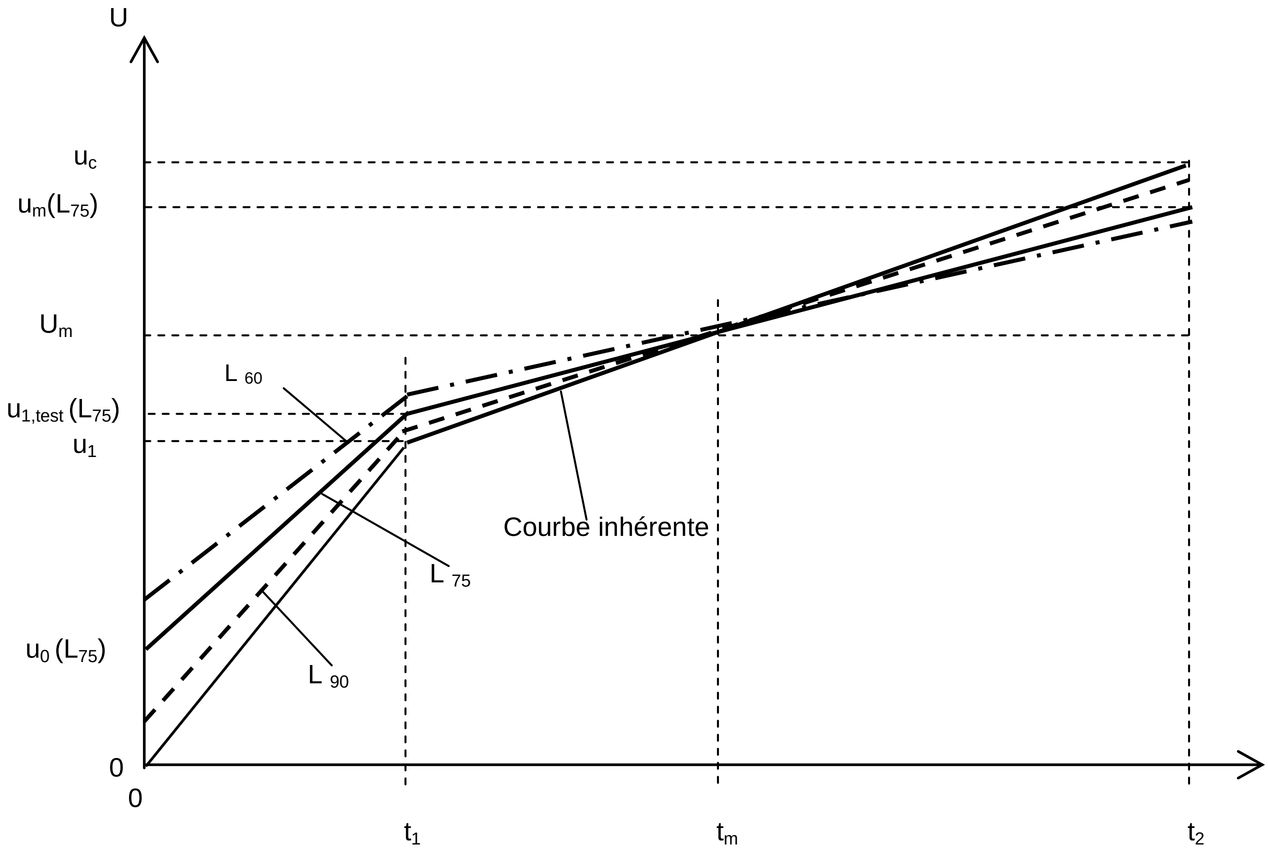


Figure A.3 – Courbe effective de la tension transitoire de rétablissement côté alimentation pour les défauts proches en ligne L_{90}, L_{75} et L_{60}

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Annexe B
(normative)

Tolérances sur les paramètres d'essais lors des essais de type

Durant les essais de type, les types de tolérances suivantes peuvent être normalement distingués:

– tolérances sur les paramètres d'essais qui déterminent directement les contraintes appliquées à l'objet d'essais;
– tolérances sur les caractéristiques et sur le comportement de l'objet d'essais avant et après un essai;
– tolérances sur les conditions d'essais;
– tolérances sur les paramètres des dispositifs de mesure qui seront utilisés.

Dans le Tableau B.1, seules les tolérances sur les paramètres d'essais ont été considérées.

Une tolérance est définie comme étant l'intervalle de la valeur d'essai spécifiée dans cette norme à l'intérieur duquel il convient que la valeur mesurée en essai se trouve pour que l'essai soit valable. Dans certains cas (voir 6.105.5 et Tableau 12), l'essai peut rester valable même si la valeur mesurée est hors tolérance.

Tout écart dû à l'imprécision de la mesure sur la valeur mesurée durant l'essai par rapport à la valeur réelle n'est pas pris en considération.

Les règles de base pour l'application des tolérances sur les paramètres d'essais durant les essais de type sont les suivantes:

a) les stations d'essais doivent tenter, dans la mesure du possible, d'obtenir les valeurs d'essais spécifiées;
b) les tolérances spécifiées sur les paramètres d'essais doivent être respectées par les stations d'essais. Des contraintes plus élevées que celles données par les tolérances spécifiées peuvent être appliquées au disjoncteur seulement avec le consentement du constructeur. Des contraintes moins élevées rendent l'essai invalide;
c) lorsque cette norme, ou la norme applicable, ne donne aucune tolérance sur un paramètre d'essais, les essais de type doivent être réalisés à des valeurs pas moins sévères que celles spécifiées. La limite supérieure des contraintes est sujette au consentement du constructeur;
d) si pour n'importe quel paramètre d'essais, seulement une limite est donnée, alors l'autre limite est considérée comme étant le plus près possible de la valeur spécifiée.

NOTE Il ne faut pas confondre l'expression "tolérances sur les grandeurs d'essais" avec la largeur de l'intervalle des paramètres d'essais qui peut être ouverte sur un côté, par exemple le courant d'essai pour LC2, CC2 et BC2.

Tableau B.1 – Tolérances sur les paramètres d'essais lors des essais de type

Paragraphe	Identification de l'essai	Paramètre d'essais	Valeur d'essais spécifiée	Tolérance d'essais/limites des valeurs d'essais	Référence à
6.2	Essais diélectriques				
6.2.6.1 et 6.2.7.1	Essais de tension à fréquence industrielle	Tension d'essais (valeur efficace)	Tension de tenue assignée de courte durée à fréquence industrielle	± 1 %	CEI 62271-1, CEI 60060-1
		Fréquence	--	45 Hz à 65 Hz	CEI 60060-1
		Forme d'onde	Valeur de crête/valeur efficace = √2	± 5 %	
6.2.6.2 et 6.2.7.3	Essais de tension de choc de foudre	Valeur crête	Tension de tenue assignée aux chocs de foudre	± 3 %	
		Durée du front	1,2 µs	± 30 %	
		Durée jusqu'à la mi-valeur	50 µs	± 20 %	
6.2.7.2	Essais à la tension de choc de manœuvre	Valeur de crête	Tension de tenue assignée aux chocs de manœuvre	± 3 %	
		Durée du front	250 µs	± 20 %	
		Durée jusqu'à la mi-valeur	2 500 µs	± 60 %	
6.2.11	Essais de tension pour vérification de l'état utilisant une onde de surtension de manœuvre normale				
		Valeur de crête de la surtension de manœuvre	Voir 6.2.11	± 3 %	CEI 60060-1
		Durée du front	250 µs	± 20 %	
		Durée jusqu'à la mi-valeur	2 500 µs	± 60 %	
	Utilisation d'un circuit de TTR de T10	Valeur de crête de la surtension de manœuvre	Voir 6.2.11	± 3 %	
		Temps à la crête	Valeur normalisée pour T10 (voir Tableau 14)	${}^{+200}_{-10}$ %	
6.3	Essais de tension de perturbation radioélectrique	Tension d'essais	Voir 6.3 de CEI 62271-1	± 1 %	CEI 60060-1
6.4	Mesure de la résistance du circuit principal	Courant d'essais c.c., I_{DC}	--	50 A ≤ I_{DC} ≤ courant assigné en service continu	CEI 62271-1

Tableau B.1 *(suite)*

Paragraphe	Identification de l'essai	Paramètre d'essais	Valeur d'essais spécifiée	Tolérance d'essais/limites des valeurs d'essais	Référence à
6.5	Essais d'échauffement	Vitesse de l'air ambiant	--	≤0,5 m/s	CEI 62271-1
		Fréquence du courant d'essais	Fréquence assignée	$^{+2}_{-5}$ %	
		Courant d'essais	Courant assigné en service continu	$^{+2}_{0}$ % Ces limites doivent être observées seulement durant les deux dernières heures d'essai.	
		Température de l'air ambiant T	--	+ 10 °C < T < 40 °C	
6.6	Essais au courant de courte durée et à la valeur crête du courant admissible	Fréquence du courant d'essais	Fréquence assignée	± 10 %	CEI 62271-1
		Courant crête (dans une des phases extérieures)	Valeur de crête du courant admissible assigné	$^{+5}_{0}$ %	
		Moyenne de la composante c.a. du courant lors d'un essai en triphasé	Courant de courte durée admissible assigné	± 5 %	
		Composante c.a. du courant dans n'importe quel phase/valeur moyenne du courant	1	± 10 %	
		Durée du courant de court-circuit	Durée de court-circuit assignée	Voir tolérances pour I^2t	
		Valeur du I^2t	Valeur I^2t assignée	$^{+10}_{0}$ %	
6.101.3	Essais à haute et à basse températures	Variation de la température de l'air ambiant le long de la hauteur de l'objet d'essais	--	≤ 5 K	
		Température de l'air ambiant pour l'enregistrement des caractéristiques avant l'essai	20 °C	± 5 K	
		Températures maximales et minimales de l'air ambiant durant les essais	Selon la classe du disjoncteur (voir CEI 62271-1)	± 3 K	
6.101.4	Essais d'humidité	Température minimale pour un cycle	25 °C	± 3 K	
		Température maximale pour un cycle	40 °C	± 2 K	
6.101.6	Guide pour l'essai avec efforts statiques sur les bornes	Forces	Tel que spécifié en 6.101.6	$^{+10}_{0}$ %	

Tableau B.1 *(suite)*

Paragraphe	Identification de l'essai	Paramètre d'essais	Valeur d'essais spécifiée	Tolérance d'essais/limites des valeurs d'essais	Référence à
6.102	Dispositions diverses pour les essais d'établissement, de coupure et de manœuvre	Durée d'arc maximale à contrôler Durée d'arc moyenne à contrôler	Valeur d'essais spécifiée	± 0,5 ms ± 1 ms	
6.103	Circuits d'essais pour les essais d'établissement et de coupure en court-circuit	Facteur de puissance (valeur moyenne)	--	≤ 0,15	
		Facteur de puissance dans n'importe quelle phase/valeur moyenne	--	± 25 %	
		Fréquence	Fréquence assignée	± 8 %	
6.104	Caractéristiques pour les essais de court-circuit				
6.104.1	Tension appliquée avant les essais d'établissement en court-circuit	Tension appliquée	Voir 6.104.1	$^{+10}_{\ 0}$ %	
		Tension appliquée sur chaque phase/valeur moyenne (trois phases)	1	± 5 %	
6.104.3	Pouvoir de coupure en court-circuit	Composante périodique dans n'importe quelle phase / valeur moyenne	1	± 10 %	
		Composante périodique du courant présumé à l'extinction finale de l'arc dans le dernier pôle qui coupe	Courant coupé spécifié pour la séquence d'essais applicable	≥ 90 % NOTE Pour la séquence d'essais T100a, les tolérances sur la forme de la dernière alternance de courant (amplitude et durée) sont données en 6.102.10.2.1.2 b) et en 6.106.6.1.	
6.104.4	Composante apériodique du courant coupé en court-circuit	Composante apériodique pour T10, T30, T60, T100s	---	≤ 20 %	
		Composante apériodique au zéro de courant pour T100a	Pour les essais directs: 6.106.6.2 (en monophasé) et 6.106.6.1 (en triphasé)	≤ 110% de la valeur spécifiée et ≥ 95% de la valeur spécifiée	
		Valeur moyenne de la composante apériodique au zéro de courant	Pour les essais directs: 6.106.6.2 (en monophasé) et 6.106.6.1 (en triphasé)	≤ 100% de la valeur spécifiée et ≥ 95% de la valeur spécifiée	

Tableau B.1 *(suite)*

Paragraphe	Identification de l'essai	Paramètre d'essais	Valeur d'essais spécifiée	Tolérance d'essais/limites des valeurs d'essais	Référence à
6.104.5	Tension transitoire de rétablissement (TTR) pour les essais de défauts aux bornes	Valeur crête de la TTR: - pour disjoncteurs ≤ 52 kV - pour disjoncteurs > 52 kV	 Voir Tableaux 24 et 25 Voir Tableaux 24, 25, 26 et 27	 $^{+10}_{\ 0}$ % $^{+5}_{\ 0}$ %	
		Vitesse d'accroissement de la TTR: - pour disjoncteurs ≤ 52 kV - pour disjoncteurs > 52 kV	 Voir Tableaux 24 et 25 Voir Tableaux 24, 25, 26 et 27	 $^{+15}_{\ 0}$ % [1)] $^{+8}_{\ 0}$ %	
		Retard t_d	Voir Tableaux 24, 25, 26 et 27	± 20 %	
6.104.7	Tension de rétablissement à fréquence industrielle (TR)	Tension de rétablissement à fréquence industrielle	Valeurs spécifiées en 6.104.7	± 5 %	
		TR de n'importe quel pôle à la fin de l'application/valeur moyenne	1	± 20 %	
6.106	Séquences d'essais de court-circuit fondamentales	Courant coupé pour T10	10 % du courant de court-circuit assigné	± 20 %	
		Courant coupé pour T30	30 % du courant de court-circuit assigné	± 20 %	
		Courant coupé pour T60	60 % du courant de court-circuit assigné	± 10 %	
		Courant coupé pour T100s	100 % du courant de court-circuit assigné	$^{+5}_{\ 0}$ %	
		Courant coupé pour T100a	100 % du courant de court-circuit assigné	±10%	
		Courant de court-circuit crête pour T100s et T100a	Pouvoir de fermeture assigné en court-circuit	$^{+10}_{\ 0}$ %	
6.107	Essais au courant critique	Courant coupé	Voir 6.107.2	± 20 %	
		Composante c.c. du courant coupé	≤ 20 %	Limite supérieure 25 %	

Tableau B.1 *(suite)*

Paragraphe	Identification de l'essai	Paramètre d'essais	Valeur d'essais spécifiée	Tolérance d'essais/limites des valeurs d'essais	Référence à
6.108	Essais de défaut monophasé ou biphasé à la terre	Courant coupé	Voir Figure 45	$^{+5}_{0}$ %	
		Composante ~~apériodique~~ c.c. du courant coupé	≤ 20 %	~~Limite supérieure 25 %~~	
		Valeur crête de la TTR: - pour disjoncteurs ≤ 52 kV - pour disjoncteurs > 52 kV	Voir 6.108.2 et Tableaux 24, 25, 26 et 27	 $^{+10}_{0}$ % $^{+5}_{0}$ %	
		Vitesse d'accroissement de la TTR: - pour disjoncteurs ≤ 52 kV - pour disjoncteurs > 52 kV	Voir 6.108.2 et Tableaux 24, 25, 26 et 27	 $^{+15}_{0}$ % $^{+8}_{0}$ %	
6.109	Essais de défaut proche en ligne	Composante c.c. du courant coupé	≤ 20 %	~~Limite supérieure 25 %~~	Voir NOTE
		Courant coupé pour L_{90}	90 % du courant de court-circuit assigné	90 % à 92 %	
		Courant coupé pour L_{75}	75 % du courant de court-circuit assigné	71 % à 79 %	
		Courant coupé pour L_{60}	60 % du courant de court-circuit assigné	55 % à 65 %	
		Impédance d'onde Z	~~450 Ω~~	± 3 %	
		Valeur crête de la tension côté ligne		$^{+20}_{0}$ %	
		Vitesse d'accroissement de la tension côté ligne	Voir Tableau 8 et Annexe A	$^{+5}_{0}$ %	
		Retard t_{dL}		$^{0}_{-10}$ %	

Tableau B.1 *(suite)*

Paragraphe	Identification de l'essai	Paramètre d'essais	Valeur d'essais spécifiée	Tolérance d'essais/limites des valeurs d'essais	Référence à
6.110	Essais d'établissement et de coupure en discordance de phases	Facteur de puissance	--	≤ 0,15	
		Composante c.c. du courant coupé	≤ 20 %	~~Limite supérieure 25 %~~	
		Tension appliquée et tension de rétablissement à fréquence industrielle	Telles que spécifiées en 6.110.2	± 5 %	
		Valeur crête de la TTR:			
		- pour disjoncteurs ≤ 52 kV	Voir Tableaux 1 et 2	$^{+10}_{\ 0}$ %	
		- pour disjoncteurs > 52 kV	Voir Tableaux 1, 2, 3, 4 et ~~5~~ 26	$^{+5}_{\ 0}$ %	
		Vitesse d'accroissement de la TTR:			
		- pour disjoncteurs ≤ 52 kV	Voir Tableaux 1 et 2	$^{+15}_{\ 0}$ %	
		- pour disjoncteurs > 52 kV	Voir Tableaux 1, 2, 3 , 4 et ~~5~~ 26	$^{+8}_{\ 0}$ %	
		Moment de la fermeture pour OP2	À la crête de la tension appliquée dans un pôle	± 15°	
		Courant coupé pour OP1	30 % du pouvoir de coupure assigné en discordance de phases	± 20 % de la valeur spécifiée	
		Courant coupé pour OP2	100 % du pouvoir de coupure assigné en discordance de phases	$^{+10}_{\ 0}$ %	

Tableau B.1 *(suite)*

Paragraphe	Identification de l'essai	Paramètre d'essais	Valeur d'essais spécifiée	Tolérance d'essais/limites des valeurs d'essais	Référence à
6.111	Essais d'établissement et de coupure de courants capacitifs	Variation de la tension à fréquence industrielle: - pour LC1, CC1 et BC1 - pour LC2, CC2 et BC2		 ≤ 2 % ≤ 5 %	
		Décroissance de la tension de rétablissement 300 ms après l'extinction de l'arc		≤ 10 %	
		Valeur efficace du courant / valeur efficace de la composante fondamentale	--	≤ 1,2	
		Tension d'essai	Telle que spécifiée en 6.111.7	$^{+3}_{0}$ %	
		Fréquence de la tension de rétablissement	Fréquence assignée	± 2%	
		Courant coupé / pouvoir de coupure assigné de courants capacitifs	LC1, CC1, BC1 LC2, CC2, BC2	10 % à 40 % ≥ 100 %	
		Amortissement du courant d'appel	Disjoncteurs < 52 kV	≥ 0,75	
			Disjoncteurs ≥ 52 kV	≥ 0,85	
		Établissement et coupure de courants de batteries de condensateurs à gradins: valeur crête inhérente du pouvoir de fermeture	BC2	~~± 10 %. La tolérance sur la valeur inhérente du courant d'appel établi pour des batteries de condensateurs à gradins doit être~~ $\cancel{^{+10}_{0}}$ $^{+10}_{-0}$ %	
		Établissement et coupure de courants de batteries de condensateurs à gradins: fréquence du pouvoir de fermeture	BC2	Aussi proche que possible de la valeur requise. Ne doit pas être inférieure à 77% de la condition d'utilisation et ne doit pas être supérieure à 6 000 Hz.	
	Essais d'établissement et de coupure de courants capacitifs avec TTR spécifiée	Forme d'onde de la tension de rétablissement	Forme d'onde de la tension d'essai théorique de l'essai direct monophasé correspondant (courbe 1-cos)	$\cancel{^{+6}_{0}}$ $^{+6}_{-0}$ % de la valeur de crête de la tension d'essai (c'est-à-dire environ 3 % de la tension de crête de rétablissement $\cancel{u_c}$ u_C présentée à la Figure 54)	

Tableau B.1 *(suite)*

Paragraphe	Identification de l'essai	Paramètre d'essais	Valeur d'essais spécifiée	Tolérance d'essais/limites des valeurs d'essais	Référence à
Annexe M	Tension transitoire de rétablissement (TTR) pour T30, pour les disjoncteurs de tension assignée inférieure à 100 kV prévus pour être connectés à un transformateur par une liaison de faible capacitance	Valeur crête de la TTR	Voir Tableau M.1	$^{+10}_{\ 0}$ %	
		Vitesse d'accroissement de la TTR		$^{+5}_{-10}$ %	

[1] Si pour T10 et T30 la limite supérieure est dépassée alors la plus petite valeur possible doit être utilisée.

NOTE Le paramètre le plus important pour les essais de défaut proche en ligne est la forme d'onde de la tension du côté ligne et non pas l'impédance d'onde de la ligne.

Annexe C
(normative)

Enregistrement et comptes rendus des essais de type

C.1 Renseignements et résultats à enregistrer

Toutes les informations utiles et résultats concernant les essais de type doivent être contenus dans le compte rendu d'essais de type.

Des enregistrements oscillographiques, conformément à C.2, doivent être faits pour toutes les manœuvres en court-circuit, les manœuvres d'établissement et de coupure dans des conditions de discordance de phases, les manœuvres d'établissement et de coupure de courants capacitifs et les manœuvres à vide.

Le compte rendu d'essais de type doit inclure une déclaration relative à l'incertitude des systèmes de mesure utilisés pour les essais. Cette déclaration doit se référer aux procédures internes du laboratoire avec lesquelles le suivi de l'incertitude de mesure est effectué.

Le compte rendu d'essais de type doit préciser comment s'est comporté le disjoncteur pendant chaque séquence d'essais et l'état du disjoncteur après chaque séquence d'essais, dans la mesure où un examen est effectué à ce stade, et à la fin des séries de séquences d'essais. Ce relevé doit comprendre les points suivants:

a) état du disjoncteur donnant le détail de tous les remplacements et réglages faits, ainsi que l'état des contacts, des dispositifs de contrôle de l'arc, de l'huile (y compris la quantité perdue) et l'indication de toutes détériorations aux écrans de protection de l'arc, enveloppes, supports isolants et traversées;
b) description du fonctionnement durant la séquence d'essais, y compris les observations concernant l'émission d'huile, de gaz ou de flammes.

C.2 Renseignements à fournir dans les comptes rendus

C.2.1 Généralités

a) date des essais;
b) référence au numéro du compte rendu;
c) numéros des essais;
d) numéros des oscillogrammes.

C.2.2 Appareillage essayé

Le paragraphe 6.1.3 et l'Annexe A.2 de la CEI 62271-1 sont applicables avec les ajouts suivants:

Les plans de référence donnés dans le rapport d'essai doivent indiquer le numéro de référence du constructeur, l'indice de révision et le contenu correspondant.

La caractéristique de déplacement mécanique de référence, si applicable, doit être incluse, ou on doit y faire référence dans le rapport d'essai par l'utilisation d'un numéro de plan ou d'une manière équivalente.

C.2.3 Caractéristiques assignées du disjoncteur, incluant celles des mécanismes d'entraînement et des équipements auxiliaires

Les valeurs des caractéristiques assignées spécifiées à l'Article 4 ainsi que la durée d'ouverture minimale doivent être données par le constructeur.

C.2.4 Conditions de l'essai (pour chaque série d'essais)

a) nombre de pôles;

b) facteur de puissance;

c) fréquence, en hertz;

d) neutre du générateur (mis à la terre ou isolé);

e) neutre du transformateur (mis à la terre ou isolé);

f) point où est fait le court-circuit ou neutre du côté charge (mis à la terre ou isolé);

g) schéma du circuit d'essais y compris la ou les liaisons à la terre;

h) détails des raccordements du disjoncteur au circuit d'essais (par exemple orientation);

i) pression du fluide pour l'isolation et/ou l'interruption;

j) pression du fluide pour la manœuvre.

C.2.5 Essais d'établissement et de coupure en court-circuit

a) séquence de manœuvres et intervalles de temps;

b) tension appliquée, en kV;

c) courant établi (valeur de crête), en kA;

d) courant coupé:

   1) valeur efficace de la composante périodique, en kA, pour chacune des phases ainsi que la valeur moyenne;

   2) composante apériodique présumée au zéro du courant (calculée à partir du pourcentage de la composante apériodique à la séparation des contacts et à partir de la constante de temps de la composante apériodique du circuit d'essai; applicable seulement pour T100a);

   3) valeur crête dans la dernière alternance du courant (applicable seulement en T100a pour la phase ayant la composante apériodique la plus élevée);

   4) durée de la dernière alternance du courant (applicable seulement en T100a pour la phase ayant la composante apériodique la plus élevée et pour le premier pôle qui coupe; pour une grande alternance allongée, on doit indiquer la durée présumée de l'alternance obtenue lors de l'essai de calibrage du courant présumé);

e) tension de rétablissement à fréquence industrielle, en kV;

f) tension transitoire de rétablissement présumée;

   1) conformément à l'exigence a) de 6.104.5.1; les tensions et les coordonnées de temps peuvent être indiquées;

   2) conformément à l'exigence b) de 6.104.5.1;

g) durée d'arc, en millisecondes;

h) durée d'ouverture, en millisecondes;

i) durée de coupure, en millisecondes;

   Lorsque cela est applicable, les durées de coupure jusqu'à l'instant de l'extinction de l'arc principal et jusqu'à l'instant de la coupure du courant dans la résistance doivent être indiquées.

j) durée de fermeture, en millisecondes;

k) durée d'établissement, en millisecondes;

l) comportement du disjoncteur durant les essais, incluant, si applicable, l'émission de flammes, gaz, huile, etc.; l'apparition de décharges disruptives non maintenues (NSDD) doit être indiquée;

m) état après les essais;

n) pièces remplacées ou remises à neuf durant les essais.

C.2.6 Essai au courant de courte durée admissible

a) courant
   1) valeur efficace, en kA;
   2) valeur de crête, en kA;
b) durée, en s;
c) comportement du disjoncteur durant les essais;
d) état après les essais;
e) résistance du circuit principal avant et après les essais, en $\mu\Omega$.

C.2.7 Manœuvre à vide

a) avant les essais d'établissement et de coupure (voir 6.102.6);
b) après les essais d'établissement et de coupure (voir 6.102.9.2 et 6.102.9.3).

C.2.8 Essais d'établissement et de coupure en discordance de phases

a) courant coupé dans chaque phase, en kA;
b) courant établi dans chaque phase, en kA;
c) tension aux bornes de chaque phase, en kV;
d) tension transitoire de rétablissement présumée;
e) durée d'arc, en ms;
f) durée d'ouverture, en ms;
g) durée de coupure, en ms;
h) durée de fermeture, en ms;
i) durée d'établissement, en ms;
j) durée du courant dans la résistance (si applicable), en ms;
k) comportement du disjoncteur durant les essais, incluant, si applicable, l'émission de flammes, gaz, huile, etc; l'occurrence de décharges disruptives non maintenues doit être indiquée;
l) état après les essais.

C.2.9 Essais d'établissement et de coupure de courants capacitifs

a) tension d'essai, en kV;
b) courant coupé dans chaque phase, en A;
c) courant établi dans chaque phase, en kA;
d) valeurs crêtes de la tension entre phase et la terre, en kV:
   1) du côté alimentation du disjoncteur;
   2) du côté charge du disjoncteur;
e) nombre de réamorçages (éventuels); l'apparition de décharges disruptives non maintenues (éventuelles) doit être indiquée;
f) détails concernant le réglage du déclenchement synchrone, durée d'arc en ms;
g) durée de fermeture, en ms;
h) durée d'établissement, en ms;
i) comportement du disjoncteur pendant les essais;
j) état du disjoncteur après les essais.

C.2.10 Relevés oscillographiques et autres enregistrements

Les oscillogrammes doivent représenter la totalité de la manœuvre. Les grandeurs suivantes doivent être enregistrées. Certaines de ces grandeurs peuvent être enregistrées séparément et plusieurs oscillographes utilisant différentes échelles de temps peuvent être nécessaires:

a) tension appliquée;
b) courant dans chaque pôle;
c) tension de rétablissement (tension du côté alimentation et du côté charge du disjoncteur pour les essais de courants capacitifs);
d) courant dans la bobine de fermeture;
e) courant dans la bobine d'ouverture;
f) échelles d'amplitude et de temps appropriées pour la précision demandée;
g) caractéristiques de déplacement mécanique (si applicable).

Tous les cas pour lesquels les exigences de cette norme ne sont pas strictement respectées et toutes les dérogations doivent être explicitement mentionnés au début du compte rendu d'essais.

Annexe D
(normative)

Détermination du facteur de puissance d'un court-circuit

Il n'existe pas de méthode permettant de déterminer avec précision le facteur de puissance d'un court-circuit, mais pour l'application de cette norme, la détermination du facteur de puissance de chaque phase du circuit d'essai pourra être faite avec une précision suffisante en utilisant la plus appropriée des deux méthodes suivantes.

D.1 Méthode I – Détermination d'après la composante apériodique

L'angle φ (angle de phase entre le vecteur de tension et le vecteur de courant) peut être déterminé d'après la courbe de la composante apériodique de l'onde d'un courant asymétrique, entre l'instant d'initiation du court-circuit et l'instant de la séparation des contacts, comme indiqué ci-après:

D.1.1 Equation de la composante apériodique

L'équation de la composante apériodique est:

$$i_{\mathrm{d}} = I_{\mathrm{d0}} \times \mathrm{e}^{-\frac{R}{L}t} = I_{\mathrm{d0}} \times \mathrm{e}^{-\frac{t}{\tau}}$$

où

i_{d}	est la valeur de la composante c.c. à tout instant;
I_{d0}	est la valeur initiale de la composante apériodique;
$\tau = L/R$	est la constante de temps du circuit, en s;
t	est la durée, en s, depuis l'initiation du court-circuit;
e	est la base des logarithmes népériens.

La constante de temps L/R peut être déterminée d'après la formule ci-dessus comme suit:

a) mesurer la valeur de I_{d0} au moment du court-circuit et la valeur de i_{d} à tout autre moment t, avant la séparation des contacts;

b) déterminer la valeur de $\mathrm{e}^{-Rt/L}$ en divisant i_{d} par I_{d0};

c) d'après les valeurs e^{-x}, déterminer la valeur de $-x$ correspondant au rapport $i_{\mathrm{d}}/I_{\mathrm{d0}}$;

d) la valeur x représente alors Rt/L, d'où L/R peut être déterminée.

D.1.2 Angle de phase φ

Déterminer l'angle de phase φ selon

$$\varphi = \arctan\left(\omega \frac{L}{R}\right)$$

où ω est 2π fois la fréquence réelle.

D.2 Méthode II – Détermination avec un générateur pilote

Lorsqu'un générateur pilote est monté sur le même arbre que celui du générateur d'essais, la tension du générateur pilote peut être comparée sur l'oscillogramme, du point de vue de l'angle de phase, d'abord avec celle du générateur d'essais et ensuite avec le courant du générateur d'essais.

La différence d'angle de phase entre la tension du générateur pilote et celle du générateur principal d'une part, et entre la tension du générateur pilote et le courant du générateur principal d'autre part, donne l'angle de phase entre la tension et le courant du générateur d'essai, à partir duquel on peut déterminer le facteur de puissance.

Annexe E
(normative)

Méthode de tracé de l'enveloppe de la tension transitoire de rétablissement présumée d'un circuit et détermination des paramètres représentatifs

E.1 Introduction

Une onde de tension transitoire de rétablissement peut se présenter sous différentes formes, aussi bien oscillatoires que non oscillatoires.

L'onde peut être définie au moyen d'une enveloppe constituée de trois segments de droite consécutifs; lorsque l'onde correspond sensiblement à une oscillation amortie à une seule fréquence, l'enveloppe, elle-même, se réduit à deux segments de droite consécutifs. Dans tous les cas, il convient que l'enveloppe reflète d'aussi près que possible la forme réelle de la tension transitoire de rétablissement. La méthode décrite ici permet d'atteindre ce résultat dans la majorité des cas pratiques avec une approximation suffisante.

NOTE Néanmoins, on peut rencontrer certains cas pour lesquels la construction proposée conduirait à des paramètres manifestement plus sévères que la représentation par une courbe de la tension transitoire de rétablissement. En principe, de tels cas sont considérés comme des exceptions et, en conséquence, font l'objet d'un accord entre le constructeur et l'utilisateur ou le laboratoire d'essais.

E.2 Tracé de l'enveloppe

La méthode suivante est utilisée pour construire les segments de droite formant l'enveloppe de la courbe de la tension transitoire de rétablissement présumée.

a) Le premier segment de droite passe par l'origine O, est tangent à la courbe et ne coupe pas (voir Figures E.1 à E.3, segment OB et Figure E.4, segment OA).

   Dans le cas de courbes dont la partie initiale présente une concavité vers la gauche, le point de contact est souvent au voisinage de la première crête (voir Figures E.1 et E.2, segment OB).

   Si la concavité est vers la droite, comme dans le cas d'une courbe exponentielle, le point de contact est au voisinage de l'origine (voir Figure E.3, segment OB).

b) Le deuxième segment de droite est une ligne horizontale tangente à la courbe au point correspondant à la crête la plus élevée (voir Figures E.1 à E.4, segment AC).

c) Le troisième segment de droite est tangent à la courbe en un ou plusieurs points situés entre les deux premiers points de contact et ne coupe pas la courbe.

   Trois cas peuvent se présenter pour le tracé de ce dernier segment de droite.

   1) On peut tracer un seul segment qui touche la courbe en deux points (ou, éventuellement, en plus que deux points).

      Dans ce cas, il fait partie de l'enveloppe (voir Figure E.1, segment BA).

      On obtient ainsi l'enveloppe à quatre paramètres O, B, A, C.

   2) On peut tracer plusieurs segments susceptibles de toucher la courbe en deux points (ou, éventuellement, en plus de deux points) sans la couper.

      Dans ce cas, le segment à utiliser pour former l'enveloppe est celui qui touche la courbe en un seul point situé de telle façon que les aires de chaque côté de ce point, comprises entre la courbe et l'enveloppe, soient sensiblement égales (voir Figure E.2, segment BA).

      On obtient ainsi l'enveloppe à quatre paramètres O, B, A, C.

3) On ne peut tracer aucun segment susceptible de toucher la courbe en plus d'un point sans la couper.

   Dans ce cas, il convient de faire la distinction suivante.

   i) Le point de contact du premier segment de droite et la crête la plus élevée sont relativement éloignés l'un de l'autre. C'est le cas typique d'une courbe exponentielle ou d'une courbe approximativement exponentielle.

      Dans ce cas, le segment de droite doit être tangent à la courbe en un point tel que les aires de part et d'autre de ce point, comprises entre la courbe et l'enveloppe, soient approximativement égales comme pour le cas c) 2) de E.2 (voir Figure E.3, segment BA).

      On obtient ainsi l'enveloppe à quatre paramètres O, B, A, C.

   ii) Le point de contact du premier segment de droite et la crête la plus élevée sont relativement voisins l'un de l'autre.

      C'est le cas d'une courbe représentant une oscillation amortie à une seule fréquence ou d'une courbe de forme similaire.

      Dans ce cas, on ne trace pas un troisième segment de droite et on adopte une représentation par deux paramètres correspondant aux deux premiers segments de droite (voir Figure E.4).

      On obtient ainsi l'enveloppe à deux paramètres O, A, C.

E.3 Détermination des paramètres

Les paramètres représentatifs sont, par définition, les coordonnées des points d'intersection des segments de droite constituant l'enveloppe.

Lorsque l'enveloppe est formée de trois segments de droite, les quatre paramètres u_1, t_1, u_c et t_2 indiqués dans les Figures E.1, E.2 et E.3 peuvent être obtenus en prenant les coordonnées des points d'intersection B et A.

Lorsque l'enveloppe n'est formée que de deux segments de droite, les deux paramètres u_c et t_3 indiqués sur la Figure E.4 peuvent être obtenus en prenant les coordonnées du point d'intersection A.

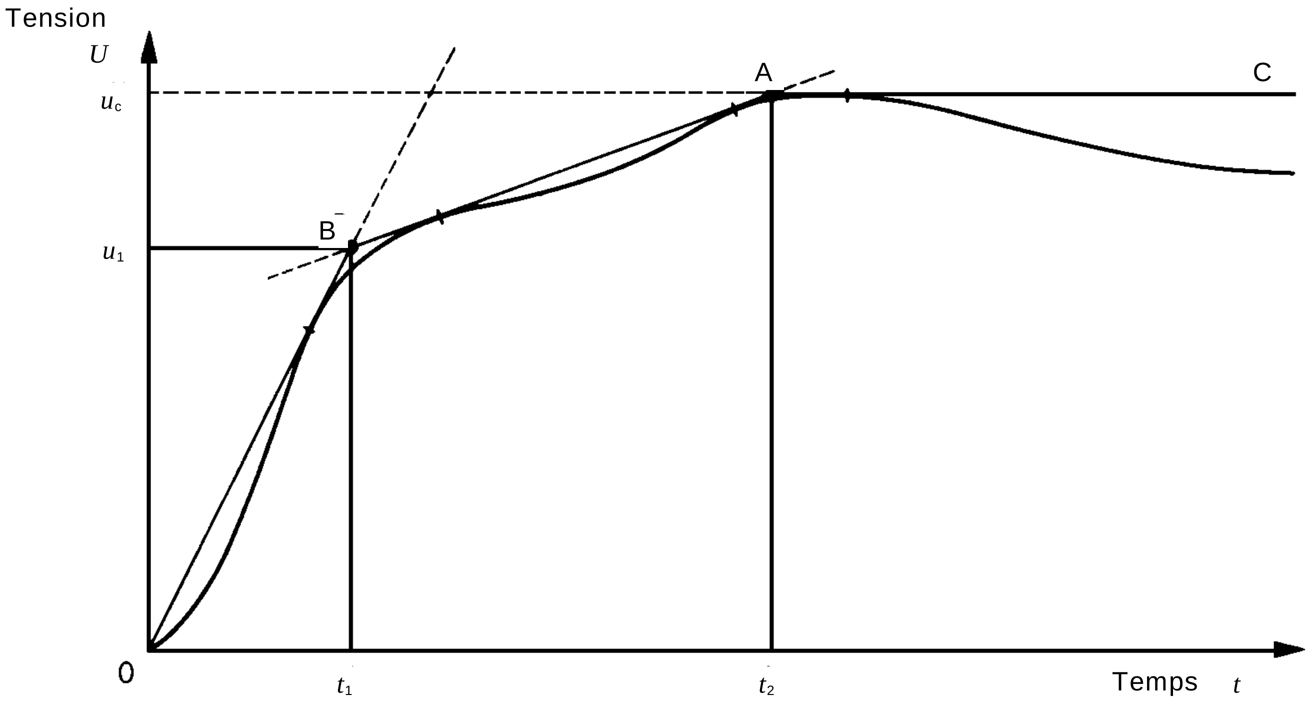


Figure E.1 – Représentation par quatre paramètres d'une tension transitoire de rétablissement présumée d'un circuit – Cas de E.2. c) 1)

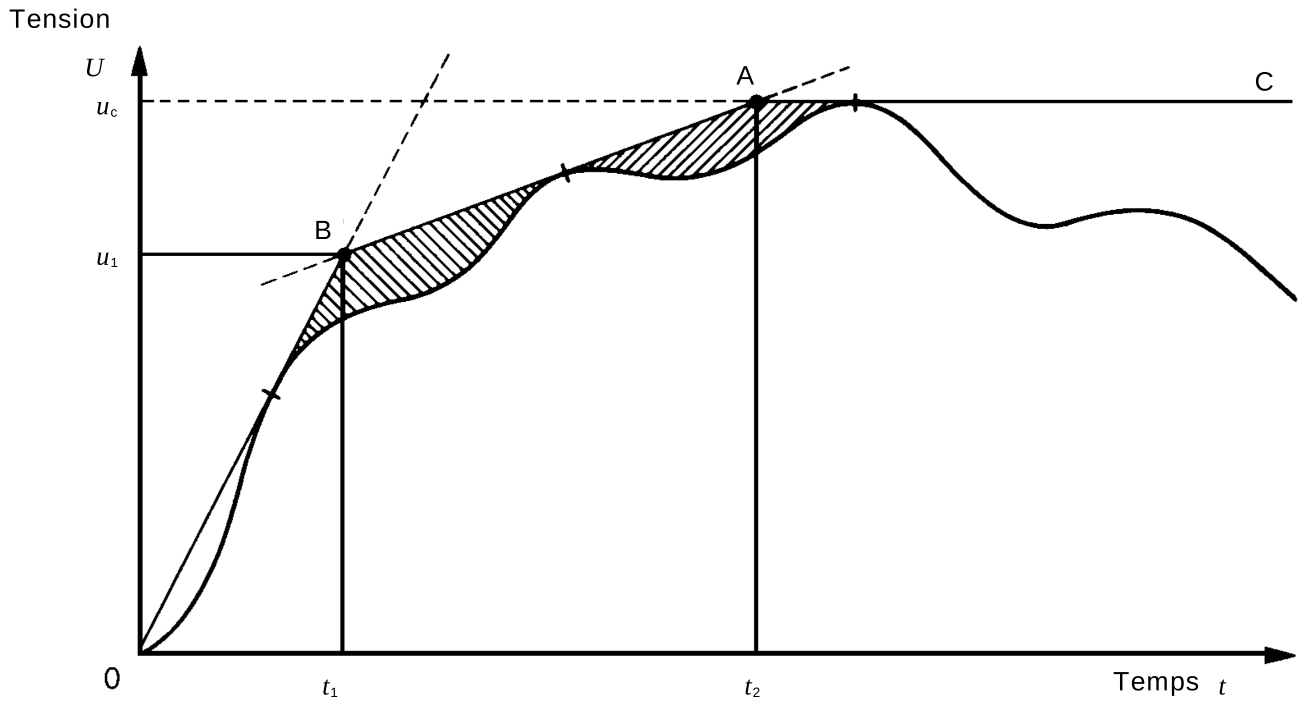


Figure E.2 – Représentation par quatre paramètres d'une tension transitoire de rétablissement présumée d'un circuit – Cas de E.2 c) 2)

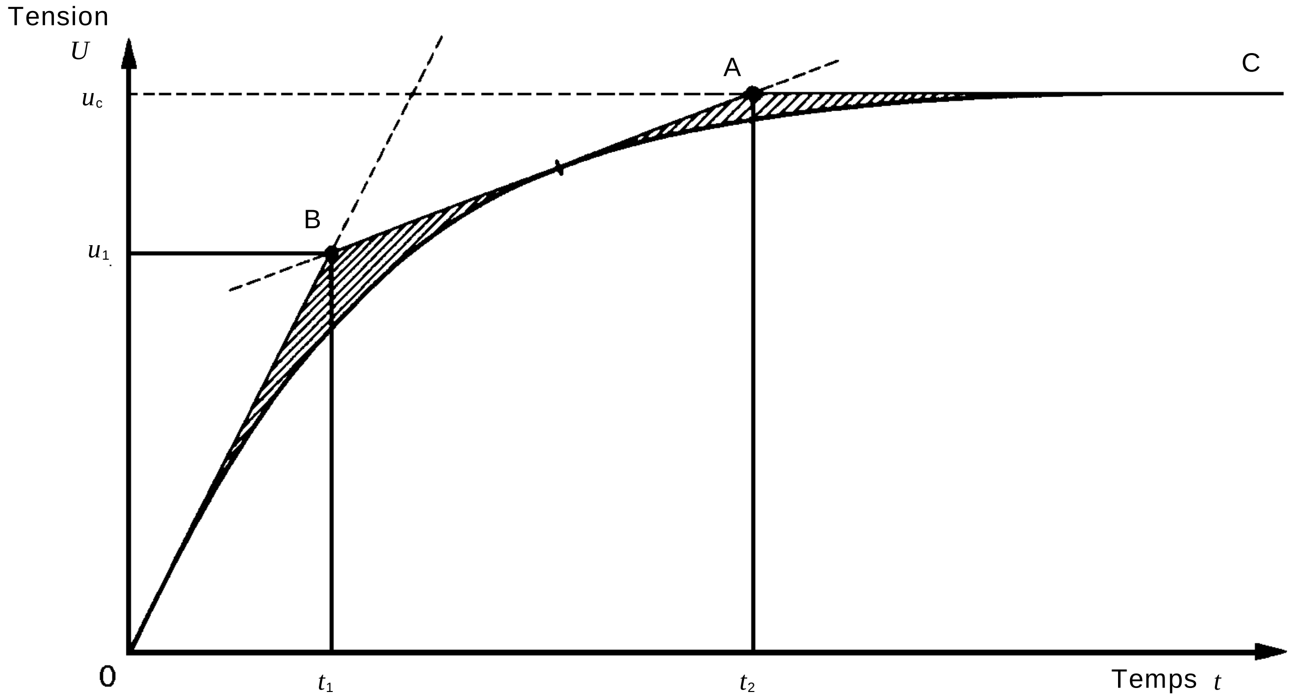


Figure E.3 – Représentation par quatre paramètres d'une tension transitoire de rétablissement présumée d'un circuit – Cas de E.2. c) 3) i)

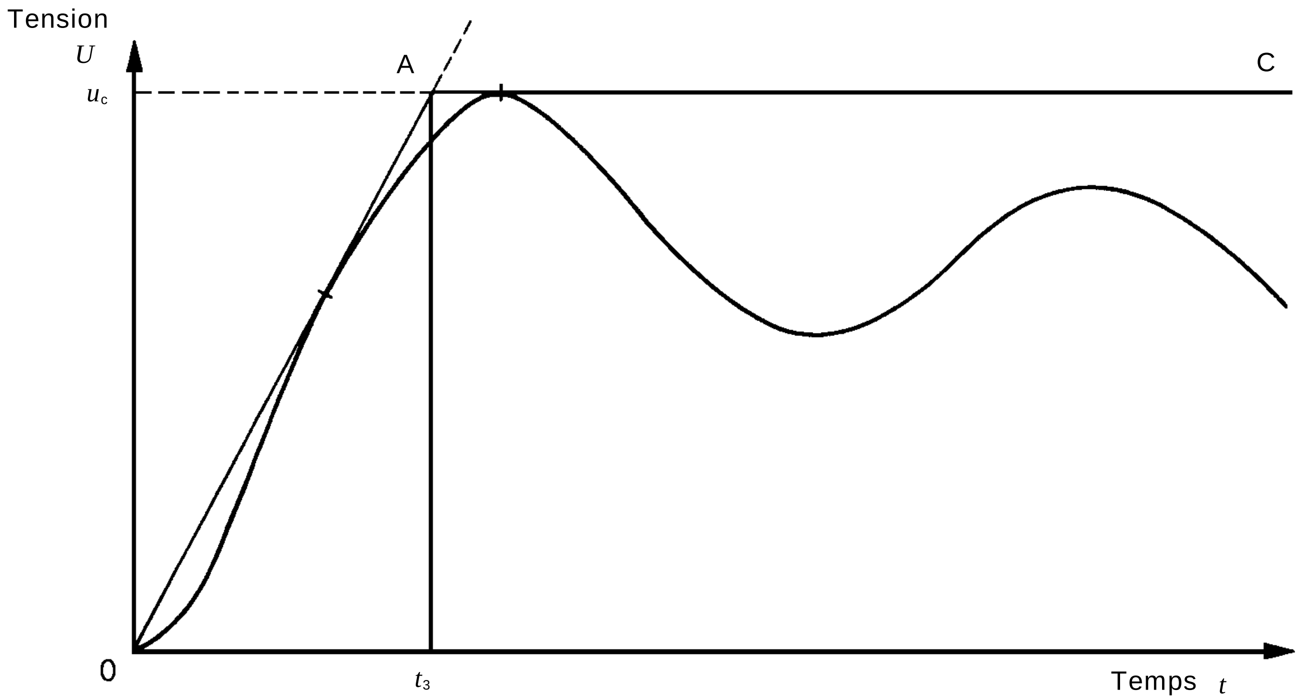


Figure E.4 – Représentation par deux paramètres d'une tension transitoire de rétablissement présumée d'un circuit – Cas de E.2. c) 3) ii)

Annexe F
(normative)

Méthodes de détermination des ondes de la tension transitoire de rétablissement présumée

F.1 Introduction

Les formes de l'onde de la tension transitoire de rétablissement (TTR) consécutives à la coupure de courants de court-circuit dépendent de deux groupes de facteurs principaux qui sont: ceux dépendant des caractéristiques du circuit (inductance, capacité, résistance, impédance d'onde, etc.) et ceux provenant des caractéristiques du disjoncteur (tension d'arc, conductivité post-arc, condensateurs et résistances intercalaires, etc.).

Des méthodes sont recommandées pour déterminer la forme de l'onde de la TTR produite seulement par les caractéristiques du circuit, celle-ci étant la «TTR présumée».

Étant donné que tout dispositif de mesure a une influence sur la forme de l'onde de la TTR présumée, des précautions convenables et éventuellement des corrections sont nécessaires.

Des méthodes sont disponibles pour l'évaluation de la TTR présumée des circuits des stations d'essais de court-circuit ainsi que pour les réseaux, et les méthodes recommandées sont énumérées et décrites brièvement en tenant compte des caractéristiques de la TTR qui sont spécifiées pour les valeurs assignées et pour les essais.

L'expérience des stations d'essais et des réseaux a montré qu'après la coupure d'un courant de court-circuit, non seulement une oscillation à une seule ou à plusieurs fréquences se superpose à l'onde de tension à fréquence industrielle, mais qu'il existe également des composantes à caractère exponentiel d'amplitude et de durée importantes. Ces composantes ont des constantes de temps qui dépendent des caractéristiques des éléments du circuit, par exemple alternateurs, transformateurs, lignes, etc. Ces composantes exponentielles ont pour effet de rendre la valeur de crête de la TTR et sa vitesse d'accroissement inférieures à celles qui existeraient si seules les composantes oscillatoires s'étaient superposées à la tension à fréquence industrielle. Cela est montré à la Figure F.1 et il convient que toute méthode de mesure tienne compte de cette influence.

Les mesures ont montré que l'inductance des divers éléments du circuit variait avec la fréquence, causé par l'effet d'écran des courants de Foucault à l'intérieur des conducteurs, de la terre et des circuits magnétiques. En même temps que d'autres facteurs qui tendent à réduire les tensions instantanées, cela introduit une constante de temps variant de quelques centaines de microsecondes pour certains alternateurs jusqu'à quelques dizaines de microsecondes pour les transformateurs, les valeurs exactes dépendant de la conception du matériel particulier et de la fréquence des composantes de la TTR. Dans certains cas, il peut en résulter une réduction de la valeur de crête de la TTR atteignant 25 %.

Il est donc important de tenir compte de ces facteurs pour l'évaluation de la TTR présumée d'une station d'essais ou d'un réseau et de donner des indications relatives aux méthodes recommandées.

Quelle que soit la méthode utilisée, les valeurs réelles de la TTR présumée mesurées dans la station d'essais doivent être conformes aux valeurs spécifiées dans la présente norme.

Lorsque le temps t_2 de la crête de la TTR dépasse, par exemple, 1 250 µs, en plus des influences décrites précédemment, la valeur instantanée de la tension à fréquence industrielle a, dans tous les cas, diminué de plus de 6 % à 50 Hz et de plus de 10 % à 60 Hz. On doit, par conséquent, prendre en considération cette influence supplémentaire lors de l'utilisation de méthodes de détermination de la TTR présumée faisant intervenir une tension de rétablissement à fréquence industrielle ou lorsqu'on effectue des calculs utilisant les constantes du circuit.

La valeur instantanée de la composante à fréquence industrielle qui suit immédiatement le passage à zéro du courant dépend également du facteur de puissance en court-circuit et du pourcentage de la composante apériodique de la dernière alternance du courant, et peut ainsi être inférieure à la pleine valeur crête. Pour des courants symétriques et des facteurs de puissance en court-circuit égaux ou inférieurs à 0,15, la réduction ne dépasse pas 1,5 % et est ainsi peu importante pour les circuits des stations d'essais; cependant, elle peut être importante pour les facteurs de puissance plus élevés qui peuvent exister en service.

Pour la TTR correspondant aux défauts aux bornes (voir 4.102), on a introduit un retard pour tenir compte de l'influence de la capacité localisée du côté source du disjoncteur. Des retards correspondants ont également été spécifiés pour les différents circuits d'essais (voir 6.104.5) et il convient que la méthode utilisée pour mesurer la TTR soit en mesure de déterminer ces retards.

Pour certains disjoncteurs, les caractéristiques pour les défauts proches en ligne sont également spécifiées (voir 4.105) et la TTR résultante correspondant aux essais de défaut proche en ligne a été spécifiée. La capacité localisée entre le disjoncteur et la ligne donne également naissance à un retard pour la composante de la TTR côté ligne. Pendant les essais, il est souhaitable de mesurer et d'enregistrer le retard du côté ligne et il convient que la méthode utilisée soit adéquate pour évaluer ce dernier.

F.2 Résumé général des méthodes recommandées

On classe comme suit les méthodes fondamentales utilisées pour la détermination des formes de l'onde de la TTR présumée:

– groupe 1 – Coupure directe du courant de court-circuit;
– groupe 2 – Injection de courant à fréquence industrielle;
– groupe 3 – Injection de courant de condensateur;
– groupe 4 – Modèles de réseaux;
– groupe 5 – Calcul à partir des paramètres du circuit;
– groupe 6 – Manœuvre à vide de circuits d'essai comprenant des transformateurs;
– groupe 7 – Combinaison de différentes méthodes.

Les groupes 1, 4 et 5 sont recommandés pour les réseaux.

Les groupes 2 et 3 peuvent être appliqués aux éléments des réseaux.

Seuls les groupes 1 à 3 ou une combinaison de ces derniers sont adéquats pour évaluer la TTR présumée des circuits d'essais utilisés dans les stations d'essais de court-circuit.

Lors de l'utilisation des groupes 1, 2, 3, 4, 6 ou 7, il est recommandé de vérifier soigneusement les circuits d'enregistrement de la tension afin de s'assurer que l'étalonnage de l'ensemble demeure constant dans toute la gamme des fréquences de la TTR à enregistrer et que les échelles de temps sont linéaires. Il est alors recommandé d'étalonner, en fonction d'une tension connue, l'oscillographe et chaque diviseur de tension. Lors de l'utilisation d'oscillographes cathodiques comportant une base de temps de balayage, il est recommandé de connaître avec précision l'échelle de temps, et de préférence, qu’elle soit linéaire afin d'éviter d'effectuer de nouveaux enregistrements pour fins de comparaison, etc.

Lorsque cela est applicable, il est recommandé que le courant injecté et la tension aux bornes du circuit étudié soient enregistrés en utilisant une base de temps de vitesse convenable et, de plus, que des enregistrements à grande vitesse du courant et de la tension au zéro de courant soient effectués. Il est recommandé d'enregistrer la TTR à l'aide d'un oscillographe de sensibilité suffisante et avec une base de temps convenable.

F.3 Étude détaillée des méthodes recommandées

F.3.1 Groupe 1 – Coupure directe d'un courant de court-circuit

Cette méthode implique la coupure d'un courant de court-circuit réel établi au moyen d'une connexion métallique dans le réseau en étude et l'enregistrement de la TTR qui en résulte à l'aide d'un oscillographe. Idéalement, le courant coupé devrait être symétrique, ou alors il conviendrait de tenir compte de la variation du di/dt s'il existe une asymétrie appréciable. Avec cette méthode, il est essentiel de tenir compte de l'influence du disjoncteur. A ce sujet, les caractéristiques les plus importantes sont la tension d'arc et la conductivité post-arc.

A cause de la tension d'arc, la tension aux bornes des contacts du disjoncteur peut ne pas être nulle à l'instant de l'interruption de l'arc et, de ce fait, la TTR ne part pas d'une tension nulle mais de la valeur de la tension d'arc à l'instant du passage à zéro du courant. La TTR commence donc en dessous de la ligne de tension nulle pour la traverser ultérieurement (voir Figure F.3).

En conséquence, la valeur de crête de la tension est supérieure à ce qu'elle serait dans le cas d'un disjoncteur idéal (tension d'arc nulle) (voir Figure F.2). Un effet semblable mais plus prononcé résulte de l'interruption nettement en avance sur le passage naturel du courant par zéro (arrachement du courant), ce qui peut se produire pour un petit courant (voir Figure F.4). De plus, si la TTR présumée comprend plusieurs composantes oscillatoires, l'arrachement du courant peut faire apparaître une forme d'onde qui est nettement différente de celle qui serait obtenue avec un disjoncteur «idéal».

Ainsi, c'est un disjoncteur comportant une faible tension d'arc immédiatement avant le passage à zéro du courant et ne provoquant pas d'arrachement du courant qui convient le mieux pour la coupure directe d'un courant de court-circuit.

On peut compenser l'influence de la tension d'arc comme illustré à la Figure F.6.

En principe, la compensation de la tension d'arc ne convient que pour les TTR comportant une composante transitoire à une seule fréquence; néanmoins, on peut l'utiliser aussi avec une bonne approximation pour les oscillations transitoires à plusieurs fréquences si l'amplitude de la composante oscillatoire principale est prédominante.

Le courant post-arc, c'est-à-dire le courant traversant la distance inter-contacts pendant l'accroissement de la TTR, peut influencer la forme d'onde de cette dernière par un amortissement, réduisant ainsi sa vitesse d'accroissement et sa valeur de crête (voir Figure F.5). L'emploi de résistances en parallèle avec les chambres de coupure du disjoncteur produit un effet semblable.

Il s'ensuit donc qu'en plus des exigences relatives à une faible tension d'arc et à l'absence d'arrachement du courant, il est recommandé d'utiliser un disjoncteur non muni de résistances shunt et ne présentant pas une importante conductivité post-arc pour les méthodes de coupure directe du courant de court-circuit.

En particulier, lorsqu'on peut faire fonctionner la station d'essais avec une excitation convenablement réduite, l'interrupteur à vide peut souvent constituer un disjoncteur presque «idéal». Toutefois, il est recommandé de s'assurer que le dispositif utilisé ne présente pas d'arrachement de courant important dans le circuit particulier étudié.

On peut parfois, de façon appropriée, améliorer les caractéristiques des disjoncteurs utilisés pour la coupure directe du courant de court-circuit, par exemple en retardant l'instant de la séparation des contacts en vue d'obtenir une durée d'arc courte et une tension d'arc faible.

Avec cette méthode, on coupe un courant réel de court-circuit dans le circuit étudié et la TTR enregistrée tient compte, plus ou moins, des influences qui contribuent à réduire la tension de rétablissement. Pour cette raison, selon les caractéristiques du disjoncteur, la méthode de la coupure directe du courant de court-circuit peut être la plus adaptée à l'évaluation de la TTR présumée et est fréquemment utilisée pour le contrôle des autres méthodes. Toutefois, la méthode de la coupure directe du courant de court-circuit est moins bien adaptée à la mesure des retards, et en particulier du retard de la TTR côté ligne, dans le cas du défaut en ligne.

F.3.2 Groupe 2 – Injection de courant à fréquence industrielle

Cette méthode est utilisée seulement avec un circuit hors tension et est donc principalement utilisée dans les stations d'essais ou lorsqu'une partie d'un réseau peut être étudiée hors tension. Elle ne tient pas compte des phénomènes d'effet couronne ou de saturation magnétique.

Le principe de cette méthode repose sur l'injection d'un courant relativement petit dans le circuit et l'enregistrement de la réponse du circuit lorsque le courant est interrompu par un appareil de connexion idéal, c'est-à-dire par un dispositif comportant une tension d'arc et un courant post-arc négligeables.

Une source convenable de courant injecté est constituée par un transformateur monophasé alimenté par le réseau local à basse tension, le secondaire fournissant par exemple une gamme de courants et de tensions comprise ente 2 A à 200 V et 300 A à 25 V. Cette gamme couvre les impédances de la majorité des circuits à considérer. La Figure F.7 représente un schéma correspondant à un exemple d'application de cette méthode ainsi que les détails des éléments. La Figure F.8 indique la séquence des manœuvres correspondant au schéma.

Il est recommandé de s'assurer que les capacités propres des dispositifs d'alimentation et de mesure n'ont pas d'influence sur les résultats.

Il convient que la tension aux bornes soit mesurée à l'entrée du circuit et, lorsque c'est possible, de mettre à la terre une borne du circuit. Lorsqu'une des bornes du circuit n'est pas mise à la terre, il est essentiel d'isoler complètement de la terre le matériel de mesure et d'injection. Cela peut être obtenu par l'emploi d'un générateur auxiliaire isolé de la terre et ayant une capacité négligeable par rapport à celle-ci.

L'appareil de connexion le mieux adapté à ce schéma est une diode semiconductrice. En général, des diodes semiconductrices comportant des temps de recouvrement inverse ne dépassant pas 100 ns conviennent. Des temps plus longs sont acceptables pour les TTR de fréquence propre équivalente basse. Pour obtenir une capacité de tenue en courant adéquate, plusieurs diodes en parallèle peuvent être utilisées.

NOTE Les caractéristiques des diodes dépendent d'un certain nombre de facteurs, par exemple la valeur du courant direct, la forme d'onde et la valeur de la tension inverse et les données fournies par les constructeurs dépendent des méthodes utilisées pour déterminer ces caractéristiques.

Pour obtenir une onde de courant symétrique, il peut être nécessaire de faire passer le courant pendant un temps atteignant 20 périodes. Pendant la plus grande partie de ce temps, les diodes seront court-circuitées par un interrupteur qu'on ouvre à la fin de cet intervalle de temps, provoquant ainsi le passage du courant à travers les diodes qui coupent ce dernier au prochain passage par zéro du courant.

Pour évaluer le retard avec précision, il est nécessaire d'amplifier les échelles de tension de temps dans la partie initiale de l'onde.

L'enregistrement du courant à plus faible vitesse montre si le courant est symétrique à l'instant de la coupure et l'enregistrement à grande vitesse indique la vitesse de variation, di/dt, immédiatement avant le passage à zéro du courant. Il montre également s'il existe ou non un courant post-arc appréciable provoquant l'amortissement de la TTR ou un arrachement appréciable du courant susceptible de modifier l'amplitude de la TTR.

L'enregistrement de la TTR représente l'oscillation propre transitoire du circuit étudié et tient compte de la plupart des facteurs provoquant une réduction de la tension.

Les valeurs peuvent être déterminées en effectuant un étalonnage de tension basé sur la pleine puissance du circuit. Des explications détaillées sont données en F.3.4.

F.3.3 Groupe 3 – Injection de courant de condensateur

Cette méthode est semblable à celle du groupe 2, sauf que le courant traversant le circuit considéré provient de la décharge d'un condensateur. Dans ces conditions, la fréquence du courant injecté dépend des valeurs du condensateur et de l'inductance du circuit.

Puisque la fréquence du courant injecté est habituellement beaucoup plus grande que la fréquence industrielle, cette méthode ne tient pas compte des facteurs qui contribuent à réduire la tension de rétablissement.

Comme la fréquence du courant de décharge devrait être de un huitième de la fréquence propre équivalente du circuit, cela impliquerait que la méthode convient à la mesure des TTR de circuits comprenant des éléments ayant des fréquences propres élevées. Elle est particulièrement utile pour la mesure des caractéristiques des éléments du côté ligne des circuits d'essais de défauts en ligne dont les fréquences propres sont très élevées et dont les retards correspondants sont petits.

La Figure F.9 représente le schéma d'un exemple de circuit d'injection de courant de condensateur ainsi que les détails des éléments. La Figure F.10 indique la séquence des manœuvres correspondant au schéma.

On prend les mêmes précautions et la même méthode d'étalonnage que pour le groupe 2, et celles-ci sont décrites en détail en F.3.4.

F.3.4 Groupes 2 et 3 – Méthodes d'étalonnage

A partir de la valeur mesurée de la vitesse de variation, di/dt, du courant injecté immédiatement avant le passage par zéro, calculer la valeur efficace équivalente du courant injecté I_i.

$$I_i = \frac{\dfrac{di_i}{dt}}{2\pi f_i \sqrt{2}}$$

où f_i est la fréquence du courant injecté.

Dans ce calcul, on admet que:

$$i_i = I_i\sqrt{2}\sin(2\pi f_i t) \cong I_i\sqrt{2}\times 2\pi f_i \mathrm{t}$$

Cette approximation est valable quand t_2 < 1 250 µs (ou quand t_2 < 1 000 µs pour une fréquence de 60 Hz).

En partant des approximations précédentes, on peut en déduire la règle suivante:

Il convient que la fréquence du courant injecté soit ≤ 1/8$^{\text{ième}}$ de la fréquence propre équivalente du circuit étudié. Lorsque le temps t_2 de la TTR présumée est supérieur à

1 250 µs (1 000 µs pour 60 Hz), il convient que la fréquence du courant injecté soit égale à la fréquence industrielle assignée.

NOTE Si le facteur est 1/8ième durant l'intervalle ($t_2 - t_0$), alors un écart maximal de la pente du courant injecté, par rapport à une droite, de 15 % sera produit. Un facteur de 1/14 donnerait un écart maximal de 5 %.

Si la valeur efficace du courant de court-circuit maximal du circuit est I_{sc}, alors l'étalonnage de tension V_{sc} (en mm) pour la TTR correspondante à I_{sc} sera:

$$V_{sc} \text{ (en mm)} = V_i \text{ (en mm)} \times (I_{sc}/I_i) \times (f_{sc}/f_i)$$

où f_{sc} est la fréquence du courant de court-circuit.

Compte tenu des indications précédentes concernant les TTR présumées comportant de longues durées t_2, dans les cas où l'écart entre la courbe du courant et une sinusoïde de forme symétrique est trop important pour être négligé, il est recommandé d'utiliser la formule fondamentale suivante:

$$V_{sc}\,\text{(en mm)} = V_i\,\text{(en mm)}\,\frac{\left(\dfrac{\mathrm{d}i_{sc}}{\mathrm{d}t}\right)_{i_{sc}\to 0}}{\left(\dfrac{\mathrm{d}i_i}{\mathrm{d}t}\right)_{i_i\to 0}}$$

où $\left(\dfrac{\mathrm{d}i_{sc}}{\mathrm{d}t}\right)_{i_{sc}\to 0}$ est la vitesse de variation du courant de court-circuit à fréquence industrielle

au passage par zéro du courant, avec la fonction définissant le courant:

$$i_{sc} = I_{sc}\sqrt{2}\sin(2\pi f_{sc}t) \;\cong\; I_{sc}\sqrt{2}\times(2\pi f_{sc}t)$$

Cette équation s'applique particulièrement à la méthode d'injection de courant de condensateur où le courant a une forme oscillatoire légèrement amortie.

La méthode suivante convient pour obtenir l'étalonnage pour les essais de défaut proche en ligne:

A partir de l'enregistrement à grande vitesse, mesurer:

$\dfrac{\mathrm{d}u_i}{\mathrm{d}t}$ = VATR de la TTR au passage par zéro du courant injecté;

u_i = première crête de la tension produite par le courant injecté;

$\left(\dfrac{\mathrm{d}i_i}{\mathrm{d}t}\right)_{i_i\to 0}$ = vitesse de variation du courant injecté à son passage par zéro.

La valeur de l'impédance d'onde Z est alors obtenue par le calcul:

$$Z = \frac{\dfrac{\mathrm{d}u_i}{\mathrm{d}t}}{\left(\dfrac{\mathrm{d}i_i}{\mathrm{d}t}\right)_{i_i\to 0}}$$

F.3.5 Groupe 4 – Modèles de réseaux

Dans cette méthode, un modèle de réseau est composé d'éléments qui doivent être une représentation exacte des éléments du circuit réel. Il est habituellement nécessaire de simuler les éléments du circuit réel qui ont des éléments distribués par un modèle ayant des éléments concentrés. De plus, il est essentiel que les caractéristiques d'impédance (particulièrement de réactance et de résistance) des éléments du modèle soient, d'aussi près que possible, une véritable imitation de ces caractéristiques des éléments réels à des fréquences atteignant au moins celle correspondant à la TTR à l'étude.

La précision de cette méthode dépend de l'obtention des données exactes concernant les paramètres du circuit à représenter et il est souvent difficile d'obtenir ces données et de les représenter par un modèle réduit à des composantes discrètes.

Cela s'applique particulièrement aux paramètres variant avec la fréquence de sorte qu'en général, cette méthode ne tient pas compte directement de la réduction de la TTR et tend à donner des valeurs un peu plus élevées que celles qui seraient obtenues à l'aide de courts-circuits directs sur un réseau réel.

Cette méthode est surtout utile pour l'étude de projets de réseaux, car elle ne nécessite pas la mise hors service du réseau et constitue un guide utile à condition d'en connaître les limites.

F.3.6 Groupe 5 – Calcul à partir des paramètres du circuit

Lorsque les données concernant les paramètres des éléments du circuit sont connues, comme pour le groupe 4, il est souvent commode de calculer la forme d'onde de la TTR, en particulier si le circuit n'est pas trop complexe.

En général, la méthode ne tient pas compte des effets de réduction, bien qu'il soit possible d'en tenir compte dans une certaine mesure si les données correspondantes du circuit sont disponibles; de même, on peut tenir compte de la décroissance de la composante à fréquence industrielle pour les TTR dont le temps t_2 dépasse 1 250 µs (1 000 µs à 60 Hz).

La méthode comporte les limites du groupe 4, auxquelles on doit ajouter les erreurs propres aux calculs, à moins d'avoir obtenu de l'expérience en comparant les résultats de calcul avec des TTR réelles obtenues à partir d'essais mettant en œuvre les techniques des groupes 1, 2, 3 ou 6.

F.3.7 Groupe 6 – Manœuvre à vide de circuits d'essai comprenant des transformateurs

Cette méthode consiste à enclencher le transformateur d'essais sur un circuit ouvert et à enregistrer, à l'aide d'oscillogrammes, l'allure de la tension transitoire aux bornes du circuit secondaire à vide.

La méthode est très utile dans les stations d'essais où le courant de court-circuit est fourni par des alternateurs. Toutefois, le disjoncteur effectuant l'enclenchement ne doit pas comporter de résistance shunt, doit être dépourvu de préamorçage notable et doit être situé à proximité immédiate du disjoncteur en essai. De plus, l'application de cette méthode est limitée aux circuits donnant naissance à une TTR à une seule fréquence et cette méthode ne reproduit pas la composante exponentielle correspondante aux courants de Foucault.

F.3.8 Groupe 7 – Combinaison de différentes méthodes

Si un circuit d'essais synthétiques est utilisé dans lequel différents circuits sont combinés, il peut être nécessaire d'utiliser une combinaison des méthodes proposées. Cela est toujours le cas si la TTR est produite par la superposition de différentes sources (il est fréquent d'utiliser jusqu'à trois sources différentes). Par exemple, dans un circuit à injection de tension, il est possible de vérifier la TTR de la source de courant séparément de la TTR du circuit à injection de tension. Cela signifie que chaque circuit séparé peut être vérifié par une des méthodes proposées. Pour les différents circuits, différentes méthodes peuvent être appliquées. La TTR totale (somme des TTR des différents circuits) peut être construite à l'aide de méthodes mathématiques. Si un équipement d'enregistrement numérique est utilisé, il est aussi possible de construire la TTR totale en combinant les données numériques obtenues par les différentes méthodes.

Dans le cas d'une combinaison des méthodes proposées, les limites spécifiques des méthodes, données au Tableau F.1, doivent être considérées.

F.4 Comparaison des méthodes

Les diverses méthodes sont classées dans le Tableau F.1 avec leurs caractéristiques, leurs avantages et leurs inconvénients.

Tableau F.1 – Méthodes pour la détermination de la TTR présumée

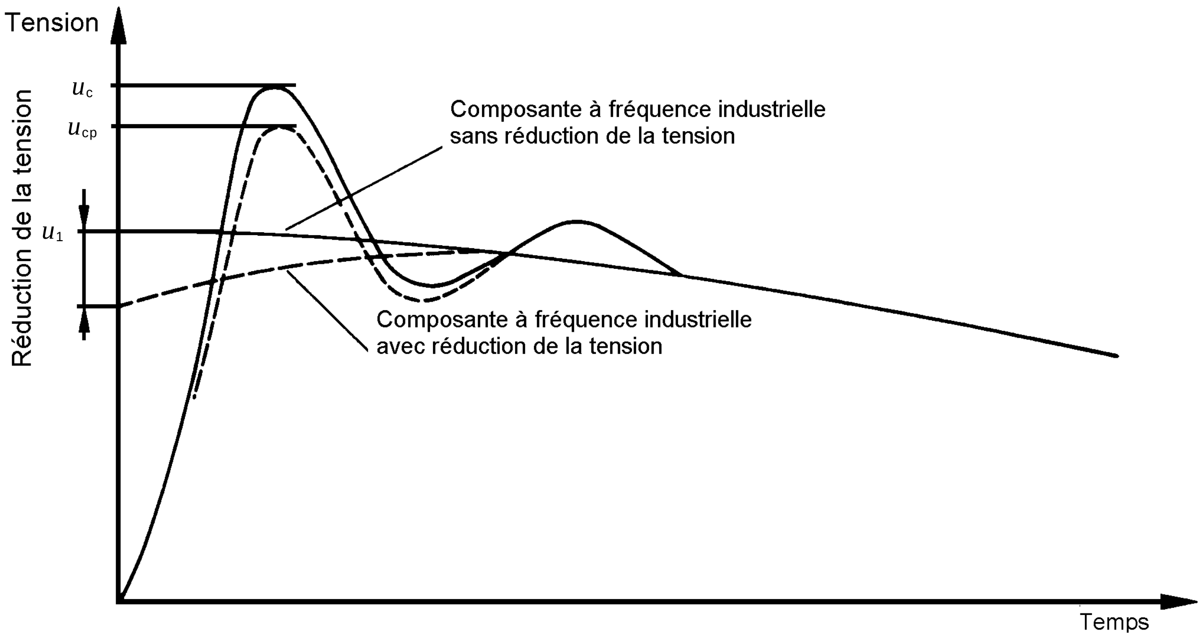
Méthode		Limites théoriques	Limites pratiques
F.1.1	Essais grandeur nature avec disjoncteur idéal	Aucune. Tous les phénomènes sont correctement représentés	Absence de disjoncteur idéal pour couvrir toute la gamme de spécifications
F.1.2	Essais à fréquence industrielle à pleine tension avec déformation limitée du courant (un essai avec un disjoncteur idéal ou un essai d'établissement est réalisable)	Ne tient pas compte des relations non linéaires qui peuvent exister dans le circuit d'essais, c'est-à-dire l'absence de relation linéaire entre le courant et la tension à une fréquence particulière (à ne pas confondre avec les influences des éléments du circuit qui dépendent du temps)	Absence de disjoncteur idéal pour couvrir toute la gamme de spécifications. L'obtention de la TTR exige des techniques de mesurage compliquées; sans cela, il est difficile d'interpréter les résultats en présence d'une importante composante à fréquence industrielle Pour des essais d'établissement, le dispositif le plus convenable est une inductance parfaite; autrement, un élément du circuit d'essais peut être utilisé lorsqu'il est disponible (par exemple résistance ou condensateur) L'utilisation de tels éléments est vraisemblablement encombrante et chère
F.1.3	Essais à fréquence industrielle à tension réduite avec un disjoncteur idéal sur un circuit d'essais par ailleurs non modifié (c'est-à-dire essais à excitation réduite)	Ne tient pas compte des relations non linéaires qui peuvent exister dans le circuit d'essais, c'est-à-dire l'absence de relation linéaire entre le courant et la tension à une fréquence particulière (à ne pas confondre avec les influences des éléments du circuit qui dépendent du temps)	Tant qu'un disjoncteur idéal couvrant la gamme complète des spécifications n'est pas disponible, le choix du disjoncteur idéal à utiliser est limité La synchronisation peut être difficile à réaliser dans les circuits utilisant plus d'un alternateur Il convient que l'excitation soit suffisante pour éviter la déformation de la forme d'onde N'est généralement pas possible dans une station d'essais alimentée par un réseau
F.1.4	Essais grandeur nature avec un disjoncteur courant	Difficultés de séparer les influences du disjoncteur des caractéristiques de la TTR enregistrées durant l'essai	Choix de disjoncteurs convenables comportant une faible tension d'arc, produisant une déformation négligeable du courant au passage par zéro, possédant un courant post-arc négligeable et sans impédance shunt Si on ne peut effectuer cela, on introduit des erreurs et il est possible d'observer un manque d'uniformité entre les stations d'essais par suite de l'utilisation de disjoncteurs ayant des caractéristiques différentes

Tableau F.1 *(suite)*

Méthode	Limites théoriques	Limites pratiques
F.2 Essais avec un disjoncteur idéal sur un circuit hors tension avec injection de courant à fréquence industrielle	Ne tient pas compte des relations non linéaires qui peuvent exister dans le circuit d'essais, c'est-à-dire l'absence de relation linéaire entre le courant et la tension à une fréquence particulière (à ne pas confondre avec les influences des éléments du circuit qui dépendent du temps)	Dans une station d'essais alimentée par un réseau, n'est applicable qu'à des éléments de circuit hors tension, par exemple les composantes constituant la ligne pour les défauts proches en ligne, ou si l'impédance du réseau est négligeable par rapport aux autres impédances du circuit d'essais Les alternateurs doivent être arrêtés pour éviter les tensions rémanentes La position du rotor peut avoir de l'importance s'il existe une différence considérable entre les réactances en phase et en quadrature Le temps de recouvrement inverse des diodes de coupure utilisées à la place d'un disjoncteur idéal, pouvant supporter le courant injecté à fréquence industrielle nécessaire pour l'essai, peut avoir de l'influence sur la TTR si celle-ci contient des composantes à haute fréquence, par exemple pour les circuits d'essais de défaut proche en ligne Les interférences induites dans le circuit d'essais hors tension provenant de sources extérieures peuvent avoir de l'influence sur la TTR si la tension d'essai est relativement faible par suite de la très faible réactance du circuit ou de la partie de circuit, par exemple comme pour les défauts proches en ligne
F.3 Essais avec un disjoncteur idéal sur un circuit hors tension avec injection de courant à une fréquence supérieure à la fréquence industrielle	Ne tient pas compte des relations non linéaires qui peuvent exister dans le circuit Ne fournit pas directement l'impédance à fréquence industrielle Donne la forme d'onde et les valeurs correctes de la TTR à partir du zéro des circuits à une et plusieurs fréquences mais seulement jusqu'au premier maximum, pourvu que la fréquence d'injection soit supérieure à la fréquence industrielle et bien inférieure à la fréquence de la TTR. Il n'est pas possible d'évaluer correctement le facteur d'amplitude	Dans une station d'essais alimentée par un réseau, n'est applicable qu'à des éléments de circuit hors tension, par exemple les composantes constituant la ligne pour les défauts proches en ligne, ou si l'impédance du réseau est négligeable par rapport aux autres impédances du circuit d'essais Les alternateurs doivent être arrêtés pour éviter les tensions rémanentes La position du rotor peut avoir de l'importance s'il existe une différence considérable entre les réactances en phase et en quadrature
F.4 Essais à l'aide de modèles de réseaux (analyseurs transitoires de réseaux)	Les données précises relatives aux caractéristiques non linéaires du réseau et dépendantes de la fréquence ne sont pas toujours disponibles Une connaissance exacte des éléments du circuit et de leurs paramètres parasites est nécessaire	Il est nécessaire de représenter de façon adéquate les éléments du circuit par les éléments de l'analyseur transitoire de réseau, y compris leurs caractéristiques non linéaires et dépendantes du temps

Tableau F.1 *(suite)*

Méthode	Limites théoriques	Limites pratiques
F.5 Calcul d'après les paramètres du circuit	Les données précises relatives aux caractéristiques non linéaires du réseau et dépendantes de la fréquence ne sont pas toujours disponibles Une connaissance exacte des éléments du circuit et de leurs paramètres parasites est nécessaire	Si l'impédance du réseau n'est pas négligeable par rapport à l'impédance de la station d'essais, il est nécessaire de connaître complètement les conditions correspondantes du réseau à l'instant de l'essai Représentation précise ou adéquate des éléments du circuit, y compris leurs caractéristiques non linéaires et dépendantes du temps, en particulier de leurs paramètres parasites
F.6 Manœuvre à vide des transformateurs d'essais	Des corrections sont nécessaires pour le front de l'onde de tension à fréquence industrielle, à moins que les transformateurs ne soient mis sous tension à la crête de l'onde de tension ou près de celle-ci	Exige le circuit réel des essais de court-circuit Applicable seulement aux circuits à une seule fréquence



u_c = valeur de crête de la TTR spécifiée

u_{cp} = TTR mesurée avec la réduction de la tension

u_1 = valeur de crête de la tension à fréquence industrielle sans réduction de la tension

Figure F.1 – Influence de la réduction de la tension sur la valeur de crête de la TTR

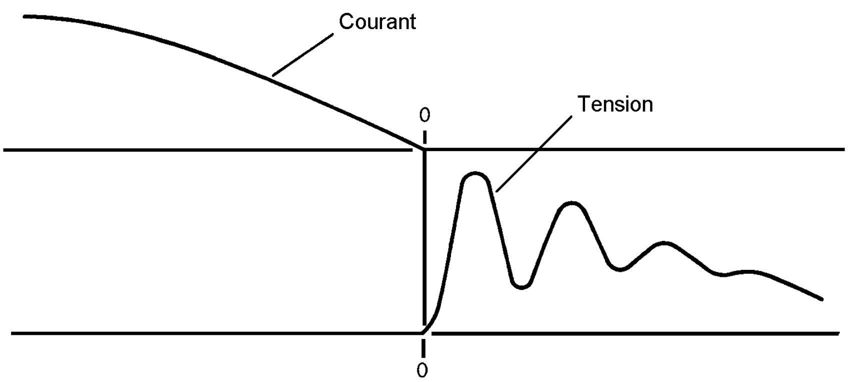


Figure F.2 – TTR pour une coupure idéale

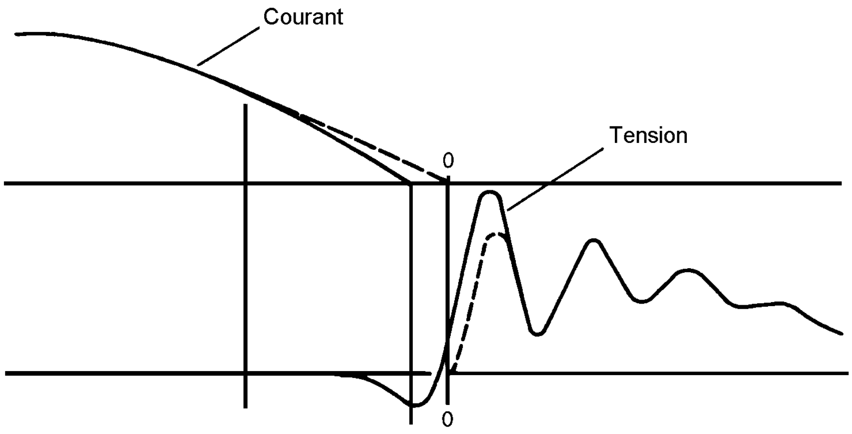


Figure F.3 – Coupure avec présence d'une tension d'arc

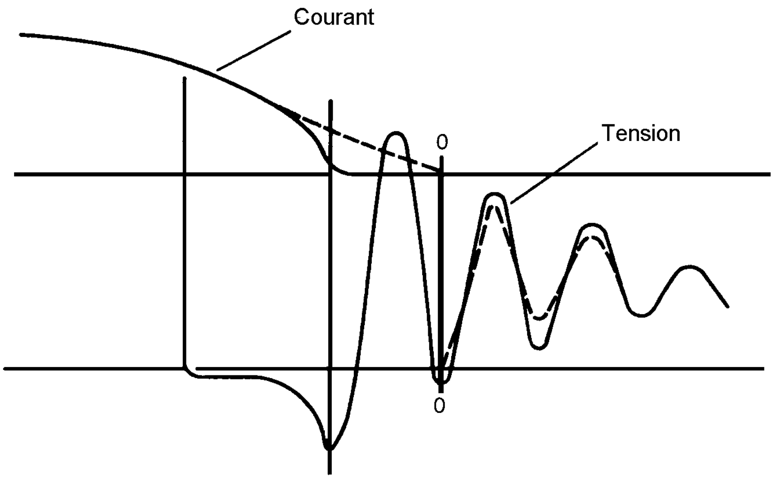


Figure F.4 – Coupure avec arrachement prononcé du courant

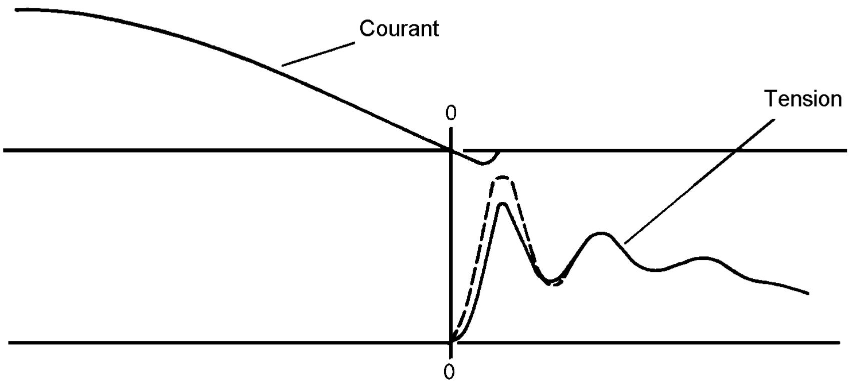
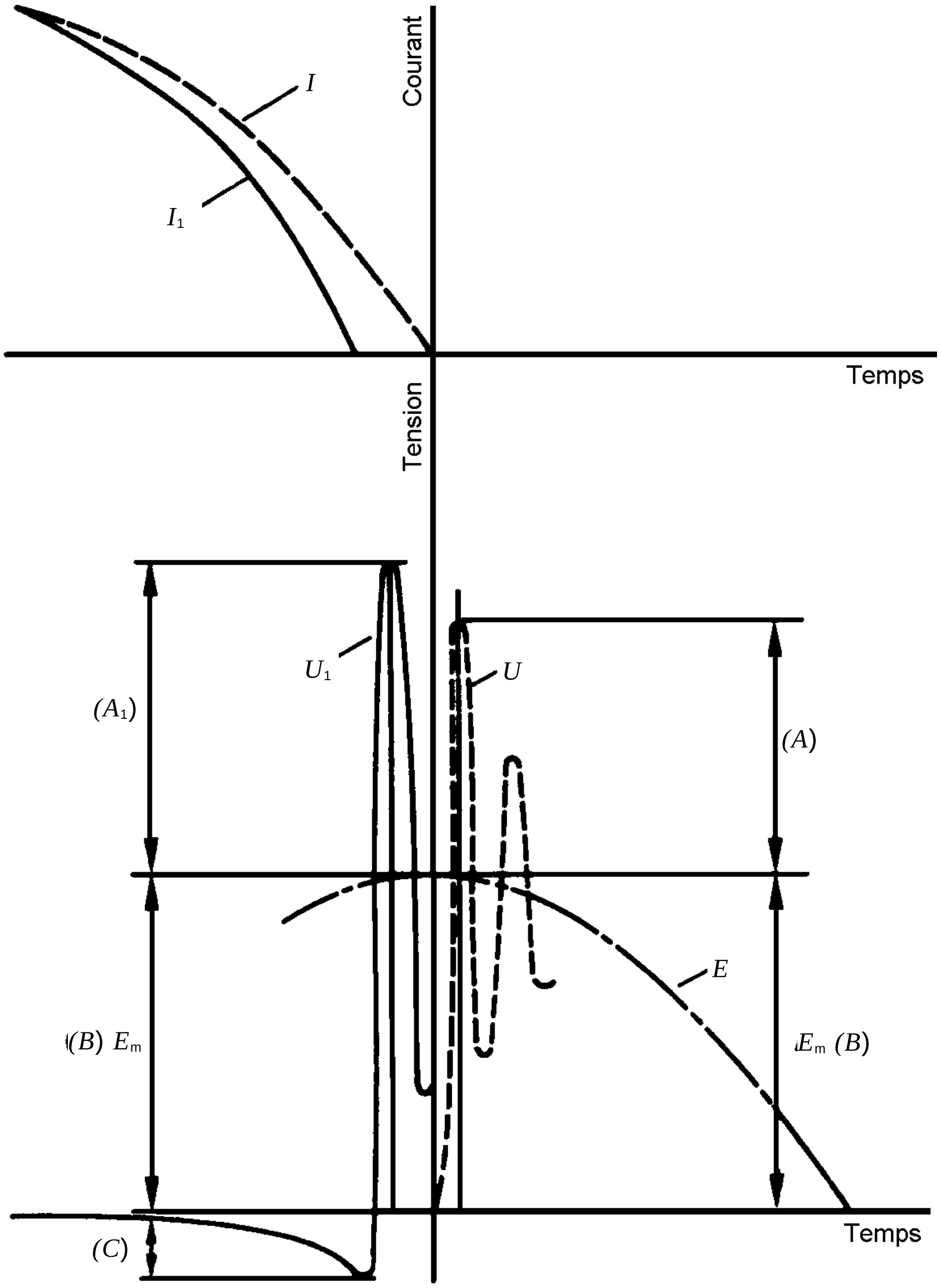


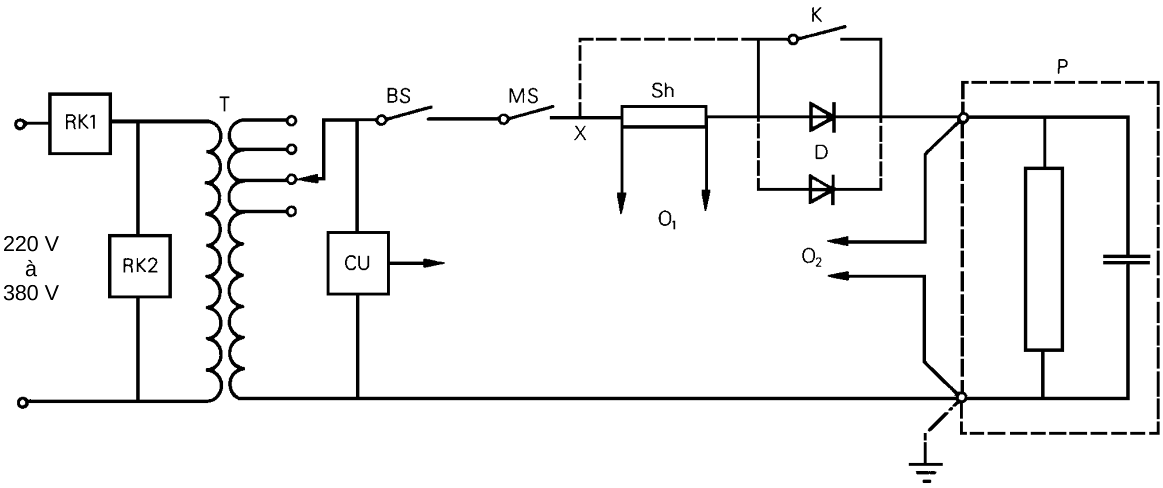
Figure F.5 – Coupure avec courant post-arc

NOTE Influence de l'arc, de l'arrachement du courant et de la conductibilité post-arc sur la tension transitoire de rétablissement. Les lignes tiretées représentent dans les Figures F.3 à F.5 l'allure de la courbe dans le cas de la coupure idéale.



I_1, U_1	=	courant et tension, respectivement obtenus en essai
I, U	=	courant et tension, respectivement, présumés du réseau
E	=	tension de rétablissement à fréquence industrielle
$A+B=A_1\dfrac{B}{B+C}+B$	=	valeur de crête de la tension transitoire de rétablissement

Figure F.6 – Relation entre les valeurs du courant et de la TTR apparaissant lors de l'essai, et les valeurs présumées du réseau



RK1, RK2 = si nécessaire, circuits résonants séries et parallèles en vue de la suppression des harmoniques

T = transformateur isolant le circuit d'injection de l'alimentation et fournissant une tension de sortie réglable

BS = interrupteur de protection

MS = interrupteur pour l'établissement du courant

K = interrupteur court-circuitant la diode

X = en variante, connexion pour K permettant l'utilisation d'un shunt comportant une caractéristique nominale temps-courant relativement faible

D = montage en parallèle de diodes au silicium à coupure rapide (jusqu'à cinq diodes)

Sh = shunt de mesure du courant

O_1 = oscillographe cathodique, première piste utilisée pour enregistrer l'amplitude à la linéarité du courant ainsi que pour contrôler le fonctionnement de la diode

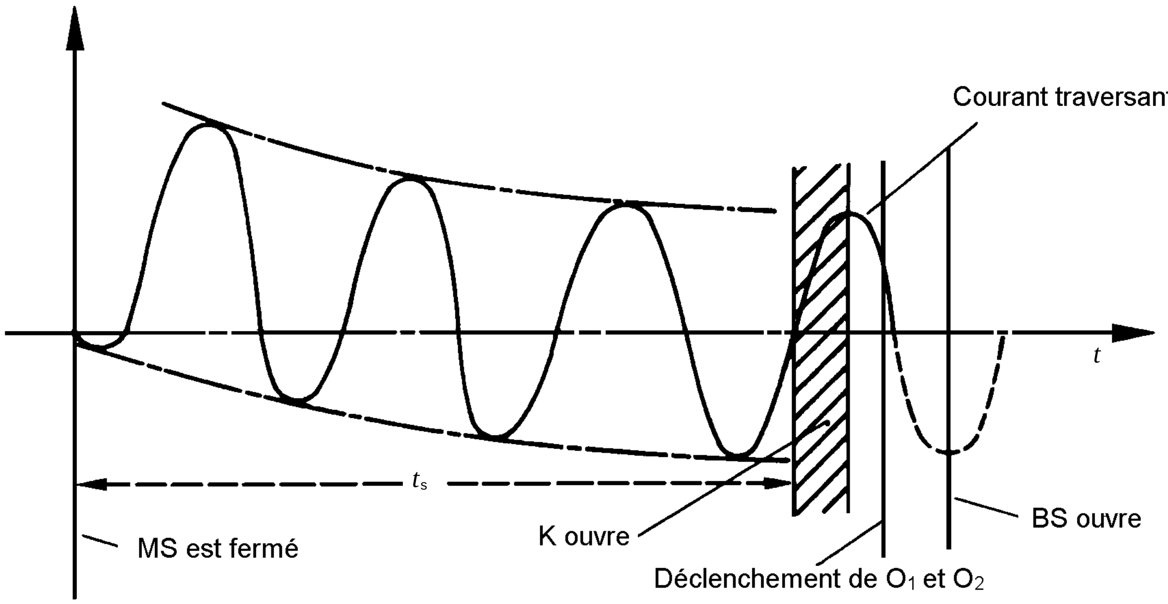
O_2 = oscillographe cathodique, seconde piste enregistrant la réponse du circuit d'essai

P = circuit dont on mesure la TTR présumée

CU = élément de commande fournissant la séquence de manœuvres indiquée sur la Figure F.8

NOTE Le mesurage du courant injecté peut également être effectué au potentiel de la terre.

Figure F.7 – Schéma de l'appareil d'injection de courant à fréquence industrielle



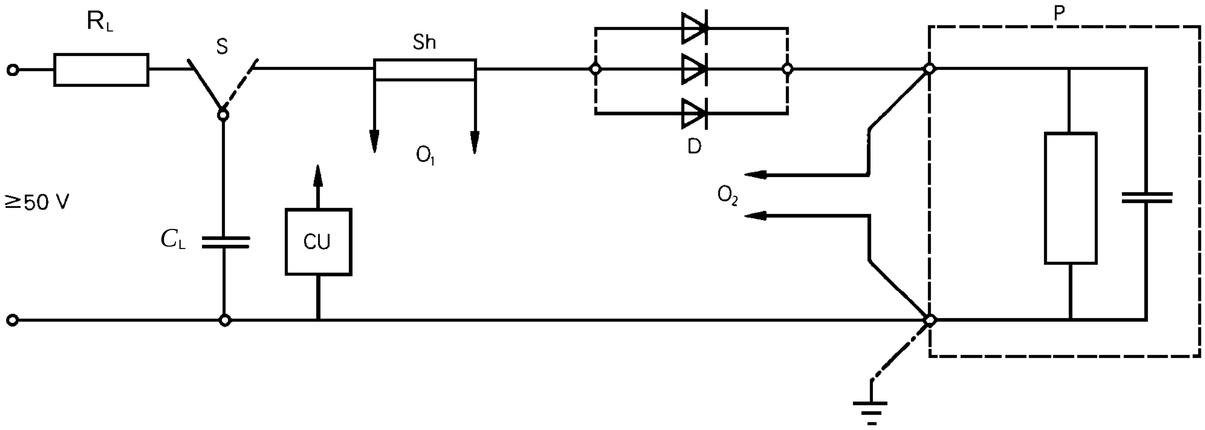
Au repos: BS et K sont en position de fermeture, MS est en position d'ouverture.

t_s = temps de passage du courant avant le fonctionnement de l'interrupteur K

Valeurs types comprises entre 10 et 20 périodes du courant injecté.

Le principal critère est que la composante apériodique du courant, si elle existe, ait une décroissance telle qu'elle devienne inférieure à 20 % de la composante périodique.

Figure F.8 – Séquence de manœuvres de l'appareil d'injection de courant à fréquence industrielle



R_L = résistance de charge

S = relais de commutation

C_L = condensateur constituant la source

NOTE 1 Quand le condensateur C_L chargé est relié au circuit P par l'intermédiaire du relais S, un courant de forme oscillatoire de fréquence f_1 circule. Il est recommandé de régler la valeur de C_L de telle façon que:

$f_i \leq \dfrac{f_e}{8}$, où f_e est la fréquence propre du circuit P, $f_e = \dfrac{1}{2T_e / 2}$

la valeur de f_i doit être telle qu'elle assure la disparition des oscillations qui se superposent au courant avant le passage à zéro de ce dernier.

Sh = shunt de mesure du courant

O_1 = oscillographe cathodique, première piste utilisée pour enregistrer l'amplitude à la linéarité du courant ainsi que pour contrôler le fonctionnement de la diode

O_2 = oscillographe cathodique, seconde piste enregistrant la réponse du circuit d'essai

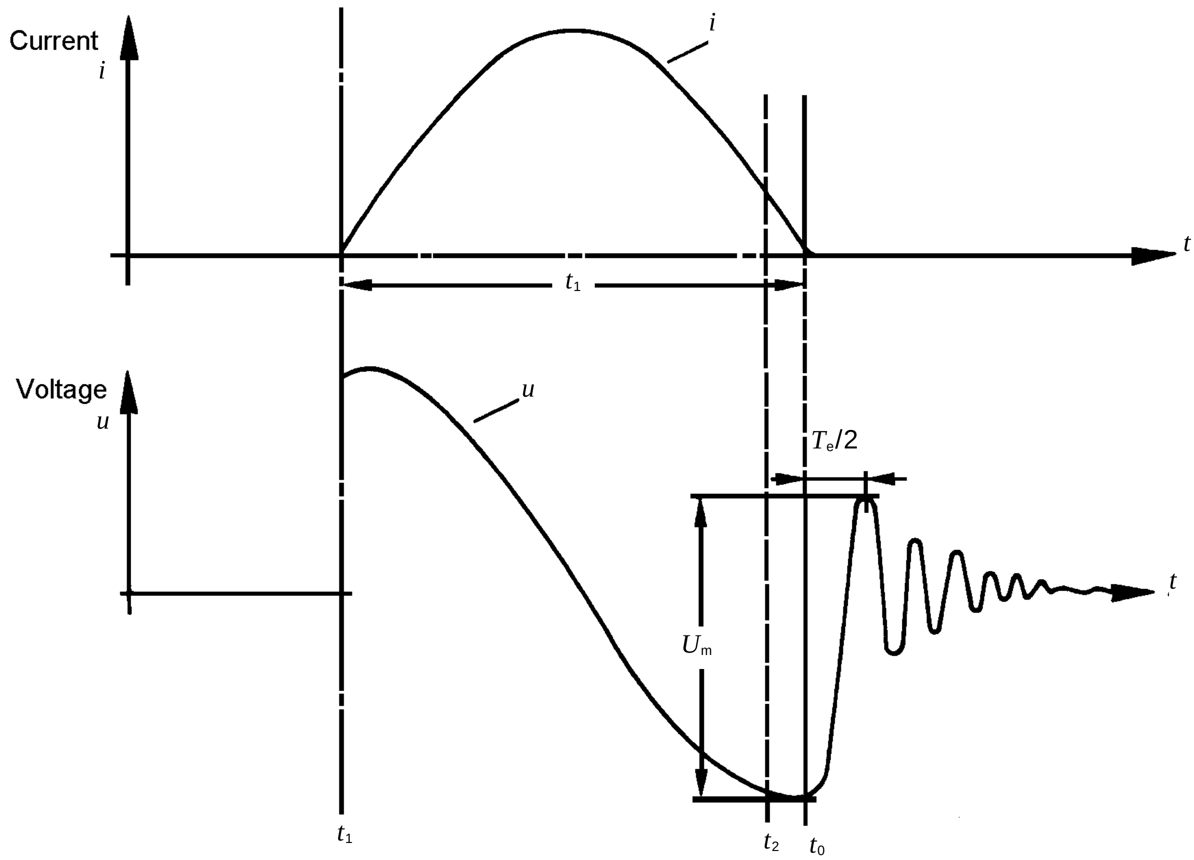
D = montage en parallèle de diodes au silicium à coupure rapide (jusqu'à 100 diodes)

P = circuit dont on mesure la TTR présumée

CU = élément de commande fournissant la séquence de manœuvres indiquée à la Figure F.10

NOTE 2 Le mesurage du courant injecté peut également être effectué au potentiel de la terre.

Figure F.9 – Schéma de l'appareillage d'injection par condensateur



t_1	=	commutation de S
t_2	=	déclenchement de l'oscillographe
u	=	courbe de la tension aux bornes du circuit P
i	=	forme de l'onde du courant injecté
U_m	=	valeur maximale de la tension qui peut être appliquée aux diodes
t_0	=	passage par zéro du courant (commencement de l'oscillation de la TTR)
t_i	=	durée du courant à travers la diode D, $f_i = \dfrac{1}{2t_i}$
$\dfrac{T_e}{2}$	=	durée d'une demi-période de la TTR

Figure F.10 – Séquence de manœuvres de l'appareil d'injection par condensateur

Annexe G
(normative)

Raison d'être de l'introduction de disjoncteurs de classe E2

On remarquera que l'introduction des disjoncteurs de classe E2 est limitée aux disjoncteurs de distribution. Il existe déjà, dans cette norme, des cas où des essais sont limités à certaines gammes de tensions; il ne devrait donc pas y avoir de problème à ajouter l'essai d'endurance électrique uniquement pour des disjoncteurs dont la tension assignée est inférieure ou égale à 52 kV.

La plupart des disjoncteurs fabriqués actuellement sont du type scellé ou à pression autonome, ne prévoyant qu'un appoint de gaz (s'il y a lieu), mais pas d'entretien interne. Il n'est pas nécessaire que les disjoncteurs traditionnels satisfassent aux exigences d'entretien réduit mais l'utilisateur peut vouloir (et dans beaucoup de cas il le voudra) spécifier, pour de bonnes raisons économiques, un disjoncteur de classe E2.

De ce fait, il y a deux possibilités: soit d'utiliser un disjoncteur dont les parties internes peuvent être entretenues et l'entretenir comme nécessaire pendant toute sa durée de vie, soit d'utiliser un disjoncteur de classe E2 mais exiger un régime d'essai plus sévère pour contrôler ses performances.

L'essai d'endurance électrique proposé pour les réseaux de câbles est une série complète des séquences d'essai T10 à T100a sans entretien intermédiaire. Il est quasi certain que tous les disjoncteurs de distribution du type scellé sous SF_6 ou sous vide ont été essayés ainsi depuis de nombreuses années. Aucun essai supplémentaire n'est donc demandé en plus des essais de type en court-circuit normaux.

Pour les réseaux aériens, l'essai standard doit être effectué séparément. L'essai supplémentaire proposé s'appuie sur une exigence d'utilisateurs, basée sur des statistiques d'expérience en service.

Il convient d'être prudent en comparant différents programmes d'essais. La relation entre courant et érosion (des contacts) n'est pas aussi simple qu'il puisse paraître.

Finalement, il convient de noter que les essais supplémentaires sont optionnels, à la demande de l'utilisateur, pour convenir à ces applications.

Annexe H
(informative)

Courants d'appel des batteries de condensateurs simples et à gradins

H.1 Généralités

La mise sous tension d'une batterie de condensateurs par fermeture d'un disjoncteur produit des phénomènes transitoires dus à la charge des condensateurs. La charge oscillante provoque une surintensité (courant d'appel) dont l'amplitude et la fréquence sont fonctions du réseau, des caractéristiques de la batterie et de l'instant de la fermeture du circuit. L'amplitude et la forme d'onde du courant d'appel sont fonctions de la tension appliquée, des capacités du circuit, des valeurs et de la localisation des inductances du circuit, des charges des condensateurs à l'instant de fermeture et de l'amortissement des phénomènes transitoires de manœuvre. Les calculs de courant d'appel sont faits habituellement avec l'hypothèse que la batterie de condensateurs n'a aucune charge initiale et que le circuit est fermé à l'instant qui entraîne le courant d'appel maximal.

Lors de l'enclenchement d'une batterie de condensateurs préchargée, le courant d'appel peut être plus élevé que lors de l'enclenchement d'une batterie non chargée. Une estimation du facteur d'accroissement du courant peut être obtenue par le rapport suivant:

$$\frac{\text{variation de tension sur une batterie préchargée lors de la mise sous tension}}{\text{variation de tension sur une batterie non chargée lors de la mise sous tension}}$$

Il convient de noter que des disjoncteurs qui réamorcent peuvent aussi imposer des contraintes sévères sur les condensateurs.

Le courant d'appel peut être calculé lorsqu'on connaît les impédances du réseau. La Figure H.3 montre les trois différents cas de couplage d'une batterie de condensateurs quand zéro, un et n gradins respectivement sont déjà connectés au jeu de barres.

Normalement, les calculs simplifiés des Figures H.3b) et H.3c) sont acceptables.

Quand deux ou plusieurs batteries de condensateurs sont connectées très près les unes des autres et que les inductances de liaison sont faibles, il peut être nécessaire, tant pour le condensateur que pour le disjoncteur, de réduire l'amplitude du courant d'appel en insérant des impédances en série avec les condensateurs.

En pratique, l'inductance est calculée en prenant pour principe que la valeur de crête du courant d'appel résultante est inférieure à ce qui est indiqué par les valeurs préférentielles du Tableau 9. Il convient aussi de dimensionner l'inductance, afin de réduire la fréquence du courant d'appel en dessous des valeurs préférentielles indiquées au Tableau 9 (4 250 Hz).

Dans la première édition précédente de la CEI 62271-100, la règle d'équivalence entre les essais réalisés et les conditions de service était fondée sur le produit "$i_{\text{max peak}} \times f_{\text{inrush}}$", $i_{\text{max peak}}$ représentant la valeur de crête du courant d'appel et f_{inrush} représentant la fréquence du courant d'appel. Des calculs récents ont montré que l'énergie d'arc au cours d'une manœuvre d'établissement est indépendante de la fréquence du courant d'appel lorsque la durée de préarc est supérieure à la moitié d'une période de la fréquence du courant d'appel, ce qui est habituel pour l'établissement et la coupure de batteries de condensateurs à gradins. Pour l'établissement et la coupure de batteries de condensateurs à gradins, l'énergie d'arc au cours d'une manœuvre d'établissement dépend uniquement de la valeur de crête du courant d'appel. D'autre part, il est bien connu que la forme de l'usure sur les contacts d'arc ainsi que l'effet des ondes de choc dépendent quelque peu de la fréquence et qu'il convient de les prendre en compte. Par suite, une tolérance supérieure de +130 % a été spécifiée sur la fréquence du courant d'appel admissible pouvant être utilisée en service. En d’autres termes, il convient que la fréquence du courant d’appel utilisée au cours des essais ne soit pas inférieure à 77 % de la fréquence du courant d’appel prévue en service. Ce concept est limité à une fréquence du courant d’appel allant jusqu’à 6 000 Hz, étant donné que les informations disponibles pour des fréquences plus élevées sont réduites.

Deux exemples de calcul sont décrits dans les Articles H.2 et H.3.

H.2 Exemple 1 – Manœuvre d’un condensateur en parallèle (voir Figure H.1)

H.2.1 Description des batteries de condensateurs à manœuvrer

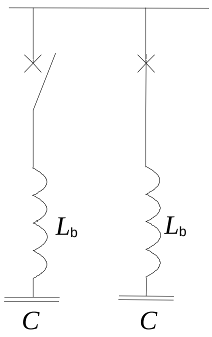


Figure H.1 – Diagramme du circuit de l’exemple 1

- tension assignée U_r = 145 kV
- fréquence assignée f_r = 50 Hz
- puissance d’un gradin de condensateurs Q_b = 16 Mvar (trois phases à 126 kV eff.)
- longueur totale des connexions entre gradins l = 40 m
- inductance par longueur L' = 1 µH/m

A partir de ces valeurs, on peut calculer la capacité C et l’inductance L_b:

C = 3,2 µF et L_b = 20 µH

H.2.2 Calcul sans dispositif de limitation

On calcule la crête du courant d’appel $\hat{\imath}$ et sa fréquence f_{ib} à partir des équations de la Figure H.3:

$$\hat{\imath} = U_r \sqrt{\frac{C}{6L_b}} = 145 \times 10^3 \sqrt{\frac{3{,}2 \times 10^{-6}}{6 \times 20 \times 10^{-6}}} = 23{,}7 \times 10^3 \text{ A} = 23{,}7 \text{ kA}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{L_b C}} = \frac{1}{2\pi\sqrt{3{,}2 \times 10^{-} \quad \times 20 \times 10^{-}}} = 19\,900 \text{ Hz}$$

Ces valeurs sont bien supérieures aux valeurs assignées du disjoncteur, s'il est soumis aux essais conformément aux valeurs préférentielles données au Tableau 9. Par conséquent, il faut utliser certains dispositifs de limitation . Dans certains cas, la seconde batterie peut être déjà totalement chargée en polarité opposée lorsque le pré-amorçage se produit à la fermeture du disjoncteur. La valeur de $\hat{\imath}$ est alors doublée.

H.2.3 Calcul du dispositif de limitation

Il convient que l'inductance L_a à ajouter sur le jeu de barres dans chaque alimentation de condensateur soit telle que les valeurs de crête et de fréquence du courant d'appel soient en dessous des valeurs préférentielles indiquées au Tableau 9 (20 kA et 4 250 Hz, dans les tolérances exigées).

Les équations suivantes sont applicables pour calculer le courant d'appel et la fréquence :

$$\hat{i} = U_r \sqrt{\frac{C}{6(L_b + L_a)}} \leq 20\,\text{kA crête} \quad \text{et} \quad f_{ib} = \frac{1}{2\pi\sqrt{(L_b + L_a)C}} \leq 4\,250\,\text{Hz} \times 1{,}3$$

D'après les équations ci-dessus, il convient que L_a soit ≥ 8,0 µH, afin d'obtenir une valeur de crête du pouvoir de fermeture ≤ 20 kA, et que L_a soit ≥ 239 µH, afin d'obtenir une fréquence du courant d'appel inférieure à 5 525 Hz (130 % de 4 250 Hz). Ainsi, il convient que L_a soit ≥ 239 µH, afin de satisfaire aux critères relatifs à la fréquence du courant d'appel. Avec une telle valeur d'inductance, la valeur de crête du courant d'appel résultante sera de 6,6 kA et la fréquence du courant d'appel sera de 5 525 Hz. Ces valeurs sont bien en conformité avec les capacités du disjoncteur, s'il est soumis aux essais conformément aux valeurs préférentielles données au Tableau 9, même si la seconde batterie est totalement pré-chargée en polarité opposée lorsque le pré-amorçage se produit à la fermeture du disjoncteur.

H.3 Exemple 2 – Manœuvre de deux condensateurs en parallèle (voir Figure H.2)

H.3.1 Description des batteries de condensateurs à manœuvrer

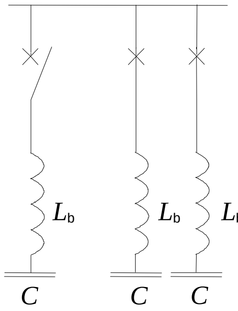


Figure H.2 – Diagramme du circuit de l'exemple 2

– tension assignée U_r = 24 kV

– fréquence assignée f_r = 50 Hz

– puissance d'un gradin de condensateurs Q_b = 5 Mvar (trois phases à 22 kV eff.)

– longueur de chaque connexion entre gradins l = 5 m

– inductance par longueur L' = 1 µH/m

De ces valeurs, on peut calculer la capacité C et l'inductance L_b.

C = 32,9 µF et L_b = 5 µH

H.3.2 Calcul sans dispositif de limitation

On calcule la crête du courant d'appel $\hat{i}$ et sa fréquence f_{ib} à partir des équations de la Figure H.3:

$$\hat{i} = U_r \frac{n}{n+1}\sqrt{\frac{2C}{3L_b}} = 24\times 10^3 \times \frac{2}{3}\sqrt{\frac{2\times 32{,}9\times 10^{-6}}{3\times 5\times 10^{-6}}} = 33{,}5\times 10^3\ \text{A} = 33{,}5\ \text{kA}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{L_b C}} = \frac{1}{2\pi\sqrt{32{,}9\times 10^{-6}\times 5\times 10^{-6}}} = 12\,400\ \text{Hz}$$

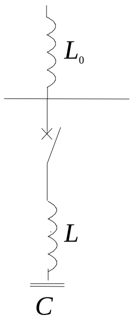
Ces valeurs sont bien supérieures aux valeurs assignées du disjoncteur, s'il est soumis aux essais conformément aux valeurs préférentielles données au Tableau 9. Par conséquent, il faut utiliser certains dispositifs de limitation. Dans certains cas, la ou les batteries de condensateurs déjà en service peuvent être totalement chargées à la polarité opposée lorsque le préamorçage se produit dans le disjoncteur qui ferme. La valeur de $\hat{\imath}$ est alors doublée.

H.3.3 Calcul du dispositif de limitation

Il convient que l'inductance L_a à ajouter sur le jeu de barres dans chaque alimentation de condensateur soit telle que les valeurs de crête et de fréquence du courant d'appel soient en dessous des valeurs préférentielles indiquées au Tableau 9 (20 kA et 4 250 Hz, dans les tolérances exigées).

$$\hat{i} = U_r \frac{n}{n+1}\sqrt{\frac{2C}{3(L_b + L_a)}} \le 20\ \text{kA crête} \quad \text{et} \quad f_{ib} = \frac{1}{2\pi\sqrt{(L_b + L_a)C}} \le 4\,250\ \text{Hz} \times 1{,}3$$

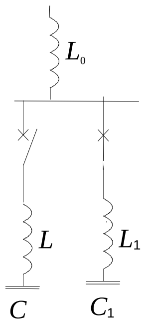
D'après les équations ci-dessus, il convient que L_a soit ≥ 9,0 µH, afin d'obtenir une valeur de crête du pouvoir de fermeture ≤ 20 kA, et que L_a soit ≥ 20,2 µH, afin d'obtenir une fréquence du courant d'appel inférieure à 5 525 Hz (130 % de 4 250 Hz). Ainsi, il convient que L_a soit ≥ 20,2 µH, afin de satisfaire aux critères relatifs à la fréquence du courant d'appel. Avec une telle valeur d'inductance, la valeur de crête du courant d'appel résultante sera de 14,9 kA et la fréquence du courant d'appel sera de 5 525 Hz. Ces valeurs sont bien en conformité avec les capacités du disjoncteur, s'il est soumis aux essais conformément aux valeurs préférentielles données au Tableau 9. Il convient de porter une attention particulière aux cas où la dernière batterie à mettre sous tension est totalement préchargée à la polarité opposée lorsque le pré-amorçage se produit dans le disjoncteur qui ferme. Si une telle situation est probable, il convient d'augmenter à nouveau la valeur de L_a, afin de limiter la valeur de crête du courant d'appel en dessous de la valeur en essai.



a) Connexion d'un seul gradin

$$\hat{\imath} = U_r \sqrt{\frac{2}{3}\frac{C}{L_0 + L}} \approx U \sqrt{\frac{2}{3}\frac{C}{L_0}} \qquad L_0 >> L$$

$$f_{ib} = \frac{1}{2\pi\sqrt{C(L_0 + L)}} \approx \frac{1}{2\pi\sqrt{CL_0}}$$



b) Connexion alors qu'un gradin est déjà connecté

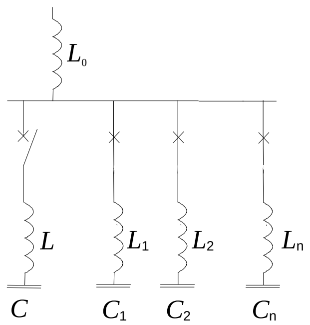
$$\hat{\imath} = U_r \sqrt{\frac{2}{3}\frac{C_1 C}{(C_1 + C)} \times \frac{1}{(L_1 + L)}}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{\frac{C_1 C}{(C_1 + C)}(L_1 + L)}}$$

$$S = \frac{U_r}{L_1 + L}\sqrt{\frac{2}{3}}$$

Si $L_1 = L$ et $C_1 = C$ alors:

$$\hat{\imath} = U_r \sqrt{\frac{C}{6L}} \text{ et } f_{ib} = \frac{1}{2\pi\sqrt{LC}}$$



c) Connexion alors que n gradins sont déjà connectés

$$L'' = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \cdots \frac{1}{L_n}} \text{ et } C'' = C_1 + C_2 + \cdots C_n$$

Si $L_1 = L_2 = ... = L_n = L$ et $C_1 = C_2 = ... = C_n = C$, alors

$$L'' = \frac{L}{n} \text{ et } C = nC$$

$$\hat{\imath} = U_r \frac{n}{n+1}\sqrt{\frac{2C}{3L}} \text{ et } f_{ib} = \frac{1}{2\pi\sqrt{LC}}$$

L' et C' remplacent L_1 et C_1 dans la Figure H.3.b).

Le calcul est valable si $L_1 \times C_1 = L_2 \times C_2 = L_n \times C_n$ et n'est qu'approximatif dans les autres cas.

Composants

U_r tension assignée

$\hat{\imath}$ crête du courant d'appel

f_{ib} fréquence du courant d'appel

S vitesse d'accroissement du courant d'appel

$\boldsymbol{L_0}$ inductance de la source

$\boldsymbol{L}$ inductance en série avec le gradin de condensateur à enclencher

C capacité du gradin à enclencher (valeur étoile équivalente)

L_1, L_2... L_n inductances en série avec les gradins de condensateurs du côté de la source

C_1, C_2... C_n capacités des gradins (valeur étoile équivalente) du côté de la source

Figure H.3 – Equations pour le calcul des courants d'appel de gradins de condensateurs

Annexe I
(informative)

Notes explicatives

I.1 Généralités

Les notes explicatives sont regroupées dans cette annexe jusqu'à la parution du guide d'application de la présente norme.

I.2 Note explicative concernant la constante de temps de la composante apériodique du pouvoir de coupure assigné en court-circuit (4.101.2) – Conseils pour le choix de la constante de temps appropriée

I.2.1 Conseils pour le choix judicieux de la constante de temps

La constante de temps apériodique de 45 ms est adéquate pour la majorité des cas réels, sauf pour les tensions assignées supérieures à 800 kV pour lesquelles la constante de temps apériodique normale est de 120 ms. Des constantes de temps pour cas spéciaux, liées à la tension assignée du disjoncteur, doivent couvrir les cas où la constante de temps de 45 ms n'est pas suffisante. Cela peut s'appliquer, par exemple, aux systèmes de très haute tension assignée (par exemple la tension de 800 kV avec une valeur de X/R de ligne supérieure), ou aux quelques systèmes de moyenne tension de structure radiale ou à tout système ayant une structure de réseau particulière ou des caractéristiques de lignes particulières. Ces constantes de temps pour cas spéciaux ont été définies, prenant en compte les résultats de l'enquête CIGRÉ WG13.04 (I.2.2).

Quand une valeur optionnelle de constante de temps est choisie, les considérations suivantes devraient être prises en compte:

a) Les constantes de temps indiquées par cette norme ne sont valides que pour les courants de défaut triphasés. Les constantes de temps pour les courants de défaut phase – terre sont plus faibles que pour les courants de défaut triphasés.

b) Pour les courants d'asymétrie maximale, l'initiation du courant de court-circuit doit se produire à un zéro de tension du système au moins sur une phase.

c) La constante de temps est liée au courant de court-circuit maximal assigné du disjoncteur. Si, par exemple, une constante de temps supérieure à 45 ms est attendue mais avec un courant de court-circuit plus faible que celui assigné, un tel cas peut être couvert par le courant de court-circuit asymétrique assigné avec une constante de temps de 45 ms.

d) La constante de temps du système complet est un paramètre dépendant du temps que l'on prend égal à une constante dérivée de la décroissance des courants de court-circuit dans les différentes branches du système et n'est pas une réelle et unique constante de temps.

e) Différentes méthodes pour le calcul de la constante de temps de la composante apériodique sont utilisées, les résultats différant considérablement. Il convient de prendre des précautions pour choisir la méthode de calcul.

f) Quand une constante de temps est choisie, il faut se rappeler que le disjoncteur est contraint par le courant asymétrique après la séparation des contacts. L'instant de la séparation de contacts correspond à la somme du temps d'ouverture du disjoncteur et du temps de réaction du relais. Dans la présente norme, on considère seulement un temps relais d'un demi-cycle. Il convient de tenir compte du temps de protection si celui-ci est plus long.

I.2.2 Composante apériodique pendant les essais T100a

Avec l'introduction de constantes de temps pour des applications particulières dans l'édition 1.0 de la CEI 62271-100, les paramètres essentiels avec leurs tolérances respectives qu'il convient de respecter durant les essais de coupure de défauts asymétriques ont besoin d'être définis de façon à:

– être en mesure de réaliser des essais asymétriques avec un circuit d'essai ayant une constante de temps de la composante apériodique différente de la constante de temps assignée du pouvoir de coupure assigné en court-circuit, étant donné que les laboratoires ne sont pas capables d'ajuster la constante de temps de la composante apériodique du circuit d'essai. Pour les essais directs, lorsque la constante de temps de la composante apériodique du circuit d'essai est plus grande que la constante de temps assignée du pouvoir de coupure assigné en court-circuit, le d*i*/d*t* et la crête de la TTR résultants sont inférieurs à ceux qui seraient obtenus dans des conditions de service. La situation inverse est aussi vraie, principalement avec l'introduction dans l'édition 1.0 de constantes de temps de la composante apériodique pour des applications particulières (60 ms, 75 ms et 120 ms);
– être en mesure d'utiliser les résultats obtenus à partir d'un essai spécifique, afin de couvrir plus d'une valeur assignée de constante de temps de la composante apériodique. Ce concept d'équivalence de l'asymétrie peut aussi aider l'utilisateur à établir une équivalence entre les besoins du réseau et les exigences relatives aux valeurs assignées.

Beaucoup de calculs ont permis de confirmer que le concept antérieur de composante apériodique à la séparation des contacts (par exemple dans la CEI 60056 et la première édition de la CEI 62271-100) entraîne des contraintes au cours des essais (y compris des coupures sur la petite et la grande alternances) différentes de celles prévues dans des conditions de service. Ceci explique pourquoi la CEI 62271-308 a été publiée et est à présent intégrée dans cette nouvelle édition de la CEI 62271-100.

La seule façon d'obtenir cette équivalence est d'introduire le concept de la composante apériodique au zéro du courant. Ce concept est déjà appliqué dans la CEI 62271-101.

La composante apériodique maximale présumée au zéro du courant requise durant les essais est déterminée en utilisant la composante apériodique donnée pour l'alternance de courant complète subséquente à la durée minimale de coupure.

Les valeurs données aux Tableaux 15 à 22 sont obtenues à partir d'une onde de courant pleinement asymétrique correspondant à la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit. Pour les valeurs relatives à une grande onde de courant, l'amplitude, la durée, le pourcentage de composante apériodique au zéro du courant et le d*i*/d*t* correspondant pour les valeurs de la grande alternance sont celles qui correspondent à la valeur la plus élevée possible de la gamme de durée minimale de coupure. Pour les valeurs relatives à une petite alternance de courant, l'amplitude, la durée, le pourcentage de composante apériodique au zéro du courant et le d*i*/d*t* correspondant sont celles de la petite alternance de courant correspondant à une durée d'arc juste supérieure à la gamme de durée minimale de coupure.

Les paramètres concernés par les critères généraux d'équivalence sont:

a) l'amplitude de la dernière alternance de courant;
b) la durée de la dernière alternance de courant avant coupure;
c) la durée d'arc;
d) le d*i*/d*t* au zéro du courant;
e) les tensions crêtes de la TTR, forme d'onde.

Les deux premiers points sont liés à l'énergie d'arc.

Pour obtenir l'équivalence selon ce concept, il peut être requis de modifier quelques tolérances; par exemple, il convient que la tolérance réelle (0 %, +10 %) de la valeur symétrique du courant d'essai soit assouplie pour toutes valeurs situées entre + 10 % et – 10 %, de façon à être en mesure d'ajuster l'amplitude et la durée de la dernière alternance du courant aux valeurs demandées. Pour certains cas, il peut être nécessaire de diminuer ou d'augmenter ces valeurs par rapport à la valeur assignée du courant de court-circuit symétrique.

Avec cette procédure, selon les paramètres d'essais réels, un essai spécifique peut couvrir plusieurs valeurs assignées si les critères d'asymétrie applicables pour chaque valeur assignée, avec leurs tolérances respectives, sont respectés.

L'Annexe Q donne quelques lignes directrices sur la façon d'utiliser les critères d'asymétrie.

I.3 Notes explicatives relatives aux essais de commutation de courants capacitifs (6.111)

I.3.1 Caractéristique de réamorçage

Etant donné qu'il existe une probabilité de réamorçage en service pour tous les disjoncteurs, il est impossible de définir un disjoncteur sans réamorçage. Au lieu de cela, il semble plus logique d'introduire la notion de caractéristique de réamorçage en cours de service.

Le niveau de probabilité de réamorçage dépend aussi des conditions d'utilisation (coordination d'isolation, nombre de manœuvres annuelles, politique d'entretien adoptée par l'utilisateur, etc.). Il est donc impossible d'introduire un niveau de probabilité commun en termes de conditions d'utilisation.

On a donc réparti les disjoncteurs en deux catégories selon leur caractéristique de réamorçage: la classe C1 et la classe C2.

I.3.2 Programme d'essais

Pour définir le programme d'essais de ces deux classes, les éléments suivants ont èté pris en compte:

– le nombre moyen de manœuvres annuelles assurées par les charges capacitives de commutation des disjoncteurs,
– l'aptitude à réduire le nombre d'essais en effectuant un plus grand nombre de manœuvres de commutation à la durée d'arc minimale, en général la commutation capacitive la plus difficile pour les disjoncteurs, permettant de maintenir un niveau élevé de fiabilité.

La probabilité de réamorçage espérée est exclusivement liée aux essais de types. En raison de la sévérité de ces essais de types, on peut s'attendre à une amélioration de la caractéristique de commutation en service.

Il est possible de remettre en cause le nombre d'essais proposé, en raison de la diversité des hypothèses adoptées pour les calculs. Toutefois, ces valeurs représentent un compromis convenable (ce qui est le rôle de la norme lorsque des points de vue s'opposent) qui reflète les besoins des utilisateurs et qui par dessus tout évite toute demande irréaliste. Ces essais ne sont pas des épreuves de fiabilité mais des essais de type destinés à établir, en termes satisfaisants, la capacité de commutation en courant capacitif des équipements en service.

I.3.3 A propos du Tableau 9

Le Tableau 9 n'envisage pas tous les cas réels de commutation en courant capacitif. Les valeurs données pour les lignes et les câbles couvrent la plupart des cas, les valeurs du courant pour les batteries de condensateurs (simple et en opposition) sont des valeurs type représentatives des valeurs réelles actuellement utilisées.

I.3.4 A propos de 6.111.1

Etant donné que de nombreux disjoncteurs sont implantés sur des circuits comportant des câbles de 12 kV et plus, il est raisonnable de prévoir des essais de commutation de câbles en charge pour des disjoncteurs de capacité nominale de 12 kV et plus.

I.3.5 A propos de 6.111.3

Le paragraphe concernant le facteur k/f_{φ} a été supprimé parce qu'il n'est ni utile ni nécessaire pour les essais.

L'écart de tension à fréquence industrielle a été adopté à hauteur de 5 % pour la séquence d'essais 2 (LC2, CC2 et BC2) et à 2 % pour la séquence d'essais 1 (LC1, CC1 et BC1). Ces valeurs représentent un compromis tenant compte des servitudes des laboratoires d'essai. Si l'on considère l'essai de type comme un tout, en raison des diverses contraintes des séquences d'essais individuels, on évite toute baisse injustifiée de la contrainte électrique en cours d'essai. Les valeurs réelles de l'écart de tension à fréquence industrielle (en fonction de la puissance de court-circuit du système et de la charge capacitive) se situent entre 1 % et 2 %.

I.3.6 A propos de 6.111.5

L'intervalle après extinction finale de l'arc, dans lequel la décroissance en tension ne doit pas excéder 10 %, a été modifié de 100 ms à 300 ms en fonction des conditions d'utilisation en service.

I.3.7 A propos de 6.111.9.1.1

L'exécution des essais de commutation en courant capacitif pour les équipements de la classe C2 sur un disjoncteur pré-conditionné est d'une part recommandé par le groupe de travail CIGRE concerné, et permet d'autre part, de s'approcher des conditions d'utilisation réelles, le fait que le pré-conditionnement améliore ou non la caractéristique de commutation en courant capacitif du disjoncteur n'entrant pas en considération.

Les manœuvres de fermeture/ouverture peuvent être effectuées avec des essais à vide pour la fermeture. De toute façon, la séquence entière fera l'objet d'un essai pour éprouver l'ouverture du disjoncteur en situation dynamique, c'est-à-dire au cours du déplacement du fluide provoqué par la manœuvre de fermeture précédente.

I.3.8 A propos des 6.111.9.1.1 et 6.111.9.2.1

La plage de tolérance des valeurs de courant d'essai pour la séquence d'essais 1 (LC1, CC1 et BC1) a été modifiée: de l'ancienne fourchette de 20 % à 40 %, elle passe à une nouvelle fourchette de 10 % à 40 % et cela pour donner plus de liberté au cours des essais de séquences mixtes destinés aux diverses applications.

Les séquences d'essais ont été testées en laboratoire (et plus particulièrement le réglage de la durée d'arc minimale par paliers de 6°) et se trouvent ainsi bien adaptées à la philosophie qui préside aux essais.

L'exécution de certains essais à pression assignée constitue une approche plus pragmatique de la notion même d'essai, sachant que le disjoncteur fonctionne habituellement dans des conditions normales de service.

I.3.9 A propos de 6.111.9.1.2 et 6.111.9.1.3

Dans la séquence d'essais 2 relative aux essais de câbles en charge et de lignes monophasées (LC2 et CC2), les essais sont répartis entre manœuvres d'ouverture et des cycles de manœuvres de fermeture/ouverture (6.111.9.1.3) pour se conformer plus ou moins, aux conditions d'utilisation réelles. Cependant, pour des raisons pratiques propres au petit nombre d'essais triphasés (6.111.9.1.2) de la séquence d'essais 2 (LC2 et CC2) seules les cycles de manœuvres de fermeture/ouverture sont effectués.

I.3.10 A propos de 6.111.9.1.2 à 6.111.9.1.5

Pour la commutation des batteries de condensateurs, les cycles de manœuvres de fermeture/ ouverture sont importants en raison de l'effet du courant d'appel. Les manœuvres de fermeture/ouverture ne sont pas significatives pour les applications de commutation de câbles ou de lignes; aussi pour les essais de commutation de câbles et de lignes un nombre limité de cycles de manœuvres de fermeture/ouverture est nécessaire.

Lorsque en raison des limites du laboratoire d’essai il n’est pas possible de satisfaire aux exigences spécifiées pour le cycle de manœuvres CO, une série d’essais d’établissement séparée est nécessaire pour produire l’usure provoquée par l’établissement du courant d’appel (seulement pour l’établissement de bancs de condensateurs) et pour vérifier le comportement lors des préamorçages (c’est-à-dire commutation entre contacts sans usure excessive, le préamorçage a lieu entre contacts d’arc et non entre contacts principaux, etc.).

On a conservé une répartition à peu près égale entre les essais monophasés et triphasés.

L’ordre imposé des essais de commutation de batteries de condensateurs tient à l'obligation de tenir compte du courant d’appel au début des essais.

I.3.11 A propos de 6.111.9.1.4 et 6.111.9.1.5

En raison du grand nombre de manœuvres en utilisation réelle par rapport au nombre limité de manœuvres au cours des essais de types, un nombre élevé (80 ou 120 respectivement) de cycles de manœuvres de fermeture/ouverture pour les essais des batteries de condensateurs sera exécuté pour simuler l'usure, même si le cycle de manœuvre de fermeture/ouverture ne constitue pas la séquence de commutation usuelle.

Il faut aussi, pour les essais relatifs aux batteries de condensateurs, effectuer la séquence d'essais 1 (BC1), même si la sollicitation de commutation en service réel est toujours à 100 % du courant nominal, pour les raisons suivantes:

– les essais à 10 % – 40 % du courant nominal couvrent un plus grand nombre de courants réels;
– la connaissance de la caractéristique de commutation de courant capacitif est améliorée.

I.3.12 A propos de 6.111.9.2

Les exigences relatives aux essais de la classe C1 sont dérivées de la norme ANSI/IEEE C37.012 [11].

Annexe J
(Informative)

Tolérances sur le courant d'essai et la longueur de ligne en essai de défaut proche en ligne

La réactance de ligne qui correspond à la longueur de ligne normalisée peut être calculée comme suit:

$$X_{\text{L,stand}} = \frac{1 - \dfrac{I_{\text{L,stand}}}{I_{\text{sc}}}}{\dfrac{I_{\text{L,stand}}}{I_{\text{sc}}}} X_{\text{source}}$$

où

$I_{\text{L,stand}}$ est le courant coupé de défaut en ligne correspondant à la longueur de ligne normalisée;

$X_{\text{L,stand}}$ est la réactance de ligne correspondant à la longueur de ligne normalisée;

X_{source} est la réactance correspondant au courant assigné de coupure en court-circuit.

Si la réactance de la ligne utilisée en pratique est différente de la réactance qui correspond à la longueur de ligne normalisée, avec les tolérances de –20 % pour L_{90} et $\pm$ 20 % pour L_{75} et L_{60} comme indiqué en 6.109.2, les valeurs correspondantes du courant peuvent être calculées comme suit:

$$I_{\text{L,act}} = \frac{U_{\text{r}}}{\sqrt{3}(X_{\text{L,act}} + X_{\text{source}})}$$

où

$I_{\text{L,act}}$ est le courant coupé de défaut en ligne correspondant à la longueur de ligne utilisée en pratique;

$X_{\text{L,act}}$ est la réactance de ligne correspondant à la longueur de ligne utilisée en pratique.

La longueur de ligne utilisée en pratique est calculée en considérant la longueur assignée et l'écart en pourcentage par rapport à cette longueur assignée:

$$l_{\text{act}} = l_{\text{stand}}\left(1 + \frac{d}{100}\right)$$

où

l_{stand} est la longueur de ligne normalisée;

l_{act} est la longueur de ligne utilisée en pratique;

d est l'écart en pourcentage par rapport à la longueur de ligne normalisée.

La réactance de la ligne utilisée en pratique est calculée à partir de l'équation suivante:

$$X_{\text{L,act}} = X_{\text{L,stand}} \times \frac{l_{\text{act}}}{l_{\text{stand}}} = X_{\text{L,stand}}\left(1 + \frac{d}{100}\right)$$

Le pourcentage pratique du courant de défaut proche en ligne $I_{\text{perc,act}}$ est déterminé à partir de l'équation suivante:

$$I_{\text{perc,act}} = \frac{I_{\text{L,act}}}{I_{\text{sc}}} \times 100 = \frac{I_{\text{perc,stand}}}{1 + \dfrac{d}{100} \times \left(1 - \dfrac{I_{\text{perc,stand}}}{100}\right)}$$

Le pourcentage pratique du courant de défaut proche en ligne est donné dans le Tableau J.1 pour chaque valeur normalisée du courant de défaut proche en ligne $I_{perc,stand}$ en tenant compte des valeurs extrêmes de tolérance sur la longueur de ligne.

Tableau J.1 – Pourcentage pratique du courant de défaut proche en ligne

Valeur normalisée du courant de défaut proche en ligne $I_{perc,stand}$ %	**Ecart** d %	**Pourcentage pratique du courant de défaut proche en ligne** $I_{perc,act}$ %
90	–20	91,8
90	0	90
75	–20	78,9
75	+20	71,4
60	–20	65,2
60	+20	55,5

Annexe K
(informative)

Liste des symboles et abréviations utilisés dans cette norme

Symbole/ abréviation	Référence	Signification
% dc	4.101.2	Pourcentage de composante apériodique
τ	4.101.2	Constante de temps
ω	Tableau 11	Fréquence angulaire
τ_1	Figure 9	Constante de temps normale
τ_2	Figure 9	Constante de temps pour applications particulières
τ_3	Figure 9	Constante de temps pour applications particulières
τ_4	Figure 9	Constante de temps ~~pour applications particulières~~ normale pour tensions assignées supérieures à 800 kV et constante de temps pour applications particulières pour des tensions assignées inférieures ou égales à 800 kV
Δt_1	6.102.10.2.1.2	Durée de la grande onde
Δt_2	6.102.10.2.1.2	Durée de la petite onde
A	Tableau 34	Désignation d’une borne du disjoncteur
A	6.101.6.2	Direction d’un effort horizontal
A_1	Annexe P	Constante de calcul
A_2	Annexe P	Constante de calcul
a	Tableau 34	Désignation d’une borne du disjoncteur
B	Tableau 34	Désignation d’une borne du disjoncteur
b	Tableau 34	Désignation d’une borne du disjoncteur
B_1	6.101.6.2	Direction d’un effort horizontal
B_2	6.101.6.2	Direction d’un effort horizontal
BC1	6.111.9	Séquence d’essais N°1, courants de batteries de condensateurs
BC2	6.111.9	Séquence d’essais N°2, courants de batteries de condensateurs
BS	Figure F.7	Interrupteur de protection
C	Tableau 34	Désignation d’une borne du disjoncteur
c	A.2	Vitesse de propagation des ondes mobiles
c	Tableau 34	Désignation d’une borne du disjoncteur
C	H.2.1	Capacité d’une batterie unique de condensateurs
C	Tableau 13	Manœuvre de fermeture
C.B.	Figure 12 a	Disjoncteur
C_1	Figure H.3	Capacité d’une première batterie de condensateurs déjà connectée
C_1	6.101.6.2	Direction d’un effort vertical
C1	3.4.114	Classe de disjoncteur à faible probabilité de réamorçage
C_2	Figure H.3	Capacité d’une seconde batterie de condensateurs déjà connectée
C_2	6.101.6.2	Direction d’un effort vertical
C2	3.4.115	Classe de disjoncteur à très faible probabilité de réamorçage
CC1	6.111.9	Séquence d’essais N°1, courants de câbles à vide
CC2	6.111.9	Séquence d’essais N°2, courants de câbles à vide
C_d	Figure 12 a	Capacité de temps de retard côté alimentation
C_{dL}	Figure 15	Capacité de temps de retard côté ligne

Symbole/ abréviation	Référence	Signification
C_L	Figure F.9	Condensateur constituant la source
C_n	Figure H.3	Capacité de la n-ième batterie de condensateurs déjà connectée
CO	4.104	Manœuvre de fermeture-ouverture
CU	Figure F.7	Elément de commande fournissant la séquence de manœuvres
D	Figure F.7	Montage en parallèle de diodes à coupure rapide
D	Figure 22	Dispositif de commande, organe de manœuvre
d	Annexe J	Ecart par rapport à la longueur de ligne normalisée
dα	6.102.10.2.1.1	Différence angulaire utilisée pour la détermination des durées d'arc
$\mathrm{d}u/\mathrm{d}t_{\mathrm{SLF}}$	A.3	Vitesse de rétablissement de la TTR côté alimentation pour le défaut proche en ligne
$\mathrm{d}u/\mathrm{d}t_{\mathrm{TF}}$	A.3	Vitesse de rétablissement de la TTR pour le défaut aux bornes T100s
$\mathrm{d}u_{\mathrm{L}}/\mathrm{d}t$	6.109.3	Vitesse de rétablissement de la TTR côté ligne
E	Figure F.6	Tension de rétablissement à fréquence industrielle
E1	3.4.112	Classe de disjoncteurs avec une endurance électrique de base
E2	3.4.113	Classe de disjoncteurs avec une endurance électrique accrue
F	Tableau 34	Désignation du bâti d'un disjoncteur
f_{bi}	Tableau 9	Fréquence du courant d'appel (à gradins)
f_{i}	Tableau 11	Coefficient multiplicateur servant à déterminer la forme d'onde de la TTRI
f_{inrush}	4.107.5	Fréquence du courant d'appel (batterie unique de condensateur)
f_{r}	4.3	Fréquence assignée
F_{shA}	6.101.6.1	Effort sur les bornes, effort horizontal
F_{shB}	6.101.6.1	Effort sur les bornes, effort horizontal
F_{sr1}, F_{sr2}, F_{sr3}, F_{sr4}	6.101.6	Effort statique assignés sur les bornes (efforts résultants)
F_{sv}	6.101.6.1	Effort sur les bornes, effort vertical
F_{th}	Tableau 14	Effort statique horizontal
F_{thA}	Tableau 14	Effort statique horizontal, longitudinal
F_{thB}	Tableau 14	Effort statique horizontal, transversal
F_{tv}	Tableau 14	Effort statique vertical
F_{wh}	6.101.6.2	Effort horizontal sur le disjoncteur dû à la pression exercée par le vent sur un disjoncteur sous glace
$\hat{I}$	Tableau 10	Courant de crête lié à la valeur crête du courant de court-circuit
$\hat{i}$	H.2.2	Valeur crête du courant d'appel
I_{AC}	Figure 8	Valeur crête de la composante périodique du courant
I_{bb}	Tableau 9	Pouvoir de coupure assigné de batteries de condensateurs à gradins
I_{bi}	Tableau 9	Pouvoir de fermeture assigné de batteries de condensateurs à gradins
I_{c}	Tableau 9	Pouvoir de coupure assigné de câbles à vide
i_{d}	D.1.1	Valeur à tout instant de la composante apériodique du courant
I_{d}	Tableau 10	Pouvoir de coupure assigné en discordance de phases
I_{d0}	D.1.1	Valeur initiale de la composante apériodique
I_{DC}	Figure 8	Composante apériodique du courant
I_{i}	F.3.4	Courant injecté
i_{i}	F.3.4	Courant injecté
I_{k}	4.5	Courant de courte durée admissible assigné

Symbole/ abréviation	Référence	Signification
I_l	Tableau 9	Pouvoir de coupure assigné de lignes à vide
I_L	6.109.2	Courant d'essai pour défaut proche en ligne
$I_{L,act}$	Annexe J	Courant coupé de défaut proche en ligne correspondant à la longueur de ligne utilisée en pratique
$I_{L,stand}$	Annexe J	Courant coupé de défaut proche en ligne correspondant à la longueur de ligne normalisée
I_m	Figure R.1	Courant traversant l'interrupteur principal
$i_{max\ peak}$	4.107.5	Valeur crête du courant d'appel
I_{MC}	Figure 8	Courant établi
I_p	4.6	Valeur crête du courant admissible assigné
$I_{perc,act}$	Annexe J	Pourcentage pratique du courant de défaut proche en ligne
$I_{perc,stand}$	Annexe J	Pourcentage normalisé du courant de défaut proche en ligne
I_r	4.4	Courant assigné en service continu
I_{res}	Figure R.1	Courant traversant l'interrupteur de résistance
I_s	Figure R.1	Courant de source
I_{sb}	Tableau 9	Pouvoir de coupure assigné de batterie unique de condensateurs
I_{sc}	4.101	Pouvoir de coupure assigné en court-circuit
i_{sc}	F.3.4	Courant de court-circuit
I_{sh}	4.107.5	Courant de court-circuit au niveau d'une batterie de condensateurs
I_{si}	Tableau 10	Pouvoir de fermeture assigné de batteries de condensateurs
TTRI	4.102.1	Tension transitoire de rétablissement initial
k	A.2	Facteur de crête (Défaut proche en ligne)
k	4.107.5	Multiplicateur pour le calcul de la valeur crête du courant d'appel
k_1	Annexe P	Constante de calcul
k_2	Annexe P	Constante de calcul
k_3	Annexe P	Constante de calcul
K	Figure F.7	Interrupteur pour l'établissement du courant
k_{af}	4.102.2	Facteur d'amplitude (TTR)
k_c	6.111.7	Facteur de tension capacitive
k_i	A.3	Facteur de crête pour la TTRI
k_p	6.102.10.2.5	Facteur de tension pour la détermination de la TTR dans chaque pôle
k_{pp}	4.102.2	Facteur de premier pôle
L	Figure 15	Longueur de ligne jusqu'au défaut
l	H.2.1	Longueur totale de conducteurs entre batteries de condensateurs
L'	H.2.1	Inductance par unité de longueur
L_0	Figure H.3	Inductance côté alimentation de la batterie de condensateurs
L_1	Figure H.3	Inductance de la première batterie de condensateurs connectée
L_2	Figure H.3	Inductance de la seconde batterie de condensateurs connectée
L_{60}	6.109.2	Séquence de défaut proche en ligne à 60 % du pouvoir de coupure en court-circuit
L_{75}	6.109.2	Séquence de défaut proche en ligne à 75 % du pouvoir de coupure en court-circuit
L_{90}	6.109.2	Séquence de défaut proche en ligne à 90 % du pouvoir de coupure en court-circuit

Symbole/ abréviation	Référence	Signification
L_a	H.2.3	Inductance additionnelle du jeu de barre
l_{act}	Annexe J	Longueur de ligne en pratique
L_B	A.1	Inductance du jeu de barre côté alimentation
L_b	H.2.1	Inductance de la batterie de condensateurs
LC1	6.111.9	Séquence N°1, courants de lignes à vide
LC2	6.111.9	Séquence N°2, courants de lignes à vide
L_f	6.109.3	Facteur de courant de défaut proche en ligne
L_L	A.1	Inductance côté ligne
L_n	Figure H.3	Inductance de la n-ième batterie de condensateurs connectée
L_S	A.1	Inductance côté alimentation
l_{stand}	Annexe J	Longueur de ligne normalisée
M	Tableau 10	Masse du disjoncteur
m	Tableau 10	Masse du fluide pour la coupure
M1	3.4.116	Classe de disjoncteurs avec une endurance mécanique de base
M2	3.4.117	Classe de disjoncteurs avec une endurance mécanique accrue
MS	Figure F.7	Interrupteur pour l'établissement du courant
NSDD	3.1.126	Décharge disruptive non maintenue
O	4.104	Manœuvre d'ouverture
O_1	Figure F.8	Oscillographe cathodique, piste 1
O_2	Figure F.8	Oscillographe cathodique, piste 2
O-t-CO	4.104	Cycle d'ouverture – fermeture – ouverture
OP1	6.110.3	Discordance de phases, séquence d'essais 1
OP2	6.110.3	Discordance de phases, séquence d'essais 2
p_{re}	Tableau 10	Pression assignée pour la coupure
p_{rm}	Tableau 10	Pression assignée pour la manœuvre
Q_b	H.2.1	Puissance d'une batterie unique de condensateurs
RV	Tableau O.3	Tension rétablie
VATR	Tableau 24	Vitesse d'accroissement de la tension rétablie
S	Figure H.3	Vitesse d'accroissement du courant d'appel
s	Figure F.9	Relais de commutation
s	A.2	Facteur de VATR
S1	3.4.119	Classe de disjoncteurs de tensions assignées supérieures à 1 kV et inférieures à 100 kV, prévus pour des réseaux à câbles
S2	3.4.12	Classe de disjoncteurs de tensions assignées supérieures à 1 kV et inférieures à 100 kV, prévus pour des réseaux aériens
SLF	6.104.5.2	Défaut proche en ligne
~~T~~	~~6.102.10.2.1.1~~	~~Période de la fréquence industrielle~~
T	4.109.1	Période de la fréquence industrielle
TTR	Tableau O.3	Tension rétablie
$t_{arc\ max}$	6.102.10.2.1.1	Durée d'arc maximale
$t_{arc\ med}$	6.102.10.2.1.1	Durée d'arc moyenne
$t_{arc\ min}$	6.102.10.2.1.1	Durée d'arc minimale
$t_{arc\ new\ min}$	6.102.10.2.3	«Nouvelle» durée d'arc minimale

Symbole/ abréviation	Référence	Signification
$t_{arc\ ult\ max}$	6.102.10.2.3	Durée d'arc maximale «ultime»
t'	4.102.2	Durée pour atteindre u' (construction du segment de retard)
t'	4.104	Intervalle de temps de la séquence de manœuvre assignée
t''	4.104	Intervalle de temps de la séquence de manœuvre assignée
t_1	4.109.1	Durée d'arc maximale enregistrée pendant T30, T60 and T100s
t_1	4.102.2	Durée pour atteindre u_1 (TTR)
$t_{1,sp}$	6.108.2	Durée pour atteindre u_1 (TTR) dans le cas de défaut monophasé et double défaut à la terre
~~t_2~~	~~4.109.1~~	~~Durée d'ouverture maximale enregistrée en ouverture à vide~~
t_2	4.102.2	Durée pour atteindre u_c (TTR à 4 paramètres)
$t_{2,sp}$	6.108.2	Durée pour atteindre u_c (TTR à 4 paramètres) dans le cas d'un défaut monophasé ou d'un double défaut à la terre
t_3	4.109.1	Durée d'ouverture assignée
t_3	4.102.2	Durée pour atteindre u_c (TTR à 2 paramètres)
$t_{3,sp}$	6.108.2	Durée pour atteindre u_c (TTR à 2 paramètres) dans le cas d'un défaut monophasé ou d'un double défaut à la terre
T_A	6.101.3.3	Température de l'air ambiant
t_a	6.101.2.3	Durée entre 2 manœuvres pour les essais de manœuvre mécanique à l'air ambiant
t_a	6.108.3	Durée d'arc pour des manœuvres de coupure monophasée
$t_{a,100s}$	6.108.3	Durée d'arc minimale pour le premier pôle qui coupe T100s
t_b	4.109.1	Durée assignée de coupure
t_{bm}	4.109.1	Plus longue des durées de coupure minimales enregistrées pendant T30, T60 et T100s
t_d	4.102.2	Temps de retard
t_{dL}	6.104.5.2	Temps de retard côté ligne (défaut proche en ligne)
T_H	6.101.3.4	Température maximale de l'air ambiant
t_i	4.102.2	Durée pour atteindre u_i (TTRI)
t_k	4.7	Durée assignée de court-circuit
T_L	6.101.3.3	Température minimale de l'air ambiant
t_L	A.2	Durée pour atteindre la première crête de la TTR côté ligne
t_m	A.3	Durée pour atteindre le niveau de tension U_m
T_{max}	6.101.4.2	Haute température de l'air (essai à l'humidité)
T_{min}	6.101.4.2	Basse température de l'air (essai à l'humidité)
t_{om}	4.109.1	Durée d'ouverture maximale enregistrée en ouverture à vide
T_{op}	4.101.2	Durée d'ouverture du premier pôle
T_{op}	6.106.5	Durée d'ouverture minimale
t_{or}	4.109.1	Durée d'ouverture assignée
T_r	4.101.2	Durée relais, un demi-cycle à fréquence industrielle
TR	Tableau O.3	Tension rétablie
t_T	A.3	Durée jusqu'à la crête de la TTR côté ligne (défaut proche en ligne)
t_x	6.101.3.3	Intervalle de temps pour l'essai à basse température
u'	4.102.2	Tension de référence (construction du segment de retard)
u_0	A.1	Chute de tension aux bornes de la ligne à l'instant de coupure (défaut proche en ligne)

Symbole/ abréviation	Référence	Signification
u_1	4.102.2	Première tension de référence (tracé de référence à 4 paramètres)
$u_{1,test}$	A.3	Valeur effective u_1 en essai de défaut proche en ligne
u_c/t_3	6.104.5.1	Vitesse de rétablissement de tension (tracé de référence à 2 paramètres)
u_1/t_1	4.102.2	Vitesse de rétablissement de tension (tracé de référence à 4 paramètres)
$u_{1,sp}$	6.108.2	Première tension de référence dans le cas de défaut monophasé ou de double défaut à la terre
U_a	4.8	Tension assignée d'alimentation des dispositifs de fermeture et d'ouverture, des circuits auxiliaires et de commande
u_A	O.3.1.2	Tension résultante entre les bornes de l'(des) élément(s) auxiliaire(s), connecté dans le circuit de courant et l'enveloppe
u_B	O.3.1.2	TTR entre les bornes de l'(des) éléments en essai
u_C	4.102.2	Tension de référence (valeur crête de la TTR)
$u_{c,sp}$	6.108.2	Tension de référence dans le cas de défaut monophasé et de double défaut à la terre
U_{CB}	Figure 12a	Tension aux bornes du disjoncteur
$U_{C/C'}$	Tableau O.1	Tension entre contacts en position ouvert
$U_{C/E}$	Tableau O.1	Tension entre la borne côté alimentation et la terre
$U_{C'/E}$	Tableau O.1	Tension entre la borne côté charge et la terre
U_{cp}	Figure F.1	TTR mesurée avec réduction de la tension
u_E	O.3.1.2	Tension entre l'enveloppe et la terre
U_G	A.1	Tension d'alimentation
u_i	4.102.2	Tension de référence (valeur crête de TTRI)
u_{i0}	A.3	Chute de tension aux bornes du jeu de barre
U_L	A.1	Chute de tension le long de la ligne
u_L	A.2	Chute de tension transitoire le long de la ligne
u_L*	6.109.3	Valeur crête de la tension le long de la ligne (Défaut proche en ligne)
$u_{L,mod}*$	6.109.3	Valeur ajustée crête de la tension le long de la ligne (Défaut proche en ligne)
U_m	A.1	Valeur crête de la tension induite totale
U_m	Figure R.1	Tension aux bornes de l'interrupteur principal
U_{op}	Tableau 10	Tension de tenue assignée aux chocs de foudre
U_p	Tableau 10	Tension côté alimentation
U_r	4.1	Tension assignée
U_{res}	Figure R.1	Tension aux bornes de l'interrupteur de résistance
U_s	Tableau 10	Tension de tenue assignée aux chocs de manœuvre
U_s	Figure R.1	Tension source
U_S	Figure 12a	Tension aux bornes de la réactance d'alimentation
u_S*	A.3	Contribution à la première crête de la tension côté alimentation
u_T	A.3	Valeur totale de la première crête de tension
U_X	A.1	Chute de tension côté alimentation (défaut proche en ligne)
u_X	A.1	Chute de tension côté alimentation à l'instant de coupure (défaut proche en ligne)
V_{sc}	F.3.4	Etalonnage de tension pour la TTR correspondant au courant maximal de court-circuit
X_B	Figure 12a	Réactance du jeu de barre à fréquence industrielle
X_L	Figure 15	Réactance de la ligne à fréquence industrielle

Symbole/ abréviation	Référence	Signification
$X_{L,act}$	Annexe J	Réactance de la ligne correspondant à la longueur de la ligne en pratique
$X_{L,stand}$	Annexe J	Réactance de la ligne correspondant à la longueur normalisée de la ligne
X_N	Figure 13	Réactance de neutre
X_S	Figure 12a	Réactance à fréquence industrielle du circuit d'alimentation
X_{source}	Annexe J	Réactance correspondant au courant de court-circuit assigné
Z	Figure 15	Impédance caractéristique de la ligne
Z	6.103.3	Impédance
Z_0	6.103.3	Impédance homoplaire
Z_1	4.102.3	Impédance directe
Z_a	Figure 13	Impédance entre phases
Z_b	Figure 13	Impédance phase-terre
Z_i	Tableau 7	Impédance caractéristique du jeu de barre
Z_i	Figure 12a	Eléments de réglage de la TTRI
Z_S	Figure 12a	Eléments de réglage de la TTR côté alimentation
Z_{sn}	Figure 13	Impédance de neutre de la source

Annexe L
(informative)

Notes explicatives à propos de la révision des TTR pour disjoncteurs de tensions assignées supérieures à 1 kV et inférieures à 100 kV

A la suite de la décision du SC17A prise lors de la réunion de Beijing (CN) en Octobre 2002, le GT 35 du SC17A de la CEI a préparé une proposition de révision des TTR pour les disjoncteurs de tensions supérieures à 1 kV et inférieures à 100 kV.

Cette proposition utilise les données des groupes de travail CIGRE du Comité d'études A3 (Appareillage de coupure) qui a étudié la nécessité d'adapter les exigences de TTR pour les disjoncteurs de tension assignées inférieures à 100 kV. En 1983, un Groupe d'Action du CIGRE A3 a fait un rapport sur les TTR dans les réseaux à moyenne tension. Les résultats de cette étude ont été publiés dans Electra 88. Un autre groupe de travail, WG 13.05, a étudié les TTR générées dans le cas de défauts alimentés par un transformateur et défauts au secondaire de transformateurs. Les résultats ont été présentés dans Electra 102 (1985). En 1992, en association avec CIRED, CIGRE A3 a créé le groupe de travail CC03 pour faire à nouveau des investigations sur la définition des TTR pour l'appareillage de coupure à moyenne tension. Le résultat de ces investigations a été publié dans la brochure technique CIGRE 134 (1998) et est en ligne avec les études antérieures.

L.1 Généralités

Les principales modifications introduites par cet amendement peuvent être résumées comme suit:

a) Deux types de réseaux sont définis pour couvrir tous les types de réseaux (distribution, industriels et transport) dans la gamme de tensions supérieures à 1 kV et inférieures à 100 kV, et dans le but de standardiser les exigences,

   – réseaux par câbles

     Les réseaux par câbles sont définis en 3.1.132.

   – réseaux aériens

     Les réseaux aériens sont définis en 3.1.133.

b) Une séquence d'essais T30 est spécifiée dans le cas particulier de disjoncteurs destinés à être connectés à un transformateur avec une liaison de faible capacitance (longueur de câble inférieure à 20 m), pour vérifier leur capacité à couper des défauts limités par un transformateur. Cela est traité dans la nouvelle Annexe M (normative).

   Dans le cas général où la capacitance de la liaison est suffisamment grande, la séquence normale T30 démontre la capacité de coupure des défauts alimentés par transformateur(s).

c) La coupure du défaut proche en ligne est exigée pour les disjoncteurs de tensions assignées supérieures ou égales à 15 kV lorsqu'ils sont connectés directement à des lignes. Comme il est déjà spécifié pour les disjoncteurs de tensions assignées supérieures ou égales à 48,3 kV, le pouvoir de coupure assigné doit être supérieur à 12,5 kA (c'est-à-dire $I_{sc} \geq 16$ kA).

d) Le cas particulier de disjoncteurs installés immédiatement en série avec une réactance de limitation est couvert dans un nouveau paragraphe 8.103.7.

L.2 Défaut aux bornes

L.2.1 TTR pour disjoncteurs de réseaux aériens

Les réseaux aériens sont plus communs selon la pratique en Amérique du Nord que selon la pratique européenne. Par suite les valeurs normalisées données dans le Tableau 2 de ANSI C37.06-2000 sont prises comme base pour la définition du nouveau Tableau 25. Les valeurs de t_3 sont celles de T_2 spécifiées dans ANSI multipliées par 0,88.

NOTE Le facteur 0,88 est dérivé d'une forme "1-cos" multiplié par la moitié du facteur d'amplitude. La forme normalisée de TTR "-cos" dans ANSI C37.06-2000 pour les tensions assignées inférieures à 100 kV ne coïncide pas avec l'équation mathématique précise pour des circuits avec amortissement série ou parallèle, pour lesquels un autre rapport t_3/T$_2$ est applicable.

Le temps t_3 pour le défaut aux bornes et le défaut proche en ligne est égal à $4{,}65 \times U_r^{0{,}7}$, avec t_3 en micro-secondes et U_r en kV. Cette formule est dérivée des valeurs données dans le Tableau 2 de ANSI/IEEE C37.06-2000 pour des tensions assignées 15,5 kV, 25,8 kV, 48,3 kV et 72,5 kV. Cette même formule est utilisée pour les autres tensions assignées.

La vitesse de rétablissement de tension est dérivée de u_c et t_3.

Le temps t_3 pour la discordance de phases est le double du temps t_3 pour le défaut aux bornes.

L.2.2 Temps de retard

Temps de retard du Tableau 24 pour les disjoncteurs de réseaux par câbles:

> Le temps de retard t_d est le même que celui défini dans la première édition de cette norme pour les tensions inférieures à 52 kV. Il est généralisé pour tous les réseaux par câbles (tensions assignées inférieures à 100 kV).

Temps de retard du Tableau 25 pour les disjoncteurs de réseaux aériens:

> Le temps de retard du Tableau 25 est 0,05 × t_3, comme dans la première édition de cette norme pour les tensions assignées 48,3 kV – 52 kV et 72,5 kV. Cette formule a été étendue aux tensions inférieures car aucun changement dans la forme de la TTR initiale n'est attendu (la partie initiale est exponentielle, même avec les courtes longueurs de lignes qui peuvent être rencontrées dans les réseaux de distribution et de transport). Cette exigence n'est pas jugée excessive car dans le cas extrême (U_r = 15 kV) le temps de retard de 2 µs est tel que spécifié pour les disjoncteurs de tensions assignées supérieures à 72,5 kV.
>
> Il est reconnu que pendant la phase thermique de la coupure, ce temps de retard peut être critique et doit être pris en compte. Cependant, comme montré dans les Tableaux 13 et 14 de la 1re édition de cette norme, cette vérification peut être faite en effectuant les essais de défaut en ligne. Par suite, comme il est déjà indiqué pour les tensions supérieures à 38 kV, il est permis d'avoir un temps de retard plus long pendant les essais T100, jusqu'à 0,15 × t_3, si les essais de défaut en ligne sont effectués. Cette possibilité est indiquée dans le Tableau 25.

L.2.3 Facteur d'amplitude pour T100s et T100a

Pour les disjoncteurs de réseaux par câbles, une valeur de 1,4 est retenue du fait de l'expérience positive avec les éditions antérieures de cette norme.

Pour les disjoncteurs de réseaux aériens, la valeur de 1,54, définie dans la norme ANSI C37.06-2000, est retenue.

L.2.4 Facteur d'amplitude pour T60, T30 et T10

Pour les disjoncteurs de réseaux par câbles, la valeur de 1,5 pour T60 dans la première édition de cette norme est conservée, en raison de l'expérience positive obtenue. Pour T30 et T10, le facteur d'amplitude a été augmenté de 1,5 à respectivement 1,6 et 1,7, car la contribution à la TTR est due principalement à la variation de tension aux bornes du ou des transformateurs avec un faible amortissement, et la combinaison avec la tension source conduit à une TTR avec un facteur d'amplitude relativement élevé.

Pour les disjoncteurs de réseaux aériens, les valeurs sont celles de ANSI C37.06-2000: 1,65 pour T60, 1,74 pour T30 et 1,8 pour T10.

L.3 Défaut proche en ligne

Dans la première édition de cette norme, les exigences de défaut proche en ligne étaient spécifiées pour les disjoncteurs de tensions assignées 52 kV et 72,5 kV, dans la gamme de tensions assignées considérées pour cette édition, et directement connectés à des lignes aériennes.

Dans cette deuxième édition, les exigences de défaut proche en ligne sont spécifiées pour les disjoncteurs de classe S2 de tensions assignées supérieures ou égales à 15 kV et directement connectés (par jeux de barres) à des lignes aériennes, quel que soit le type de réseau côté alimentation.

Comme la topologie et la configuration des sous-stations des réseaux 48,3 kV sont identiques à celles des réseaux 52 kV et 72,5 kV, la séquence d'essais pour 48,3 kV est spécifiée de la même manière que pour 52 kV et 72,5 kV.

Pour les tensions assignées 15 kV, 25,8 kV et 38 kV, les caractéristiques et procédures d'essais sont légèrement différentes. Etant donné qu'aucun équipement est normalement connecté du côté ligne au disjoncteur, les caractéristiques de ligne sont adaptées au cas pratiquement sans capacitance: t_{dL} < 0,1 µs. Comme la longueur de ligne jusqu'au point de défaut doit correspondre à une distance réaliste, la séquence d'essais L_{90} a été abandonnée et les tolérances de la longueur de ligne pour L_{75} ont été adaptées.

L'essai de défaut en ligne spécifié est considéré comme couvrant les défauts proche en ligne triphasés ainsi que les défauts biphasés et monophasés pour les raisons suivantes:

– l'impédance caractéristique représentative, vue aux bornes du pôle qui coupe, est telle que dans tous les cas la VATR pour tous les pôles qui coupent est couverte par les caractéristiques spécifiées dans le Tableau 8;
– l'essai de défaut en ligne monophasé, avec une plage de durée d'arc (180°−dα), couvre l'exigence pour les cas de défauts multi-phases pour des réseaux avec neutre effectivement ou non effectivement à la terre;
– la tenue à la valeur crête de la TTR pendant la coupure d'un défaut triphasé est démontrée par la séquence de défaut aux bornes T100.

L.4 Discordance de phases

Il n'y a pas suffisamment d'informations disponibles pour réviser les paramètres de TTR dans le cas de coupure de défaut en discordance de phases. Il a été demandé au CIGRE SC A3 de faire des investigations sur les conditions de réseaux et de fonctionnement conduisant à des coupures de courants de discordance de phases. Par suite, les TTR pour discordance de phases sont en principe inchangées.

Les valeurs de t_3 pour la discordance de phases sont dans tous les cas le double des valeurs pour le défaut aux bornes T100.

L.5 Défaut avec réactance de limitation (ou réactance série)

En raison de la très faible capacitance inhérente à un certain nombre de réactances, la fréquence naturelle des tensions transitoires concernant ces réactances peut être très grande. Un disjoncteur installé immédiatement en série avec ce type de réactance subira une TTR à fréquence élevée en coupure de défaut aux bornes (la réactance étant du côté alimentation du disjoncteur) ou dans le cas de coupure d’un défaut en aval de la réactance (réactance du côté charge du disjoncteur). La fréquence de la TTR résultante excède généralement nettement les valeurs normalisées.

Dans de tels cas, il est nécessaire de prendre des mesures de correction, comme le montage de condensateurs en parallèle aux réactances ou connectées à la terre, de manière à réduire la fréquence de la TTR. Ces mesures de correction sont disponibles, efficaces et économiques [12]. Il est particulièrement recommandé de les utiliser, à moins qu’il puisse être démontré par des essais que le disjoncteur est capable d’interrompre les défauts avec une haute fréquence de la TTR.

Selon l’opinion du GT 35 du SC 17A de la CEI, l’expérience en service avec des mesures de correction de TTR est si bonne et les dépenses engagées relativement si faibles, qu’il n’est pas raisonnable de spécifier des exigences particulières pour les disjoncteurs concernés par de type d’application.

L.6 TTR pour les derniers pôles qui coupent / Topologie de circuit d’essais

Dans le Tableau 2 de la première édition de cette norme, les multiplicateurs des valeurs de TTR pour les 2èmes et 3èmes pôles qui coupent sont donnés pour les disjoncteurs de tension assignée supérieure à 72,5 kV. Dans la NOTE 1 il est indiqué que pour les tensions assignées inférieures ou égales à 72,5 kV les valeurs sont à l’étude.

Pour les disjoncteurs de tensions assignées inférieures ou égales à 72,5 kV, dans la mesure où il n’y a pas d’informations suffisantes pour définir des valeurs autres que celles spécifiées pour les tensions assignées plus élevées, le SC 17A de la CEI a décidé lors de sa réunion de Montréal (CA), Octobre 2003, d’étendre la validité du Tableau 2 à toutes les tensions assignées supérieures à 1 kV. Ces valeurs seront révisées ultérieurement lorsque les résultats d’études seront publiés.

Annexe M
(normative)

Exigences pour la coupure de défauts limités par un transformateur pour des disjoncteurs de tensions assignées supérieures à 1 kV ~~et inférieures à 100 kV~~

M.1 Généralités

Les Figures M.1 et M.2 illustrent deux cas typiques de défauts limités par un transformateur. Ces types de défauts peuvent être subdivisés en:

– défauts alimentés par un transformateur (Figure M.1);

– défauts au secondaire d'un transformateur (Figure M.2).

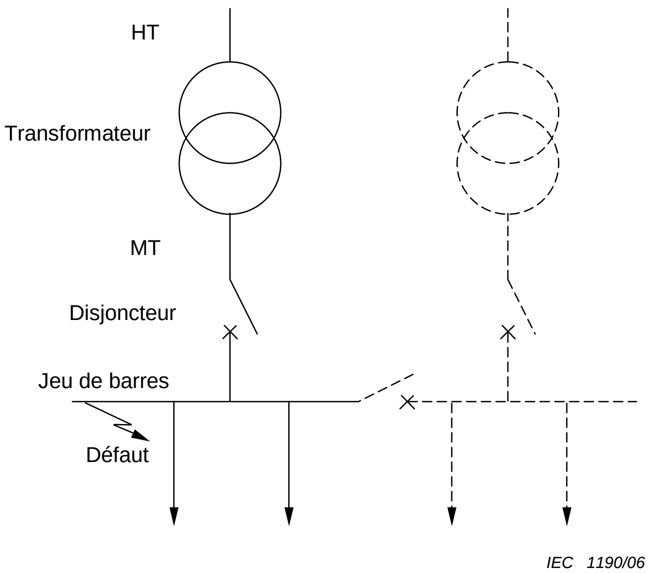


Figure M.1 – Premier exemple de défaut limité par un transformateur
(aussi appelé défaut alimenté par un transformateur)

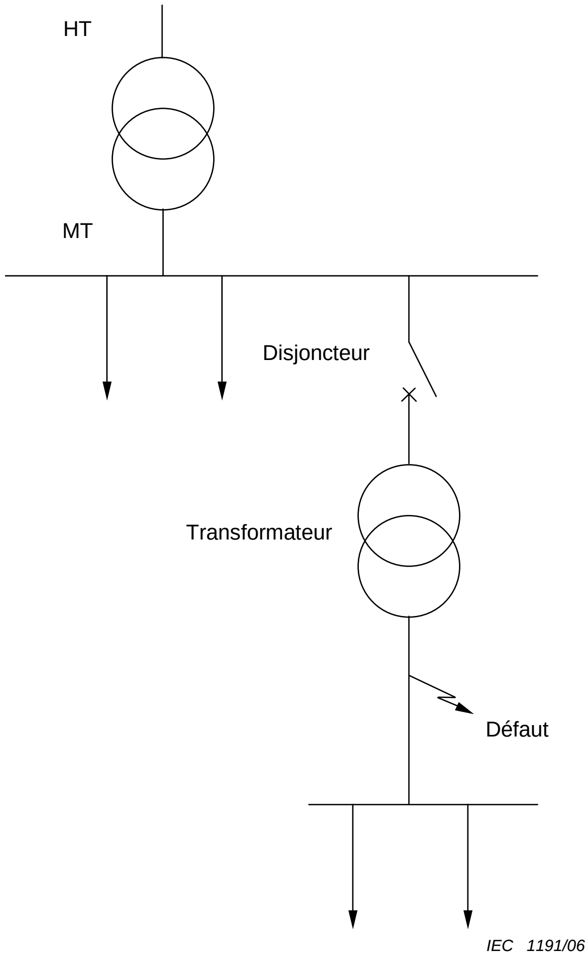


Figure M.2 – Deuxième exemple de défaut limité par un transformateur
(aussi appelé défaut au secondaire d'un transformateur)

M.2 Disjoncteurs de tension assignée inférieure à 100 kV

~~Dans la mesure où les sous-stations ont plus d'un transformateur, le courant à couper par le disjoncteur de transformateur est seulement une fraction du courant de court-circuit total de la sous-station. En général, le même pouvoir de coupure est spécifié pour les disjoncteurs de transformateur et pour les départs même si le pouvoir de coupure nécessaire est très différent. Il existe deux raisons pour ce sur-dimensionnement: l'uniformité des disjoncteurs de la sous-station et le fait que, pour des courants permanents élevés comme exigés pour des disjoncteurs de transformateurs, la coordination des valeurs assignées peut conduire à des pouvoirs de coupure plus élevés que nécessaire. Par suite, et dans un objectif de normalisation, la séquence T30 est spécifiée pour démontrer la capacité d'un disjoncteur à couper les défauts limités par un transformateur.~~

Comme la plupart des postes ont plus d'un transformateur, le courant à couper par le disjoncteur de transformateur est seulement une fraction du courant de court-circuit total de la sous-station. En général, le même pouvoir de coupure est spécifié pour les disjoncteurs de transformateur et pour les départs même si le pouvoir de coupure nécessaire est très différent. Il existe deux raisons pour ce surdimensionnement: l'uniformité des disjoncteurs de la sous-station et le fait que, pour des courants permanents élevés comme exigés pour des disjoncteurs de transformateurs, la coordination des valeurs assignées peut conduire à des pouvoirs de coupure plus élevés que nécessaire. Par suite, et dans un objectif de normalisation, la séquence T30 est spécifiée pour démontrer la capacité d'un disjoncteur à couper les défauts limités par un transformateur.

Deux cas d'application doivent être considérés:

a) ~~les cas où la capacitance par rapport à la terre entre le transformateur et le disjoncteur est suffisante: la coupure des défauts limités par un transformateur est démontrée en effectuant la séquence T30 avec les paramètres de TTR définis dans le Tableau 24 pour les disjoncteurs de classe S1 (pour réseaux par câbles) ou Tableau 25 pour les disjoncteurs de classe S2 (pour réseaux aériens). Lorsque des câbles ou des jeux de barres isolés sont utilisés, la capacitance à la terre de la connexion entre le transformateur et le disjoncteur est généralement supérieure à la valeur requise.~~

   les cas où la capacité par rapport à la terre entre le transformateur et le disjoncteur est suffisante: la coupure des défauts limités par un transformateur est démontrée en effectuant la séquence T30 avec les paramètres de TTR définis dans le Tableau 24 pour les disjoncteurs de classe S1 ou le Tableau 25 pour les disjoncteurs de classe S2. Lorsque des câbles ou des jeux de barres isolés sont utilisés, la capacité à la terre de la connexion entre le transformateur et le disjoncteur est généralement supérieure à la valeur requise.

   ~~NOTE 1 Le calcul montre que la capacitance nécessaire pour réduire la fréquence naturelle d'un transformateur à celle spécifiée pour la TTR de T30 dans les Tableaux 24 et 25, est indépendante de la tension assignée et proportionnelle au courant de court-circuit assigné. Il y a lieu que la capacitance additionnelle à la terre soit d'au moins:~~

$$\cancel{C_0 = 0{,}6\times I_{30}\ \text{(50 Hz) ou } 0{,}7\times I_{30}\ \text{(60 Hz)}}$$

   ~~où~~

   ~~I_{30} est 30 % du pouvoir de coupure assigné en court-circuit, en kA ;~~

   ~~C_0 est en nF.~~

   ~~Des câbles avec typiquement 0,3 à 0,5 nF/m donnent facilement les valeurs de capacitance additionnelle nécessaires.~~

   ~~Par exemple, dans le cas d'un disjoncteur de pouvoir de coupure assigné 31,5 kA-50 Hz, la longueur minimale de câble pour laquelle l'essai de type T30 couvre la coupure de défauts limités par un transformateur est~~ $\cancel{\frac{0{,}6\times 0{,}3\times 31{,}5}{0{,}3} = 19\text{ m}}$~~, en supposant que la capacitance est 0,3 nF/m.~~

   NOTE 1 Le calcul montre que la capacité nécessaire pour réduire la fréquence naturelle d'un transformateur à celle spécifiée pour la TTR de T30 dans les Tableaux 24 et 25, est indépendante de la tension assignée et proportionnelle au courant de court-circuit assigné. Il convient que la capacité additionnelle à la terre soit d'au moins:

$$C_0 = 0{,}6\times I_{30}\ \text{(50 Hz) ou } 0{,}7\times I_{30}\ \text{(60 Hz)}$$

   où

   I_{30} est égal à 30 % du pouvoir de coupure assigné en court-circuit, en kA;

   C_0 est en nF.

   Des câbles types (0,3 nF/m à 0,5 nF/m) donnent facilement les valeurs de capacité additionnelle nécessaires.

   Par exemple, dans le cas d'un disjoncteur de pouvoir de coupure assigné 31,5 kA - 50 Hz, la longueur minimale de câble pour laquelle l'essai de type T30 traite la coupure de défauts limités par un transformateur est $\frac{0{,}6\times 0{,}3\times 31{,}5}{0{,}3} = 19\text{ m}$, en supposant que la capacité est de 0,3 nF/m.

b) Dans le cas particulier où la capacitance de la liaison entre le transformateur et le disjoncteur est inférieure à Co définie ci-dessus en a), une séquence T30 particulière peut être spécifiée à des disjoncteurs avec une TTR définie dans le Tableau M.1.

   En variante, une capacitance peut être ajoutée au réseau pour permettre l'utilisation de disjoncteurs de classe S1 ou S2.

NOTE 2 Des cas particuliers d'application peuvent exister où la sous-station est alimentée par un seul transformateur et avec un courant de court-circuit pour le disjoncteur de transformateur égal à son pouvoir de coupure en court-circuit. Dans de tels cas, le pouvoir de coupure peut être démontré en effectuant la séquence d'essai T100, lorsque la liaison a une capacité suffisante, comme expliqué ci-dessus en a), ou alternativement une capacité peut être ajoutée pour obtenir les paramètres de TTR couverts par les valeurs des Tableaux 1 ou 2.

Tableau M.1 – Valeurs normales de la TTR inhérente pour T30, cas de disjoncteurs prévus pour être connectés à un transformateur avec une liaison de faible capacité – Tension assignée supérieure à 1 kV et inférieure à 100 kV – Représentation par deux paramètres

Tension assignée U_r Kv	Séquence d'essai	Facteur de 1^er pôle k_{pp} p.u.	Facteur d'ampli -tude k_{af} p.u.	Valeur de crête de TTR u_c kV	Temps t_3 µs	Temps de retard t_d µs	Tension u' kV	Temps t' µs	VATR [a] u_c/t_3 kV/µs
3,6	T30	1,5	1,6	7,1	4,5	1	2,4	2	1,58
4,76 [b]	T30	1,5	1,6	9,3	5,0	1	3,1	2	1,86
7,2	T30	1,5	1,6	14,1	5,5	1	4,7	3	2,56
8,25 [b]	T30	1,5	1,6	16,2	6,0	1	5,4	3	2,70
12	T30	1,5	1,6	23,5	6,5	1	7,8	3	3,62
15 [b]	T30	1,5	1,6	29,4	7,0	1	9,8	3	4,20
17,5	T30	1,5	1,6	34	7,5	1	11,4	4	4,53
24	T30	1,5	1,6	47	9,5	1	15,7	5	4,95
25,8 [b]	T30	1,5	1,6	51	9,5	1	16,9	5	5,37
36	T30	1,5	1,6	71	11,5	2	23,5	6	6,17
38 [b]	T30	1,5	1,6	74	11,5	2	24,8	6	6,43
48,3 [b]	T30	1,5	1,6	95	14	2	31,5	7	6,79
52	T30	1,5	1,6	102	14	2	34	7	7,29
72,5	T30	1,5	1,6	142	18	3	47,4	9	7,89

[a] VATR = vitesse d'accroissement de la tension rétablie.

[b] Utilisé en Amérique du Nord.

M.3 Disjoncteurs de tension assignée de 100 kV à 800 kV

Les valeurs normales de la tension transitoire de rétablissement présumée sont à l'étude par le CIGRÉ, aucune exigence d'essai n'est donc spécifiée.

M.4 Disjoncteurs de tension assignée supérieure à 800 kV

Des conditions sévères de TTR peuvent survenir lorsqu'un court-circuit a lieu juste derrière un transformateur sans aucune capacité appréciable entre le transformateur et le disjoncteur. Dans ce cas, la vitesse d'accroissement de la tension transitoire de rétablissement (VATR) dépasse les valeurs spécifiées pour les séquences d'essais de défaut aux bornes. Ceci est dû au fait que les capacités à la terre des transformateurs sont relativement petites, à savoir, 9 000 pF pour une tension assignée supérieure à 800 kV. La fréquence naturelle correspondante du transformateur conduit à une TTR ayant une vitesse d'accroissement approximativement égale à deux fois la valeur pour T10.

La TTR du réseau peut être modifiée par une capacité et elle se trouve alors dans l'enveloppe de performance de TTR normale. En variante, l'utilisateur peut choisir de spécifier un pouvoir de coupure de courant de défaut assigné limité par un transformateur (TLF).

Le courant de coupure de TLF est choisi dans la série R10 pour limiter le nombre de valeurs d'essai possibles. Pour les applications avec une tension assignée supérieure à 800 kV, les valeurs préférentielles sont de 10 kA et 12,5 kA.

Les paramètres de TTR sont calculés d'après le courant de TLF, la tension assignée et la capacité du transformateur de 9 nF. Le facteur de premier pôle correspondant à ce type de défaut est de 1,2. En attendant des études complémentaires, des valeurs sont prises avec prudence pour le facteur d'amplitude et la chute de tension aux bornes du transformateur. Celles-ci sont respectivement égales à 1,7 et 0,9.

Tableau M.2 – Valeurs normales de la tension transitoire de rétablissement présumée pour des disjoncteurs de tension assignée supérieure à 800 kV prévus pour être connectés à un transformateur avec une liaison de faible capacité

Tension assignée U_r kV	Courant de défaut de TLF kA eff. sym.	Facteur de 1er pôle k_{pp} p.u.	Facteur d'amplitude k_{af} p.u.	Valeur de crête de TTR u_c kV	Temps t_3 µs	Temps de retard t_d µs	Tension u' kV	Temps t' µs	VATR [a] u_c/t_3 kV/µs
1 100	10	1,2	1,7 × 0,9	1 649	107	16	550	51	15,4
1 100	12,5	1,2	1,7 × 0,9	1 649	96	14	550	46	17,2
1 200	10	1,2	1,7 × 0,9	1 799	112	17	600	54	16,1
1 200	12,5	1,2	1,7 × 0,9	1 799	100	15	600	48	18,0

[a] VATR = vitesse d'accroissement de la tension rétablie.

Annexe N
(normative)

Utilisation de caractéristiques mécaniques et exigences liées

Au début des essais de type, les caractéristiques mécaniques du disjoncteur doivent être déterminées, par exemple, en enregistrant les courbes de déplacement à vide. Ceci peut également être effectué par l'utilisation de paramètres caractéristiques, par exemple la vitesse momentanée après une certaine course, etc. Les caractéristiques mécaniques serviront de référence pour la caractérisation du comportement mécanique du disjoncteur.

Les caractéristiques mécaniques doivent être utilisées pour confirmer que les différents spécimens d'essais utilisés durant les essais de type mécaniques, d'établissement, de coupure et de manœuvre sont identiques au niveau mécanique. Tous les spécimens d'essais utilisés durant les essais de type mécaniques, d'établissement, de coupure et de manœuvre doivent avoir une caractéristique mécanique à l'intérieur des enveloppes décrites ci-dessous. Il convient de prendre des précautions dans l'interprétation des courbes lorsqu'en raison de méthodes de mesure variables dans différents laboratoires, une comparaison directe entre les enveloppes ne peut être effectuée.

Le type et l'emplacement du capteur utilisé pour l'enregistrement des caractéristiques mécaniques doivent être indiqués dans le rapport d'essai. La courbe des caractéristiques mécaniques qui peut être mesurée en tout point de la chaîne cinématique de puissance peut être enregistrée de manière continue ou discrète. Dans le cas d'une mesure discrète, il convient d'enregistrer au moins 20 valeurs discrètes pour la course complète.

Les caractéristiques mécaniques doivent être utilisées pour déterminer les limites des écarts acceptables au-dessus ou au-dessous de cette courbe de référence. A partir de cette courbe de référence, deux enveloppes doivent être tracées depuis l'instant de séparation des contacts jusqu'à la fin du déplacement des contacts pour la manœuvre d'ouverture et depuis le début du déplacement des contacts jusqu'à l'instant d'entrée en contact des contacts pour la manœuvre de fermeture. La distance des deux enveloppes par rapport à la course originale doit être de $\pm$ 5 % de la course totale, comme indiqué sur la Figure 23b. Dans le cas de disjoncteurs ayant une course totale inférieure ou égale à 40 mm, la distance entre les deux enveloppes et la courbe d'origine doit être de $\pm$2 mm. Il est reconnu que pour certaines conceptions de disjoncteurs, ces méthodes peuvent ne pas être appropriées, par exemple pour les disjoncteurs à vide ou pour certains disjoncteurs de tension assignée inférieure à 52 kV. Dans de tels cas, le constructeur doit définir une méthode appropriée pour vérifier le fonctionnement correct du disjoncteur.

Si des caractéristiques mécaniques autres que des courbes sont utilisées, le constructeur doit définir la méthode alternative et les tolérances utilisées.

Les Figures 23a à 23d sont données à titre illustratif et montrent seulement une manœuvre d'ouverture. Elles sont idéalisées, et ne montrent pas la variation en terme de profil causée par la friction des contacts ou les amortissements en fin de course. En particulier, il est important de noter que les effets d'amortissement ne sont pas montrés dans ces diagrammes. Les oscillations produites en fin de course dépendent de l'efficacité de l'amortissement du système d'entraînement. L'allure de ces oscillations peut être une fonction délibérée de la conception et peut varier légèrement d'un spécimen à un autre. Par conséquent, il est important que tous les écarts de la courbe en fin de course, hors marge de tolérance par rapport à l'enveloppe, soient clairement détaillés et interprétés avant d'être rejetés ou acceptés par rapport aux courbes de référence. En général, pour qu'elles soient acceptées, il convient que toutes les courbes soient à l'intérieur des enveloppes.

Les enveloppes peuvent être déplacées verticalement jusqu'à ce qu'une des courbes couvre la courbe de référence. Cela donne des tolérances maximales par rapport aux caractéristiques mécaniques de –0 %, +10 % et –10 %, +0 %, respectivement, comme représenté aux Figures 23c et 23d. Le déplacement de l'enveloppe peut être utilisé seulement une fois pour la procédure complète dans chaque essai, pour obtenir un écart total maximal de 10 % par rapport à la caractéristique de référence.

Le Tableau N.1 énumère les essais de type et les caractéristiques mécaniques de référence correspondantes pour les essais à vide, d'établissement et de coupure.

Tableau N.1 – Résumé des essais de type liés aux caractéristiques mécaniques

Paragraphes applicables	**Essais où les enregistrements doivent être pris**	**Méthode d'évaluation**	**Application/Notes**
6.101.1.1 Caractéristiques mécaniques	Essai à vide avant le début des essais de type	Non applicable	Guide général pour les caractéristiques mécaniques de référence
6.101.1.3 Caractéristiques et réglages du disjoncteur à enregistrer avant et après les essais	Avant et après les essais mécaniques et d'environnement	Non applicable	Eléments énumérés en 6.101.1.3 à enregistrer
6.101.2.2 Etat du disjoncteur avant l'essai (mécanique)	Essai à vide avant l'essai mécanique	[a]	Essai mécanique sur un seul pôle actionné séparément d'un disjoncteur tripolaire
6.101.2.5 Critères d'acceptation pour les essais de manœuvre mécanique	Essai à vide après l'essai mécanique	[b]	
6.101.3.3 Essai à basse température	Essai à vide avant et après l'essai à basse température	[b]	Selon une spécification de température minimale
6.101.3.4 Essai à haute température	Essai à vide avant et après l'essai à haute température	[b]	
6.101.4.2 Procédure d'essai (essai d'humidité)	Pendant et après les essais (manœuvres à vide)	[b]	Essai conditionnel si requis
6.101.6 Essai avec efforts statiques sur les bornes	Essai à vide avant et après l'essai avec efforts sur les bornes	[a]	Voir aussi la note de 6.101.6
6.102.2 Nombre de spécimens d'essais	Essai à vide avant les essais d'établissement et de coupure	[a]	Pour le deuxième spécimen d'essai, si plus d'un spécimen est utilisé
6.102.3.3 Disjoncteur à enveloppes multiples	Essai à vide avant l'essai	[a]	Pour les disjoncteurs à enveloppes multiples communément actionnés
	Manœuvres d'établissement et de coupure d'après la séquence d'essais T100s	[c]	
6.102.4.1 Essais unipolaires d'un seul pôle de disjoncteur tripolaire	Essai à vide avant l'essai	[a]	Pour les disjoncteurs avec un mécanisme d'entraînement commun
	Manœuvres d'établissement et de coupure d'après la séquence d'essais T100s	[c]	

Tableau N.1 *(suite)*

Paragraphes applicables	Essais où les enregistrements doivent être pris	Méthode d'évaluation	Application/Notes
6.102.4.2 Essais sur éléments séparés	Essai à vide avant l'essai	[a]	Pour les disjoncteurs avec deux ou plusieurs éléments, qui ne sont pas actionnés séparément à l'intérieur d'un pôle
	Manœuvres d'établissement et de coupure d'après la séquence d'essais T100s	[c]	
6.102.6 Manœuvre à vide avant les essais (d'établissement et de coupure)	Essais à vide avant l'essai [d]	[a, d]	Pour tous les essais d'établissement et de coupure
6.102.7 Mécanisme d'entraînement alternatif	Essai à vide avant l'essai	[a]	Pour les mécanismes d'entraînement alternatifs équivalents
	Manœuvres d'établissement et de coupure d'après la séquence d'essais T100s	[c]	
6.102.9.3 Etat après une séquence d'essais de court-circuit	Essais à vide après la séquence d'essais	[d]	Si les composants sont changés ou si la maintenance est effectuée après la séquence d'essais
6.102.9.3 Etat après une série d'essais de court-circuit	Essais à vide après la série d'essais	[d]	
6.112.2 Disjoncteurs de classe E2 prévus pour le cycle de refermeture automatique	Essais à vide après la série d'essais	[d]	Essai conditionnel si requis

[a] Evaluation de la méthode donnée en 6.101.1.1; comparaison des caractéristiques mécaniques.

[b] Evaluation de la méthode donnée en 6.101.1.3 et 6.101.1.4.

[c] Evaluation de la méthode donnée en 6.102.4.1 pour les essais unipolaires.

[d] Méthode d'essai donnée en 6.102.6.

Annexe O
(informative)

Lignes directrices pour la procédure d'essai d'établissement et de coupure de courants de court-circuit pour les disjoncteurs sous enveloppe métallique et à cuve mise à la terre

O.1 Introduction

La présente annexe contient des informations et des recommandations relatives aux circuits et aux procédures d'essais utilisées concernant les essais de type d'établissement et de coupure de courants de court-circuit et de courants de charge des disjoncteurs sous enveloppe métallique et à cuve mise à la terre. D'autres méthodes ne sont pas à écarter, à condition qu'elles apportent les contraintes correctes au disjoncteur. Les autres essais, tels que les essais diélectriques, les essais individuels de série, les essais de mise en service et les essais sur site ne font pas partie du domaine d'application de cette annexe.

Les différentes situations d'essais sont évaluées et des circuits d'essais spéciaux ainsi que des précautions particulières requises pour l'utilisation de circuits d'essais développés pour du matériel à isolement dans l'air sont indiqués. Les essais décrits peuvent en principe être effectués avec des circuits d'essais directs et des circuits d'essais synthétiques. Les essais synthétiques sont traités dans la CEI 62271-101.

O.2 Généralités

O.2.1 Caractéristiques particulières des disjoncteurs sous enveloppe métallique soumis aux essais d'établissement et de coupure

Les disjoncteurs sous enveloppe métallique doivent assurer leurs fonctions dans des conditions qui sont différentes de celles qui prévalent dans les enveloppes isolantes.

Les principales caractéristiques susceptibles d'avoir des conséquences sur les essais d'établissement et de coupure sont les suivantes:

a) Les éléments de coupure font partie intégrante de la structure d'un poste donné. Par conséquent, les composants du poste qui sont voisins des éléments de coupure doivent être pris en compte lors de la détermination des conditions d'essais.

b) Plusieurs éléments de coupure d'un pôle, voire des trois pôles, peuvent être placés dans une enveloppe commune. Divers composants des éléments de coupure du poste aussi bien que des parties sous tension ou mises à la terre sont très proches les uns des autres du fait de la résistance disruptive élevée du milieu isolant. Ce phénomène peut générer de fortes interactions, de nature physique variée, entre les pièces des éléments de coupure et leur environnement. Il en résulte également une haute valeur de la capacité et une faible valeur de l'inductance des éléments soumis aux essais et des éléments avoisinants.

   Les conséquences de telles interactions doivent être prises en compte lors de la détermination des exigences d'essais.

c) Dans les installations sous enveloppe métallique, les surfaces isolantes sont exposées à une contrainte diélectrique relativement élevée, ce qui peut les rendre sensibles aux dépôts.

O.2.2 Nombre réduit d'éléments destinés aux essais

Dans les installations d'essais à grande puissance, les dispositifs d'essais utilisés ne permettent pas toujours de soumettre un disjoncteur complet ou un pôle entier aux essais, même dans des laboratoires utilisant des circuits d'essais synthétiques.

Par conséquent, il peut être nécessaire d'effectuer les essais sur des parties d'un disjoncteur complet.

En fonction du choix qui est fait, il convient d'analyser les interactions existant entre l'élément soumis à l'essai et les éléments non soumis à l'essai:

– interactions entre les éléments des disjoncteurs et les parties environnantes du poste;
– interactions entre les pôles, ou entre les pôles et l'enveloppe;
– interactions entre les différents éléments, ou entre les éléments et l'enveloppe.

Dans cette étude, il est nécessaire de faire la distinction entre:

– un pôle unique situé dans une seule enveloppe et
– trois pôles situés dans une même enveloppe.

Il est, par ailleurs, nécessaire de faire la distinction entre deux types différents de contraintes qui peuvent, habituellement, être traités séparément:

– contrainte de l'intervalle de coupure;
– contrainte de l'isolation entre les phases adjacentes ou entre les phases et l'enveloppe.

O.2.3 Description générale des caractéristiques particulières et des interactions éventuelles

Lorsque les interactions sont susceptibles d'influencer les résultats des essais et ne peuvent pas être prises en compte lors des essais sur les éléments séparés ou sur un pôle unique, les essais doivent être effectués sur un pôle entier ou sur trois pôles.

O.2.3.1 Influence des éléments environnants du poste

Des éléments intégrés, par exemple des tronçons de jeux de barres, des câbles d'alimentation, des traversées, des transformateurs de tension ou des parafoudres sont susceptibles d'influencer les contraintes prévues du circuit d'essai.

L'influence de ces éléments intégrés au système dépend de la séquence d'essais. Ainsi, dans le cas du défaut proche en ligne et du défaut aux bornes avec TTRI, la capacité élevée des éléments environnants réduit la contrainte exercée sur le disjoncteur alors que, d'un autre côté, la fermeture et l'ouverture d'une batterie de condensateurs peut s'avérer plus sévère lorsque des connexions de faible impédance sont utilisées.

O.2.3.2 Interaction entre les pôles, les éléments de coupure et les enveloppes

Divers types d'interactions, de nature physique différente, sont susceptibles de se produire entre les éléments du disjoncteur considéré. Les plus importantes sont:

– mécaniques;
– électrostatiques;
– électromagnétiques;
– dues à la dynamique des gaz.

Dans la plupart des cas, l'intensité de ces interactions dépendra de la conception spécifique de l'objet soumis à l'essai. Si une interaction particulière est éliminée pour un modèle donné, il n'est plus nécessaire d'ajuster les essais pour couvrir cette interaction. Dans ce cas, il est nécessaire de démontrer à l'aide d'un calcul type ou d'une démonstration expérimentale faisant appel à des méthodes de mesure spéciales que l'interaction considérée a une influence négligeable sur les résultats de l'essai. Il est possible d'effectuer la même démonstration pour juger du niveau d'interaction qui doit être représenté lors des essais.De plus, le cas d'un appareil de connexion dont la configuration n'est pas symétrique par rapport aux bornes doit être pris en considération.

O.2.3.2.1 Interaction mécanique

Les paragraphes 6.102.3 et 6.102.4 s'appliquent.

O.2.3.2.2 Interaction électrostatique

Le paragraphe 6.102.4.2.2 s'applique.

La répartition de la tension entre les éléments des disjoncteurs à plusieurs chambres de coupure ainsi que le champ électrique dans l'intervalle de contact sont influencés par les capacités élevées et, en particulier, par la présence de l'enveloppe mise à la terre et des autres parties sous tension. Lors de séquences d'essais différentes et dans d'autres conditions de mise à la terre, cela peut se révéler différent.

La répartition de la tension entre les éléments peut être déterminée en fonction de la capacité entre les éléments et par rapport à l'enveloppe. Les gradients maximaux sur les surfaces de contact dépendent également du nombre de chambres de coupure et, pour le même disjoncteur, de la position de l'élément de coupure dans le disjoncteur, même lorsque l'on suppose que la répartition de la tension est idéale.

Le champ électrique dans l'intervalle de coupure est influencé par les facteurs suivants:

– faibles distances entre les éléments sous tension et l'enveloppe;
– présence d'éléments adjacents sous tension.

Dans ce cas, la détermination d'une contrainte représentative dépend de la conception spécifique du disjoncteur et de l'emplacement de la zone de contrainte la plus critique.

O.2.3.2.3 Interaction électromagnétique

Les disjoncteurs unipolaires et les disjoncteurs tripolaires peuvent subir des interactions électromagnétiques susceptibles de générer des forces supplémentaires sur les arcs et sur les pièces en mouvement. Lorsque trois pôles sont situés dans une seule enveloppe, l'interaction entre phases est accentuée.

Les courants induits et les courants de retour dans l'enveloppe sont susceptibles de provoquer d'autres effets, par exemple, une chute de tension entre les éléments mis à la terre qui détériore les matériels auxiliaires ou de protection.

O.2.3.2.4 Interaction due à la dynamique des gaz

Les gaz d'échappement chauds, ionisés et/ou pollués sont susceptibles d'influencer la tenue diélectrique entre les pôles situés dans une enveloppe commune et entre le ou les pôles et l'enveloppe. Des effets analogues peuvent apparaître entre les éléments d'un pôle qui comporte plus d'un élément de coupure.

O.3 Essais d'un pôle unique dans une seule enveloppe

O.3.1 Essais d'établissement et de coupure en court-circuit

Les circuits d'essai doivent être conformes aux Figures 25a, 26a, 27a et 28a. Les circuits d'essai 25b, 26b, 27b et 28b ne soumettent pas les disjoncteurs sous enveloppe métallique et à cuve mise à la terre à des contraintes correctes dans des conditions de défaut à la terre.

Les conditions de 6.102 doivent être remplies. Les circuits d'essais synthétiques doivent être conformes aux Articles 4, 5 et 6 de la CEI 62271-101.

Deux situations doivent être prises en compte pour les essais monophasés:

a) essais unipolaires des disjoncteurs tripolaires (voir O.3.1.1);

b) essais par éléments séparés (voir O.3.1.2).

O.3.1.1 Essais unipolaires des disjoncteurs tripolaires

Lorsque les circuits d'essai montrés dans les Figures 27a et 28a sont utilisés, la pleine tension doit être appliquée à l'une des bornes du disjoncteur, l'autre borne et l'enveloppe étant mises à la terre. Il est préférable de choisir une tension de rétablissement alternative. Les circuits conventionnels directs ou synthétiques doivent être utilisés.

O.3.1.2 Essais par éléments séparés

Il est nécessaire de prendre des précautions particulières en ce qui concerne les interactions (voir 6.102.4.2.1 b)).

Les contraintes de tension requises durant les essais par éléments séparés sont:

– les tensions transitoires de rétablissement du pôle complet et les tensions de rétablissement entre les éléments sous tension correspondants et les enveloppes. Il est préférable d'utiliser une tension de rétablissement alternative;

– la portion de ces tensions, dépendant du nombre d'éléments soumis aux essais et de la répartition de la tension, traversant l'élément (les éléments) soumis aux essais.

Tous les éléments doivent interrompre le courant de court-circuit, ce qui assure une interaction correcte entre les éléments et une influence correcte sur les isolations situées entre les éléments sous tension et l'enveloppe.

Cette méthode d'essai ne peut être utilisée que si le disjoncteur est alimenté par une troisième traversée.

Cette traversée, connectée entre le ou les éléments soumis aux essais et le circuit de tension, permet l'utilisation de la ou des autres éléments comme disjoncteur auxiliaire. Il convient que cette traversée ne génère pas d'interaction mécanique, électrostatique ou magnétique avec l'élément ou les éléments soumis aux essais.

La CEI 62271-101 représente le circuit synthétique par injection de courant et de tension. Il consiste en:

– un circuit d'essai synthétique conventionnel qui fournit la portion requise de la TTR totale entre les bornes du ou des éléments soumis à l'essai u_{B};

– un circuit d'essai supplémentaire (synthétique, source de courant continu ou alternatif) qui alimente l'enveloppe, isolée de la terre, à une tension appropriée u_{E}.

La CEI 62271-101 illustre un exemple d'essai effectué sur un demi-pôle et montre les tensions requises u_{B} et u_{E}, ainsi que la tension u_{A} qui en résulte entre la borne de l'élément (ou des éléments) unités auxiliaires connectés au circuit de courant et l'enveloppe. Les contraintes de tension du pôle complet sont appliquées entre la borne mise à la terre des éléments soumis à l'essai et l'enveloppe.

Lorsqu'il est impossible d'appliquer simultanément les contraintes de tension u_{B} et u_{E}, il est possible d'utiliser une méthode d'essai en plusieurs parties (voir 6.102.4.3). Dans la première partie, seules les performances des éléments soumis à l'essai sont vérifiées (l'enveloppe du disjoncteur est mise à la terre). Dans la seconde partie, l'isolation entre les éléments sous tension du pôle et l'enveloppe est vérifiée. Ceci peut être fait en faisant interrompre le courant de court-circuit par tous les éléments du pôle, mais sous tension réduite (en fonction de la source de courant disponible) et en appliquant une tension entre l'enveloppe isolée et la terre. Au moment où se produit le pic de la TTR, la valeur instantanée de la tension appliquée à l'enveloppe doit être égale à la différence entre la «tension réduite» et le pic de la TTR devant être appliquée entre la borne subissant la contrainte et l'enveloppe.

Il existe des circuits d'essai ne faisant pas appel à une troisième traversée. La tension requise aux bornes de l'élément soumis à l'essai est produite en shuntant les autres éléments à l'aide de gros condensateurs. De tels circuits ne sont pas valables pour l'intervalle d'interaction et ne peuvent être utilisés qu'après accord entre le constructeur et l'utilisateur. Ces circuits peuvent être utilisés pour les séquences d'essais de court-circuit de base, si le comportement thermique du disjoncteur durant l'intervalle d'interaction est vérifié séparément (par exemple soit par un essai en deux parties, soit en réalisant les essais de défaut proche en ligne).

Une attention particulière doit être portée aux durées d'arc des séquences d'essais de court-circuit de base pour qu'elles ne soient pas très différentes de celles obtenues lors de l'essai thermique de vérification.

NOTE 1 Dans le passé, des essais par éléments séparés ont été effectués avec un circuit d'essai dans lequel tous les éléments ne coupaient pas le courant de court-circuit. Un tel circuit d'essai ne peut être utilisé que dans les cas où l'interaction due à la circulation de gaz est négligeable. Ce n'est généralement pas le cas et ceci est aussi très difficile à prouver.

Dans ce circuit, une partie du disjoncteur a été court-circuitée. On suppose que cela n'entraîne aucune interaction mécanique, électrostatique ou électromagnétique et il convient de porter une attention particulière à l'interaction due à la circulation de gaz.

La CEI 62271-101 représente les circuits d’essais synthétiques appropriés pour injection de courant et de tension.

La valeur et la polarité de la tension u_E, à appliquer à l'enveloppe sont telles que la tension qui en résulte entre la borne alimentée du disjoncteur et l'enveloppe est égale à la valeur requise pour la tension d'essai du pôle complet.

NOTE 2 Pour la plupart des disjoncteurs, l'isolation entre les éléments sous tension et l'enveloppe durant l'établissement et la coupure des courants de court-circuit peut être vérifiée à l'aide des séquences d'essais de court-circuit T100s et T100a. Les séquences d'essais de court-circuit T10, T30 et T60 peuvent être effectuées en appliquant les méthodes d'essais par éléments séparés conventionnelles.

NOTE 3 La technique de transmission par fibres optiques peut être utilisée avec succès pour découpler le circuit de commande du disjoncteur de l'enveloppe sous tension; le courant nécessaire à la fermeture et au fonctionnement de la bobine d'excitation peut être fourni par une génératrice à turbine entraînée par de l'air comprimé.

O.3.2 Essais de défaut proche en ligne

Lorsqu'on utilise une méthode d'essai synthétique, le paragraphe 6.109 de la CEI 62271-100 et 4.2.1, 4.2.2 et 6.109 de la CEI 62271-101 s'appliquent.

Si les séquences d'essais de court-circuit de base ont été effectuées, il n'est pas nécessaire de porter une attention particulière à l'isolation entre les éléments sous tension et l'enveloppe lors des essais de défaut proche en ligne.

O.3.3 Essais d’établissement et de coupure de courants capacitifs

La méthode d'essai doit être conforme aux exigences de 6.111.

Le Tableau O.1 donne les tensions côté source et côté charge ainsi que les tensions de rétablissement au cours de l’établissement et de la coupure de courants capacitifs en triphasé dans les conditions réelles de service.

Le Tableau O.2 donne les valeurs correspondantes des tensions côté source, côté charge ainsi que des tensions de rétablissement au cours de l’établissement et de la coupure de courants capacitifs en monophasé.

Si, au cours des essais de vérification de la capacité de tenue de la tension de rétablissement entre les contacts (voir 6.111.5), les tensions appliquées côté source et côté charge sont au moins égales aux valeurs requises entre les parties sous tension et l’enveloppe données aux Tableaux O.1 et O.2, des essais supplémentaires ne sont pas nécessaires.

Pour les essais monophasés, conformément à 6.111.7, la contrainte diélectrique entre les parties sous tension et l'enveloppe n'est pas toujours correctement reproduite. Il convient que la vérification de la tenue diélectrique entre les parties sous tension et l'enveloppe soit effectuée et elle est obtenue par toute méthode d'essai démontrant la tenue entre les parties sous tension et l'enveloppe des valeurs données au Tableau O.2.

Pour les essais monophasés effectués pour démontrer l'établissement et la coupure en triphasé des batteries de condensateurs avec un réseau à neutre non relié à la terre et l'établissement et la coupure dans des réseaux à neutre relié non effectivement à la terre, la résistance diélectrique peut être démontrée par l'une des méthodes d'essais suivantes, sans s'y limiter:

a) Essais d'établissement et de coupure avec un point de mise à la terre intermédiaire côté source ou côté charge, entraînant une tension entre les parties sous tension côté source et l'enveloppe de $1{,}5 \times U_r \sqrt{2} / \sqrt{3}$ et une tension de rétablissement de $2{,}8 \times U_r \sqrt{2} / \sqrt{3}$.

b) Essais diélectriques complémentaires aux essais d'établissement et de coupure, conformément à 6.111.7, dans le but d'appliquer des contraintes diélectriques appropriées de tension continue et/ou à fréquence industrielle entres les bornes et l'enveloppe. Il convient d'appliquer la tension à fréquence industrielle au niveau de la borne située du côté source du disjoncteur et de la maintenir pendant 1 min. Il convient d'appliquer la tension continue avec les deux polarités, au niveau de la borne située du côté charge du disjoncteur et de la maintenir pendant 0,3 s. Les tensions peuvent être appliquées sur les bornes en plusieurs étapes.

c) Sous réserve d'un accord du constructeur, les essais peuvent être réalisés avec un circuit d'alimentation comportant un neutre relié à la terre et une tension d'alimentation de $1{,}5 \times U_r \sqrt{2} / \sqrt{3}$.

Tableau O.1 – Etablissement-coupure d'un courant capacitif triphasé dans des conditions réelles de fonctionnement: valeurs habituelles de la tension côté source, de la tension côté charge et de la tension de rétablissement

Tension aux bornes du disjoncteur	Valeurs des tensions pour les réseaux à neutre relié effectivement à la terre			Valeurs des tensions pour les réseaux à neutre relié non effectivement à la terre
	Condensateurs non reliés à la terre	**Batteries de condensateurs reliées à la terre et câbles blindés**	**Lignes**	**Dans tous les cas**
$U_{C/E}$	$U_r \sqrt{2} / \sqrt{3}$	$U_r \sqrt{2} / \sqrt{3}$	$U_r \sqrt{2} / \sqrt{3}$	$1{,}5 \times U_r \sqrt{2} / \sqrt{3}$
$U_{C'/E}$	$1{,}5 \times U_r \sqrt{2} / \sqrt{3}$	$U_r \sqrt{2} / \sqrt{3}$	$1{,}2 \times U_r \sqrt{2} / \sqrt{3}$	$U_r \sqrt{2} / \sqrt{3}$
$U_{C/C'}$	$2{,}5 \times U_r \sqrt{2} / \sqrt{3}$	$2 \times U_r \sqrt{2} / \sqrt{3}$	$2{,}2 \times U_r \sqrt{2} / \sqrt{3}$	$2{,}5 \times U_r \sqrt{2} / \sqrt{3}$

On suppose que le pôle C est le premier pôle qui coupe.

C: côté alimentation C': côté charge C/C': entre contacts ouverts

U_r = tension assignée

$U_{C/E}$ = tension entre la borne côté source et la terre

$U_{C'/E}$ = tension entre la borne côté charge et la terre

$U_{C/C'}$ = tension entre contacts ouverts

NOTE 1 Les valeurs indiquées pour les réseaux à neutre relié non effectivement à la terre s'appliquent si la capacité homopolaire du circuit d'alimentation est négligeable par rapport à celle du circuit de charge.

NOTE 2 La désignation des pôles est illustrée à la Figure O.1.

Tableau O.2 – Essais d'établissement et de coupure de courants capacitifs correspondants, conformément à 6.111.7 pour les essais de laboratoire en monophasé. Valeurs de la tension côté source, de la tension côté charge et de la tension de rétablissement

Tension aux bornes du disjoncteur	Valeurs des tensions pour les réseaux à neutre relié effectivement à la terre			Valeurs des tensions pour les réseaux à neutre relié non effectivement à la terre
	Batteries de condensateurs non reliées à la terre	Batteries de condensateurs reliées à la terre et câbles blindés	Lignes	Dans tous les cas
$U_{C/E}$	$1{,}3 \times U_r \sqrt{2} / \sqrt{3}$	$U_r \sqrt{2} / \sqrt{3}$	$1{,}2 \times U_r \sqrt{2} / \sqrt{3}$	$1{,}5 \times U_r \sqrt{2} / \sqrt{3}$
$U_{C'/E}$	$1{,}5 \times U_r \sqrt{2} / \sqrt{3}$	$U_r \sqrt{2} / \sqrt{3}$	$1{,}2 \times U_r \sqrt{2} / \sqrt{3}$	$1{,}3 \times U_r \sqrt{2} / \sqrt{3}$
$U_{C/C'}$	$2{,}8 \times U_r \sqrt{2} / \sqrt{3}$	$2 \times U_r \sqrt{2} / \sqrt{3}$	$2{,}4 \times U_r \sqrt{2} / \sqrt{3}$	$2{,}8 \times U_r \sqrt{2} / \sqrt{3}$

On suppose que le pôle C est le premier pôle qui coupe.

C: côté alimentation C': côté charge C/C': entre contacts ouverts

U_r = tension assignée

$U_{C/E}$ = tension entre la borne côté source et la terre

$U_{C'/E}$ = tension entre la borne côté charge et la terre

$U_{C/C'}$ = tension entre contacts ouverts

NOTE La désignation des pôles est illustrée à la Figure O.1.

En plus des conditions des Tableaux O.1 et O.2, les alinéas suivants donnent des informations concernant les points d) et e) de 6.111.7.

Avec une alimentation à neutre relié effectivement à la terre, et en présence de défauts monophasés ou biphasés à la terre, les tensions des phases saines peuvent atteindre $1{,}4 \times U_r \sqrt{2} / \sqrt{3}$. La valeur exacte dépend des impédances homopolaires. Dans ce cas, les valeurs des tensions sur les bornes côté source et côté charge par rapport à la terre qu'il convient de prendre en considération sont:

– $U_{C/E} = U_{C'/E} = 1{,}4 \times U_r \sqrt{2} / \sqrt{3}$

– $U_{C/C'} = 2{,}8 \times U_r \sqrt{2} / \sqrt{3}$ (tension de rétablissement)

Avec une alimentation à neutre relié non effectivement à la terre, et en présence de défauts monophasés ou biphasés à la terre, les tensions des phases saines peuvent atteindre approximativement $1{,}7 \times U_r \sqrt{2} / \sqrt{3}$.

Dans ce cas, les valeurs des tensions sur les bornes côté source et côté charge par rapport à la terre qu'il convient de prendre en considération sont:

– $U_{C/E} = U_{C'/E} = 1{,}7 \times U_r \sqrt{2} / \sqrt{3}$

– $U_{C/C'} = 3{,}4 \times U_r \sqrt{2} / \sqrt{3}$ (tension de rétablissement)

O.3.3.1 Essais unipolaires des disjoncteurs tripolaires

Il est nécessaire d'utiliser des circuits directs ou des circuits synthétiques.

Dans certains circuits d'essais synthétiques, les deux tensions sont combinées à l'une des bornes du disjoncteur, l'autre borne étant reliée à la terre.

Cette condition est plus sévère en ce qui concerne l'isolation à la terre et peut avoir une influence sur la sévérité de l'essai aux bornes du disjoncteur.

Une contrainte de tension de polarisation peut être appliquée à l'enveloppe pour compenser cet effet.

La CEI 62271-101 illustre des solutions possibles pouvant être appliquées au circuit d'injection de courant et au circuit utilisant deux sources à fréquence industrielle.

O.3.3.2 Essais par éléments séparés

Il est nécessaire de tenir compte de la distorsion locale de champ dans l'intervalle séparant des éléments voisins tels que les enveloppes. Dans certains cas, en fonction du nombre de chambres d'un pôle, les circuits d'essai ne reproduisent pas les tensions de rétablissement continues et alternatives demandées entre les éléments sous tension de la ou des chambres soumises à l'essai et l'enveloppe.

Les essais par éléments séparés ne sont acceptables que si l'intensité du champ par rapport à la terre sur l'une des bornes est égale à l'intensité du champ à la terre lors des essais du pôle complet. Cette condition peut être satisfaite en:

– soumettant l'enveloppe du disjoncteur, isolée de la terre, à une tension appropriée ;
– effectuant des essais sur un demi-pôle, les deux tensions (continue et alternative) étant superposées sur l'une des bornes et l'autre borne étant reliée à la terre.

O.3.4 Etablissement et coupure en discordance de phases

Le paragraphe 6.110 s'applique.

Les considérations suivantes sont applicables:

– durant ces essais, les interactions mécaniques, magnétiques et les interactions dues à la dynamique des gaz sont faibles et de moindre importance que celles apparaissant dans des conditions d'essais de défaut en court-circuit et de défaut proche en ligne;
– la contrainte de tension entre les phases et l'enveloppe aussi bien qu'entre phases pourrait être égale ou inférieure à celle qui est appliquée dans les conditions d'essai de court-circuit.

NOTE Il est recommandé de relier l'enveloppe à la terre et d'appliquer des contraintes de tension aux deux côtés du disjoncteur afin de simuler les conditions du réseau.

La mise à la terre de l'enveloppe et de l'une des bornes génère une contrainte plus importante entre les phases et l'enveloppe; cette configuration d'essai doit, par conséquent, faire l'objet d'un accord avec le constructeur.

Pour les besoins des essais, deux situations doivent être prises en considération:

a) essais unipolaires des disjoncteurs tripolaires (voir O.3.4.1);
b) essais par éléments séparés (voir O.3.4.2).

O.3.4.1 Essais unipolaires des disjoncteurs tripolaires

Il est possible d'utiliser une méthode d'essai directe ou synthétique, réalisée dans un circuit symétrique tel qu'indiqué à la Figure 51, en appliquant les tensions aux deux côtés, l'enveloppe étant reliée à la terre. Il est préférable d'utiliser une tension de rétablissement alternative.

Les circuits d’essais synthétiques sont décrits dans la CEI 62271-101.

Par ailleurs, il est possible d'utiliser un circuit conventionnel direct ou synthétique, l'une des bornes du disjoncteur étant reliée à la terre et l'enveloppe étant sous tension et isolée de la terre.

O.3.4.2 Essais par éléments séparés

Afin de reproduire la contrainte de tension exacte entre les bornes et l'enveloppe, l'enveloppe doit être isolée et mise sous tension en utilisant une source de tension telle que celle décrite en O.3.1.2.

Les essais par éléments séparés avec mise à la terre de l'enveloppe et de l'une des bornes du disjoncteur sont tolérés sous réserve que la contrainte de tension requise entre les bornes et l'enveloppe ait déjà été vérifiée au cours des essais de court-circuit.

O.4 Essais de trois pôles dans une seule enveloppe

O.4.1 Essais de défaut aux bornes

Lorsqu'un circuit direct est disponible pour effectuer les essais sur le disjoncteur triphasé, les essais directs couvriront toutes les contraintes.

Lorsqu'une méthode synthétique est utilisée, les exigences générales suivantes doivent être satisfaites pour s'assurer que les contraintes appropriées sont appliquées aux organes de coupure et entre les bornes et l'enveloppe.

a) Les trois pôles du disjoncteur en essai doivent être alimentés avec le plein courant triphasé.

NOTE Les séquences d’essais de court-circuit T10, T30 et T60 peuvent être réalisées dans les circuits d’essais monophasés.

b) Les informations concernant les circuits d’essai requis pour les séquences d’essais T100s et T100a sont données dans la CEI 62271-101.

c) Les contraintes maximales pour la TTR et la tension rétablie (TR), entre les différents pôles et entre les pôles et l'enveloppe, sont données aux Tableaux O.3 et O.4 (voir également les Figures O.2 et O.3).

Ces contraintes peuvent être appliquées en utilisant les circuits synthétiques décrits dans la CEI 62271-101.

En ce qui concerne la séquence d'essais T100a, il est recommandé de se reporter à la CEI 62271-101. Il convient que la tension de rétablissement soit, de préférence, alternative.

Tableau O.3 – Séquences d'essais T10, T30, T60 et T100s – Facteur de premier pôle: 1,5. Valeurs de tension au cours de la coupure triphasée

Crête de TTR / Crête de TTR du premier pôle %				Crête de TR	d*u*/d*t*
		Pour la coupure du premier pôle	Pour la coupure du second pôle	p.u.	%
Phases	a	0	58	1	70
	b	0	58	1	70
	c	100	-	1	100
Entre phases	a-b	0	115	1,732	
	b-c	100	58	1,732	
	c-a	100	58	1,732	
u_c = crête de TTR du premier pôle = 1,5 × 1,4×$U_r\sqrt{2}/\sqrt{3}$ 1 p.u. = $U_r\sqrt{2}/\sqrt{3}$ Le premier pôle qui coupe se situe sur la phase c.					

Tableau O.4 – Séquences d'essais T10, T30, T60 et T100s – Facteur de premier pôle: 1,3. Valeurs de tension au cours de la coupure triphasée

Crête de TTR / Crête de TTR du premier pôle %					Crête de TR	d*u*/d*t*
		Pour la coupure du premier pôle	Pour la coupure du second pôle	Pour la coupure du troisième pôle	p.u.	%
Phases	a	0	0	77	1	70
	b	0	98	-	1	95
	c	100	-	-	1	100
Entre phases	a-b	0	98	98	1,732	
	b-c	100	89	-	1,732	
	c-a	100	-	91	1,732	
u_c = crête de TTR du premier pôle = 1,3 × 1,4×$U_r\sqrt{2}/\sqrt{3}$ 1 p.u. = $U_r\sqrt{2}/\sqrt{3}$ Le premier pôle qui coupe se situe sur la phase c.						

d) Conformément aux exigences de 6.105.1 et dans le but de réduire au minimum l'intervalle de temps et d'éviter aussi le changement du raccordement du circuit haute tension au disjoncteur entre les essais de chaque séquence d'essais, toutes les durées d'arc requises doivent être appliquées sur la même phase.

e) Il convient d'appliquer toutes les contraintes mentionnées ci-dessus au cours du même essai. Lorsque cela se révèle impossible, une méthode d'essai en plusieurs parties peut être autorisée.

O.4.2 Essais de défaut proche en ligne

L'essai est fondé sur l'interruption de défaut monophasé à la terre comme pour l'enveloppe à pôle unique (voir O.3.2).

Par conséquent, un seul pôle doit être soumis aux contraintes exercées par le courant de court-circuit et la pleine tension. Les paragraphes 6.102.3 et 6.102.4 s'appliquent.

O.4.3 Essais d'établissement et de coupure de courants capacitifs

Il est recommandé d'effectuer des essais triphasés.

Dans le cas d'essais monophasés, il est nécessaire d'effectuer des essais diélectriques supplémentaires (voir O.3.3). Dans le cas d'essais triphasés, l'isolation à la terre et l'isolation entre phases doivent être prises en compte. Ces essais diélectriques peuvent être effectués séparément, dans la mesure où cela est requis.

Tableau O.5 – Etablissement et coupure de courants capacitifs dans des conditions réelles de fonctionnement: valeurs typiques de tension maximales

Tension entre bornes	Réseaux à neutre relié effectivement à la terre			Réseaux à neutre relié non effectivement à la terre
	Batteries de condensateurs non reliées à la terre p.u.	Batteries de condensateurs reliées à la terre p.u.	Lignes p.u.	p.u.
A-terre	1,0	1,0	1,0	1,5
A'-terre	1,5	1,0	1,2	1,0
A-A'	2,5	2,0	2,2	2,5
A'-B'	≤1,73	≤1,73	≤1,73	≤1,73
A'-C'	2,37	2,0	2,1	2,37
B'-C'	≤1,73	2,0	1,9	≤1,73
A-B'	1,87	2,0	2,0	1,87
A-C'	1,87	2,0	1,9	1,87
B-A'	2,5	2,0	2,2	2,5
B-C'	1,87	2,0	1,9	1,87
C-A'	2,5	2,0	2,2	2,5
C-B'	1,87	2,0	2,0	1,87

A-A' Premier pôle qui coupe A = Côté source A' = Côté charge

NOTE 1 Les valeurs indiquées pour les réseaux à neutre relié non effectivement à la terre s'appliquent si la capacité homopolaire du circuit d'alimentation est négligeable par rapport à celle du circuit de charge.

NOTE 2 1 p.u. = $U_r \times \sqrt{2} / \sqrt{3}$

NOTE 3 Les pôles B et C coupent au premier passage par zéro du courant après la coupure du pôle A.

NOTE 4 Les valeurs de tension pour A-B, A-C et B-C sont dans tous les cas égales à $U_r\sqrt{2}$.

NOTE 5 Les tensions B-terre, B′-terre, B-B' et C-terre, C'-terre et C-C' ne sont pas dans le tableau parce que leurs valeurs sont plus faibles que celles du pôle A.

O.4.4 Essai d'établissement et de coupure en discordance de phases

Il est possible d'effectuer des essais monophasés. Les essais triphasés ne sont pas considérés comme nécessaires, étant donné les valeurs relativement faibles des courants et de la tension par rapport à l'enveloppe du fait du partage de la tension entre les deux côtés du disjoncteur.

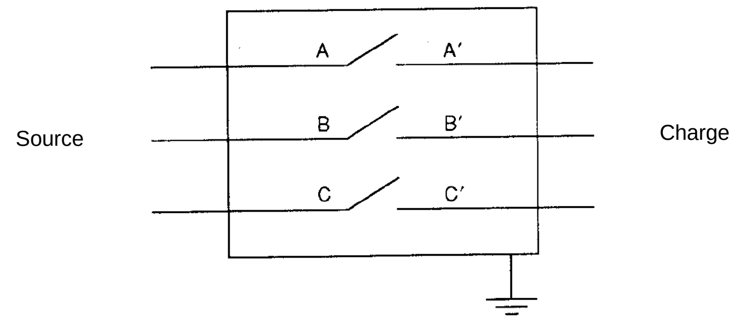


Figure O.1 – Configuration d’essai prise en compte dans les Tableaux O.1 et O.2

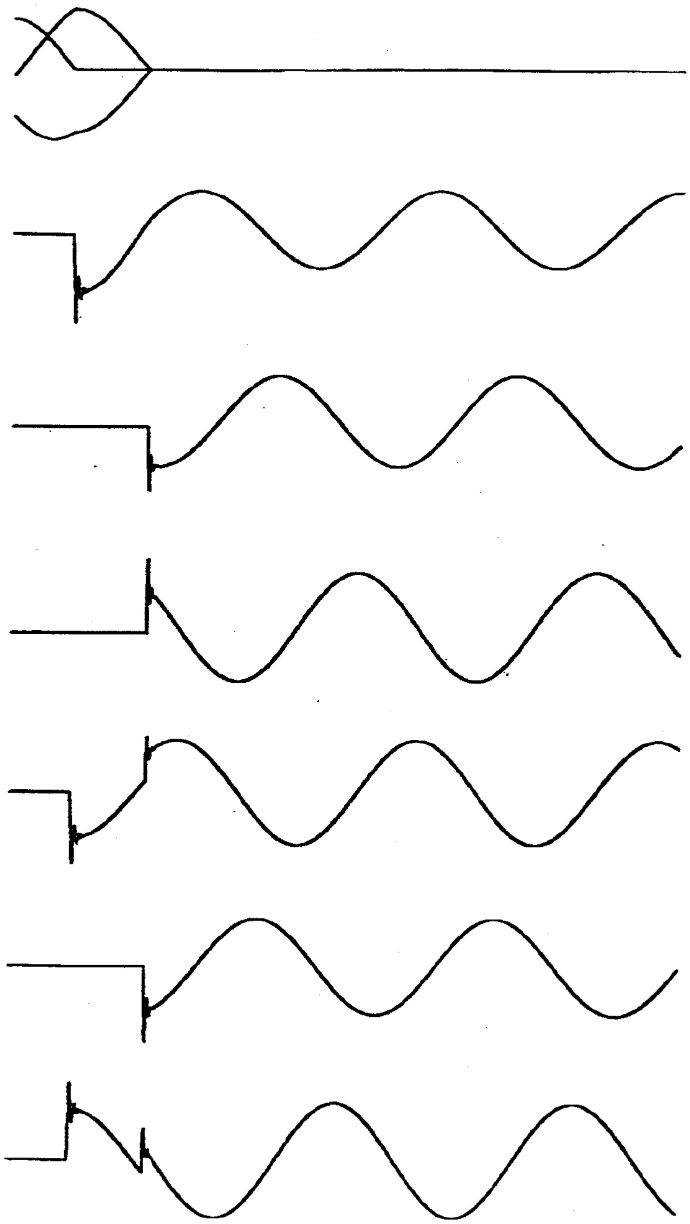


Figure O.2 – Exemple illustrant les formes d'ondes des courants symétriques, des tensions phase-terre et phase-phase, durant une coupure triphasée, telle que celle de la Figure 25a

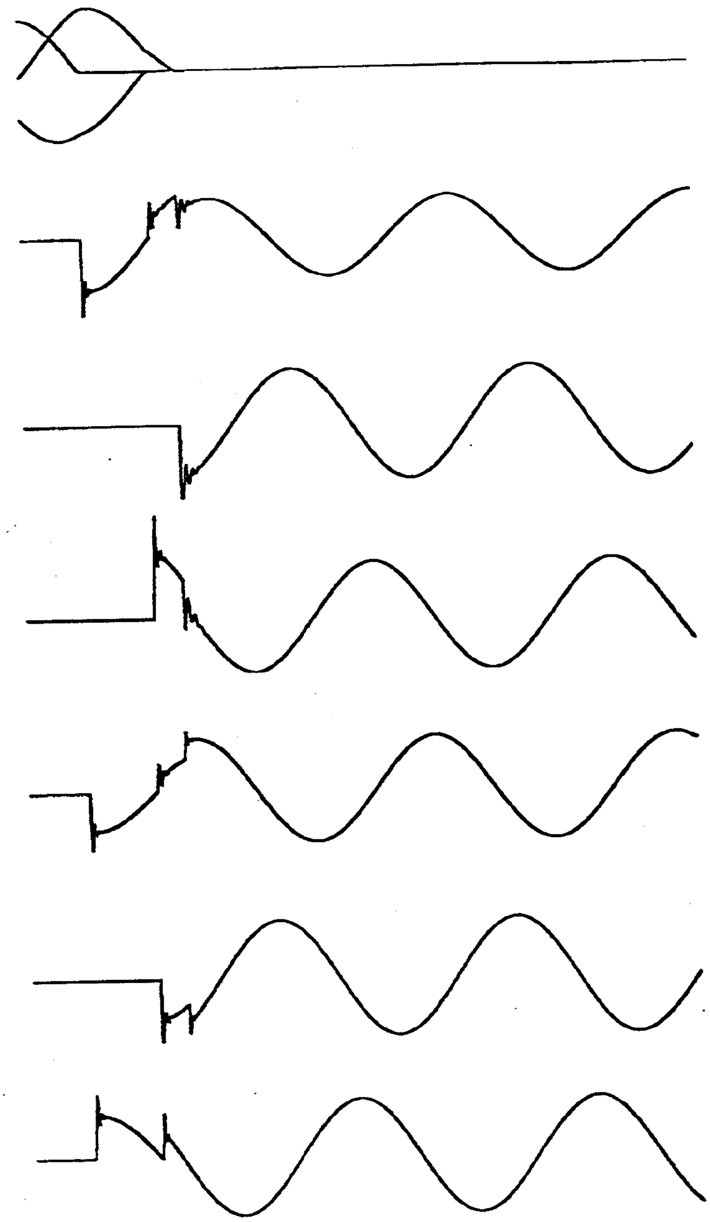


Figure O.3 – Exemple illustrant les formes d'ondes des courants symétriques, des tensions phase-terre et phase-phase, durant une coupure triphasée, telle que celle de la Figure 26a

Annexe P
(normative)

Calcul des paramètres de la TTR durant des conditions de défauts asymétriques (T100a)

Cette annexe s'applique pour le calcul des paramètres de la TTR présumée lors de conditions de défauts asymétriques.

NOTE 1 Le calcul présenté dans cette annexe s'applique uniquement au premier pôle qui coupe. Pour les deuxième et troisième pôles qui coupent, voir le Tableau 10 pour des lignes directrices.

NOTE 2 Des détails supplémentaires du calcul de la TTR pour la coupure de courant asymétrique sont donnés dans la CEI 62271-101.

Lors d'une coupure de défaut asymétrique, le di/dt et la TTR résultants sont modifiés par la composante apériodique du courant de défaut.

La valeur maximale du di/dt est atteinte pour une condition de défaut symétrique. Pour une condition de défaut asymétrique, le di/dt est réduit et est fonction de la composante apériodique au zéro du courant. Le di/dt requis au zéro du courant est calculé à partir des équations suivantes:

a) Pour la petite alternance:

$$\frac{\mathrm{d}i}{\mathrm{d}t}(\text{p.u.})_{-} = \sqrt{(1-p^2)} - \frac{p}{2\pi f\tau} \qquad \text{(P.1)}$$

b) Pour la grande alternance:

$$\frac{\mathrm{d}i}{\mathrm{d}t}(\text{p.u.})_{+} = \sqrt{(1-p^2)} + \frac{p}{2\pi f\tau} \qquad \text{(P.2)}$$

où

di/dt (p.u.) di/dt en p.u. de la condition de défaut symétrique;

– = indice utilisé pour désigner la petite alternance;

\+ = indice utilisé pour désigner la grande alternance;

p = composante apériodique au zéro de courant en p.u.;

f = fréquence (Hz);

τ = constante de temps de la composante apériodique du ou des courants de court-circuit.

Au moment de l'interruption, l'instant du zéro du courant ne correspond pas à la crête de la tension appliquée comme c'est le cas pour une condition de défaut symétrique. La composante apériodique modifie l'angle de déphasage entre les zéros du courant et la tension à fréquence industrielle appliquée. Les coordonnées d'amplitude de la TTR (u_1, u_c) sont donc modifiées selon le déphasage entre l'instant du zéro du courant et la crête de la tension à fréquence industrielle appliquée.

Les coordonnées d'amplitude de la TTR (u_1, u_c) correspondantes doivent être calculées avec les équations suivantes:

c) TTR à deux paramètres:

$$u_c(\text{p.u.}) = \frac{k_1 A_1}{2\pi f} \tag{P.3}$$

et

$$k_{1-} = \sin(2\pi f t_3 - a\sin(p)) + p \times \mathrm{e}^{-\frac{t_3}{\tau}} \text{ (pour la petite alternance)} \tag{P.4}$$

$$k_{1+} = \sin(2\pi f t_3 + a\sin(p)) - p \times \mathrm{e}^{-\frac{t_3}{\tau}} \text{ (pour la grande alternance)} \tag{P.5}$$

$$A_1 = \frac{2\pi f}{\sin(2\pi f t_3)} \tag{P.6}$$

où

- u_c = valeur crête de la TTR en p.u. du cas symétrique;
- k_1 = constante de calcul;
- – = indice utilisé pour désigner la petite alternance;
- + = indice utilisé pour désigner la grande alternance;
- A_1 = constante de calcul;
- p = composante apériodique au zéro de courant en p.u.;
- f = fréquence (Hz);
- τ = constante de temps de la composante apériodique du ou des courants de court-circuit;
- t_3 = coordonnée(s) de temps t_3 spécifiée(s).

d) TTR à quatre paramètres:

$$u_1(\text{p.u.}) = \frac{k_1 A_1}{2\pi f} \tag{P.7}$$

et

$$k_{1-} = \sin(2\pi f t_1 - a\sin(p)) + p \times \mathrm{e}^{-\frac{t_1}{\tau}} \text{ (pour la petite alternance)} \tag{P.8}$$

$$k_{1+} = \sin(2\pi f t_1 + a\sin(p)) - p \times \mathrm{e}^{-\frac{t_1}{\tau}} \text{ (pour la grande alternance)} \tag{P.9}$$

$$\mathrm{A}_1 = \frac{2\pi f}{\sin(2\pi f t_1)} \tag{P.10}$$

où

- u_1 = valeur crête de la TTR en p.u. du cas symétrique;
- k_1 = constante de calcul;
- – = indice utilisé pour désigner la petite alternance;
- + = indice utilisé pour désigner la grande alternance;
- A_1 = constante de calcul;
- p = composante apériodique au zéro de courant en p.u.;
- f = fréquence (Hz);

τ = constante de temps de la composante apériodique du (des) courant(s) de court-circuit;

t_1 = coordonnée(s) de temps t_1 spécifiée(s).

et

$$u_c(\text{p.u.}) = \frac{k_2 A_1}{1{,}4 \times 2\pi f} - \frac{k_3 A_2}{2\pi f} \qquad \text{(P.11)}$$

et

$$k_{2-} = \sin(2\pi f t_2 - a\sin(p)) + p \times e^{-\frac{t_2}{\tau}} \text{ (pour la petite alternance)} \qquad \text{(P.12)}$$

$$k_{2+} = \sin(2\pi f t_2 + a\sin(p)) - p \times e^{-\frac{t_2}{\tau}} \text{ (pour la grande alternance)} \qquad \text{(P.13)}$$

$$k_{3-} = \sin(2\pi f (t_2 - t_1) - a\sin(p)) + p \times e^{-(\frac{t_2 - t_1}{\tau})} \text{ (pour la petite alternance)} \qquad \text{(P.14)}$$

$$k_{3+} = \sin(2\pi f (t_2 - t_1) + a\sin(p)) - p \times e^{-(\frac{t_2 - t_1}{\tau})} \text{ (pour la grande alternance)} \qquad \text{(P.15)}$$

$$A_1 = \frac{2\pi f}{\sin(2\pi f t_1)} \qquad \text{(P.16)}$$

$$A_2 = \frac{A_1 \sin(2\pi f t_2)/1{,}4 - 2\pi f}{\sin(2\pi f (t_2 - t_1))} \qquad \text{(P.17)}$$

où

u_c = valeur crête de la TTR en p.u. du cas symétrique;

k_2 = constante de calcul;

k_3 = constante de calcul;

– = indices utilisés pour désigner la petite alternance;

+ = indices utilisés pour désigner la grande alternance;

A_1 = constante de calcul;

A_2 = constante de calcul;

p = composante apériodique au zéro de courant en p.u.;

f = fréquence (Hz);

τ = constante de temps de la composante apériodique du ou des courants de court-circuit;

t_1 = coordonnée(s) de temps t_1 spécifiée(s);

t_2 = coordonnée(s) de temps t_2 spécifiée(s).

À titre d'exemple, les paramètres suivants sont donnés:

- tension assignée du disjoncteur: 145 kV
- fréquence assignée: 50 Hz
- courant assigné de court-circuit: 40 kA
- constante de temps de la composante apériodique du courant de court-circuit: 45 ms
- facteur de premier pôle: 1,3
- durée d'interruption minimale: 43 ms
- TTR assignée (cas symétrique): u_1 154 kV

t_1	77 µs
u_c	215 kV
t_2	231 µs.

Selon le Tableau 15, les paramètres suivants sont donnés:

a) Pour la petite alternance:
   - pourcentage de la composante apériodique au zéro de courant: 37,9 % (0,379 p.u.);
   - pourcentage du di/dt au zéro du courant: 89,9 % (0,899 p.u.).

b) Pour la grande alternance:
   - pourcentage de la composante apériodique au zéro de courant: 28,9 % (0,289 p.u.);
   - pourcentage du di/dt au zéro du courant: 97,8 % (0,978 p.u.).

Les valeurs suivantes sont calculées à partir des équations précédentes:

k_{1-} = 0,02185;
k_{1+} = 0,02357;
A_1 = 12988,28;
u_{1-} = 0,90319 p.u.;
u_{1+} = 0,97426 p.u.;
k_{2-} = 0,06616;
k_{2+} = 0,07013;
k_{3-} = 0,04390;
k_{3+} = 0,04695;
A_2 = 7413,155;
u_{c-} = 0,91764 p.u.;
u_{c+} = 0,96325 p.u.

De ces résultats, le di/dt et la TTR modifiés résultants à appliquer au disjoncteur sont:

a) Pour la petite alternance:

di/dt = 0,899 p.u. × 40 kA × $\sqrt{2}$ × 2πf = 15,98 A/µs;
u_1 = 0,90319 p.u. × 154 kV = 139,1 kV;
t_1 = 77 µs;
u_1/t_1 = 1,81 kV/µs
u_c = 0,91764 p.u. × 215 kV = 197,3 kV;
t_2 = 231 µs.

b) Pour la grande alternance:

di/dt = 0,978 p.u. × 40 kA × $\sqrt{2}$ × 2πf = 17,38 A/µs;
u_1 = 0,97426 p.u. × 154 kV = 150,0 kV;
t_1 = 77 µs;
u_1/t_1 = 1,95 kV/µs
u_c = 0,96325 p.u. × 215 kV = 207,1 kV;
t_2 = 231 µs.

Normalement, pour les essais directs, lorsque les éléments du circuit sont ajustés pour obtenir l'enveloppe assignée de la TTR et lorsque la composante apériodique demandée au zéro du courant est obtenue, alors la réduction du di/dt et des coordonnées d'amplitude de la TTR (u_1 et/ou u_c) est automatiquement satisfaite sans effectuer les calculs décrits ci-dessus.

Les calculs décrits précédemment doivent être utilisés dans les cas suivants:

– pour les essais synthétiques, de façon à sélectionner les composants du circuit ainsi que la tension de charge de la batterie de condensateurs;
– pour les essais directs, de façon à obtenir des tolérances plus serrées sur la TTR appliquée lors des essais;
– pour les essais directs, lorsque la composante apériodique au zéro de courant est à l'extérieur des tolérances permises de façon à obtenir une TTR présumée qui est à l'intérieur des tolérances données à l'Annexe B et en 6.104.5.

Pour les essais synthétiques, deux options peuvent être utilisées:

1 Circuit d'essai réglé pour obtenir la TTR assignée associée avec T100s

   Dans ce cas, il est impossible de satisfaire simultanément à tous les paramètres (di/dt, u_1 et u_c) parce que ces paramètres ne varient pas linéairement avec la composante apériodique au zéro du courant. La tension de charge du circuit d'essais synthétiques doit être fixée pour obtenir le paramètre d'essai le plus contraignant. Pour les essais sur la petite alternance, le paramètre d'essai le plus sévère est toujours u_c, tandis que pour les essais sur la grande alternance, le paramètre le plus sévère est le di/dt. Dans le cas d'une méthode d'essai par injection de tension, le paramètre d'essai le plus sévère pour les essais sur la grande alternance devient u_1.

2 Utilisation de deux circuits d'essais différents, un premier réglé pour obtenir la TTR modifiée associée aux essais sur la petite alternance et un second circuit réglé pour obtenir la TTR modifiée associée aux essais sur la grande alternance.

   Dans ce cas, tous les paramètres requis (di/dt, u_1 et u_c), comme calculés précédemment, peuvent être satisfaits simultanément.

Le choix de l'option est laissé au constructeur, étant donné que l'option "1" peut produire des contraintes trop sévères sur le disjoncteur (par exemple, pour les essais sur la grande alternance, la correction requise pour le di/dt produira une valeur u_c plus grande que requise).

Annexe Q
(informative)

Exemples d'application des critères d'asymétrie durant la séquence d'essais asymétriques T100a

Les exemples donnés dans cette annexe sont basés sur des cas normalisés et donnent des orientations sur la façon d'utiliser les critères d'asymétrie dans un essai réel. Trois cas différents sont donnés, couvrant les cas principaux qui peuvent être rencontrés dans les laboratoires d'essais.

Q.1 Essais en triphasé d'un disjoncteur dont la constante de temps assignée de la composante apériodique du pouvoir de coupure assigné en court-circuit est supérieure à la constante de temps du circuit d'essai

Tension assignée du disjoncteur:	24	kV
Facteur de premier pôle:	1,5	
Constante de temps assignée de la composante apériodique du pouvoir de coupure assigné en court-circuit:	120	ms
Constante de temps du circuit d'essai:	60	ms
Durée d'arc minimale:	7,5	ms
Durée d’ouverture minimale :	32,5	ms
Composante apériodique à la séparation des contacts :	70,2	%
Durée minimale d'interruption:	40	ms
Fréquence:	50	Hz

La constante de temps du circuit d'essai est différente de la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit. La procédure d'ajustement choisie pour obtenir les paramètres requis est la méthode du déclenchement anticipé avec fermeture synchrone.

NOTE La fermeture synchrone est définie comme étant l'établissement du courant d'essai à un instant précis sur la tension appliquée de façon à faire varier la composante apériodique initiale du courant d'essai.

Tableau Q.1 – Exemple montrant les paramètres d'essais obtenus lors d'un essai triphasé, lorsque la constante de temps de la composante apériodique du circuit d'essai est plus courte que la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit

Paramètres	**Exigences** (valeurs calculées, des valeurs arrondies sont données aux Tableaux 17 et 18)		**Paramètres d'essais obtenus avec la méthode du déclenchement anticipé et fermeture synchrone**		**Écart entre les valeurs requises et les valeurs d'essais** %
	Grande alternance avec premier pôle qui coupe	**Deuxième pôle qui coupe** grande/petite alternances [a]	**Grande alternance avec premier pôle qui coupe**	**Second pôle qui coupe** grande/petite alternances [a]	
Composante apériodique à l'interruption du courant (%)	62,1		54,2		-13
di/dt à l'interruption du courant (%)	80,1		86,9		+8
Crête de la dernière alternance de courant (p.u.)	1,66	1,34/0,72	1,61	1,32/0,76	-3 -1,5/+5,6 [b]
Durée de la dernière alternance de courant (ms)	14,5	13,2/7,65	14,4	13,05/7,8	-2 -1/+2 [b]
$\Delta\, t$ (ms) [c]		3		3,3	+10
I x t (p.u. ms)	24,07		23,18		-3,7

[a] Valeurs calculées pour un réseau à neutre relié non effectivement à la terre à partir d'un logiciel de calcul de réseaux (voir Note).

[b] Deuxième pôle qui coupe.

[c] Δt est l'intervalle de temps entre le premier pôle qui coupe et le dernier pôle qui coupe.

Résultat: Il est possible de satisfaire aux exigences en utilisant le déclenchement anticipé et la fermeture synchrone. Les valeurs de la TTR et du di/dt seront supérieures aux valeurs requises, mais sont encore à l'intérieur des tolérances données. La durée d'arc pour le deuxième pôle qui coupe sera légèrement plus longue que celle requise. Les paramètres d'essais couvrent les valeurs demandées. Des tolérances plus serrées peuvent être obtenues en changeant le courant d'essai et/ou le facteur d'amplitude de la TTR. Les résultats sont illustrés à la Figure Q.1.

Comme indiqué dans le Tableau Q.1, les caractéristiques assignées du disjoncteur données en Q.1 sont totalement couvertes par les données d’essai. Il convient de porter une attention particulière au fait que le pourcentage d'asymétrie au zéro de courant est inférieur à la caractéristique assignée donnée par le constructeur à la séparation des contacts. Cette différence est normale parce que la valeur attribuée par le constructeur est basée sur la constante de temps de la composante apériodique spécifiée du pouvoir de coupure assigné en court-circuit de 120 ms, et ne prend pas en compte la durée d'arc et la constante de temps de la composante apériodique du circuit d'essai. Les paramètres d’essais devant être satisfaits sont ceux décrits pour la dernière alternance de courant, tel que défini en 6.106.6.

NOTE La façon recommandée (façon la plus facile) de calculer les paramètres requis pour les formes d'ondes triphasées ou monophasées est d'utiliser un logiciel de calcul de réseaux, par exemple EMTP, MATHLAB, etc. Les paramètres requis pour les formes d'ondes peuvent aussi être calculés à la main en utilisant les équations classiques applicables à un courant de court-circuit triphasé ou monophasé.

Q.2 Essais en monophasé d'un disjoncteur dont la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit est inférieure à la constante de temps du circuit d'essai

Tension assignée du disjoncteur:	550	kV
Facteur de premier pôle:	1,3	
Constante de temps assignée de la composante apériodique du pouvoir de coupure assigné en court-circuit:	45	ms
Constante de temps du circuit d'essai:	60	ms
Durée d'arc minimale:	7,5	ms
Durée d’ouverture minimale :	32,5	ms
Composante apériodique à la séparation des contacts :	38,9	%
Durée minimale d'interruption:	40	ms
Fréquence:	50	Hz

La constante de temps du circuit d'essai est différente de la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit. La procédure d'ajustement choisie pour obtenir les paramètres requis est la méthode de fermeture synchrone.

Tableau Q.2 – Exemple montrant les paramètres d'essais obtenus lors d'un essai monophasé lorsque la constante de temps de la composante apériodique du circuit d'essai est plus longue que la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit

Paramètres	**Exigences** (valeurs calculées, des valeurs arrondies sont données aux Tableaux 15 et 16)		**Paramètres d'essais obtenus avec la méthode de fermeture synchrone**		**Écart entre les valeurs requises et les valeurs d'essais** %
	Grande alternance avec la durée d'arc la plus longue possible	**Petite alternance avec la durée d'arc la plus courte possible**	**Grande alternance**	**Petite alternance**	
Composante apériodique à l'interruption du courant (%)	28,9	37,9	28,6	40,2	-1,0 +6,1 [b]
di/dt à l'interruption du courant [a] (%)	97,8	89,9	97,3	89,6	+0,5 -0,6 [b]
Crête de la dernière alternance de courant (p.u.)	1,33	0,59	1,32	0,57	-0,8 -3,4 [b]
Durée de la dernière alternance de courant (ms)	12,3	7,35	12,15	7,35	-1,2 0 [b]
u_1 [a]	96,5 %	91,9 %	96,0 %	91,3 %	-0,5 -0,7 [b]

Tableau Q.2 *(suite)*

Paramètres	**Exigences (valeurs calculées, des valeurs arrondies sont données aux Tableaux 15 et 16)**		**Paramètres d'essais obtenus avec la méthode de fermeture synchrone**		**Écart entre les valeurs requises et les valeurs d'essais** %
	Grande alternance avec la durée d'arc la plus longue possible	**Petite alternance avec la durée d'arc la plus courte possible**	**Grande alternance**	**Petite alternance**	
u_c [a]	92,3 %	97,9 %	91,9 %	97,1 %	-0,4 -0,9 [b]
I x t (p.u. ms)	16,36	4,34	16,04	4,19	-2,0 -3,5 [b]

[a] Dans le cas d'essais synthétiques, il est possible de contrôler ces valeurs indépendamment de la constante de temps.

[b] Petite alternance

Résultat: Toutes les exigences d'essais peuvent être satisfaites en utilisant la méthode de la fermeture synchrone. Toutes les valeurs obtenues sont très proches des valeurs demandées. Des tolérances plus serrées peuvent être obtenues en changeant l'amplitude du courant d'essais et/ou le facteur d'amplitude de la TTR du circuit de réglage de la TTR. Les valeurs u_1 et u_c ont été obtenues à partir des équations de l'Annexe P. Les résultats sont illustrés à la Figure Q.2.

Comme indiqué dans le Tableau Q.2, les caractéristiques assignées du disjoncteur données en Q.2 sont totalement couvertes par les données d'essai. Il convient de porter une attention particulière au fait que le pourcentage d'asymétrie au zéro de courant est inférieur à la caractéristique assignée donnée par le constructeur à la séparation des contacts. Cette différence est normale parce que la valeur attribuée par le constructeur est basée sur la constante de temps de la composante apériodique spécifiée du pouvoir de coupure assigné en court-circuit de 45 ms, et ne prend pas en compte la durée d'arc et la constante de temps de la composante apériodique du circuit d'essai. Les paramètres d'essais devant être satisfaits sont ceux décrits pour la dernière alternance de courant, tel que défini en 6.106.6.

Q.3 Essais en monophasé d'un disjoncteur dont la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit est supérieure à la constante de temps du circuit d'essai

Tension assignée du disjoncteur:	550	kV
Facteur de premier pôle:	1,3	
Constante de temps assignée de la composante apériodique du pouvoir de coupure assigné en court-circuit:	75	ms
Constante de temps du circuit d'essai:	60	ms
Durée d'arc minimale:	7,5	ms
Durée d'ouverture minimale :	32,5	ms
Composante apériodique à la séparation des contacts :	56,7	%
Durée minimale d'interruption:	40	ms
Fréquence:	50	Hz

La constante de temps du circuit d'essai est différente de la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit. La procédure d'ajustement choisie pour obtenir les paramètres requis est la méthode de fermeture synchrone.

Tableau Q.3 – Exemple montrant les paramètres d'essais obtenus lors d'un essai monophasé lorsque la constante de temps de la composante apériodique du circuit d'essai est plus courte que la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit

Paramètres	Exigences (valeurs calculées, des valeurs arrondies sont données aux Tableaux 17 et 18)		Paramètres d'essais obtenus avec la méthode de fermeture synchrone		Écart entre les valeurs requises et les valeurs d'essais %
	Grande alternance avec la durée d'arc la plus longue possible	Petite alternance avec la durée d'arc la plus courte possible	Grande alternance	Petite alternance	
Composante apériodique à l'interruption du courant (%)	47,2	56,4	39,2	48,6	-20 -16,6 [b]
d*i*/d*t* à l'interruption du courant* (%)	90,2	80,2	94,1	84,9	+4,3 +5,8 [b]
Crête de la dernière alternance de courant (p.u.)	1,51	0,41	1,44	0,44	-4,6 +7,3 [b]
Durée de la dernière alternance de courant (ms)	13,65	6,15	13,5	6,75	1,1 +9,8 [b]

Tableau Q.3 *(suite)*

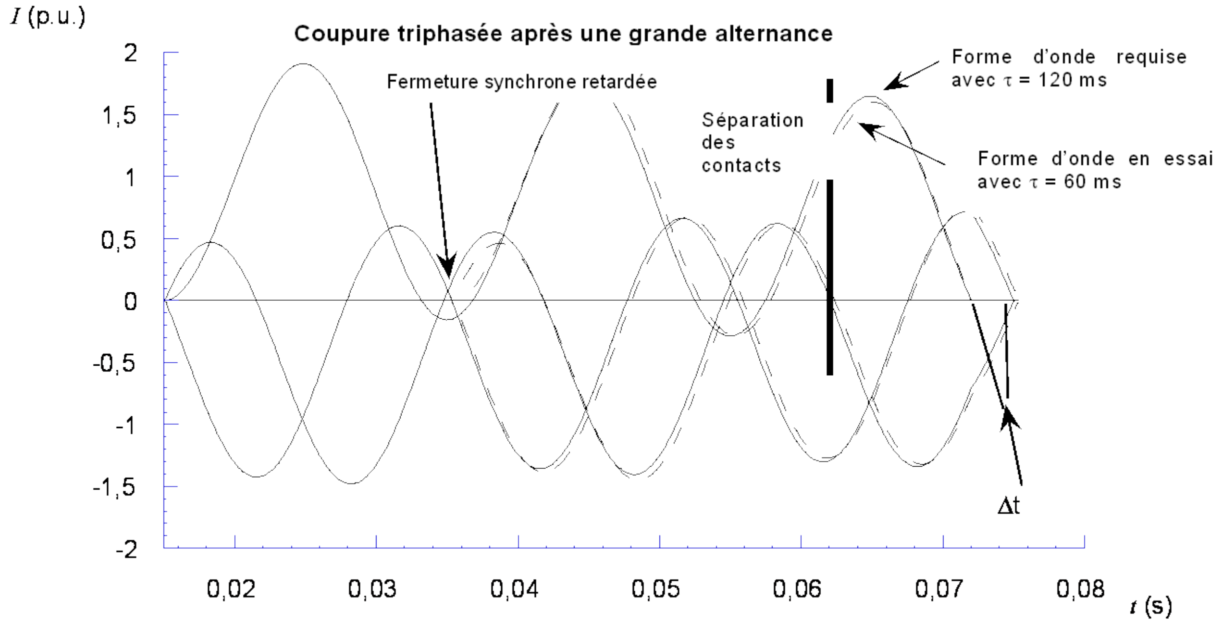
Paramètres	**Exigences (valeurs calculées, des valeurs arrondies sont données aux Tableaux 17 et 18)**		**Paramètres d'essais obtenus avec la méthode de fermeture synchrone**		**Écart entre les valeurs requises et les valeurs d'essais** %
	Grande alternance avec la durée d'arc la plus longue possible	**Petite alternance avec la durée d'arc la plus courte possible**	**Grande alternance**	**Petite alternance**	
u_1 [a]	88,1 %	82,8 %	92,3 %	82,1 %	+4,8 +5,2 [b]
u_c [a]	81,3 %	90,9 %	86,6 %	94 %	+6,5 +3,4 [b]
$I \times t$ (p.u. ms)	20,61	2,52	19,44	2,97	-5,7 +17,9 [b]

[a] Dans le cas d'essais synthétiques, il est possible de contrôler ces valeurs indépendamment de la constante de temps.

[b] Petite alternance

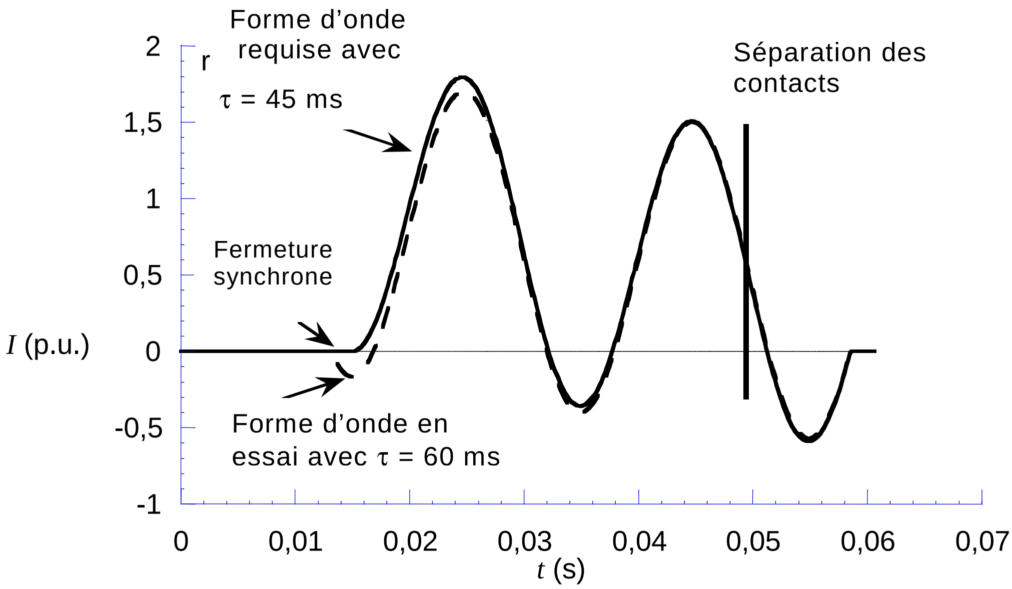
Résultat: Toutes les exigences d'essais peuvent être satisfaites en utilisant la méthode de la fermeture synchrone. Toutes les valeurs obtenues, à l'exception de la composante apériodique, sont très proches des valeurs demandées. Dans ce cas, un déclenchement anticipé supplémentaire est nécessaire pour être à l'intérieur des tolérances permises ($^{-5}_{+10}$ %). Des tolérances plus serrées peuvent être obtenues en changeant l'amplitude du courant d'essais et/ou le facteur d'amplitude de la TTR du circuit de réglage de la TTR. Les valeurs u_1 et u_c ont été obtenues à partir des équations de l'Annexe P. Les résultats sont illustrés à la Figure Q.3.

Comme indiqué dans le Tableau Q.3, les caractéristiques assignées du disjoncteur données en Q.3 sont totalement couvertes par les données d'essai. Il convient de porter une attention particulière au fait que le pourcentage d'asymétrie au zéro de courant est inférieur à la caractéristique assignée donnée par le constructeur à la séparation des contacts. Cette différence est normale parce que la valeur attribuée par le constructeur est basée sur la constante de temps de la composante apériodique spécifiée du pouvoir de coupure assigné en court-circuit de 75 ms, et ne prend pas en compte la durée d'arc et la constante de temps de la composante apériodique du circuit d'essai. Les paramètres d'essais devant être satisfaits sont ceux décrits pour la dernière alternance de courant, tel que défini en 6.106.6.

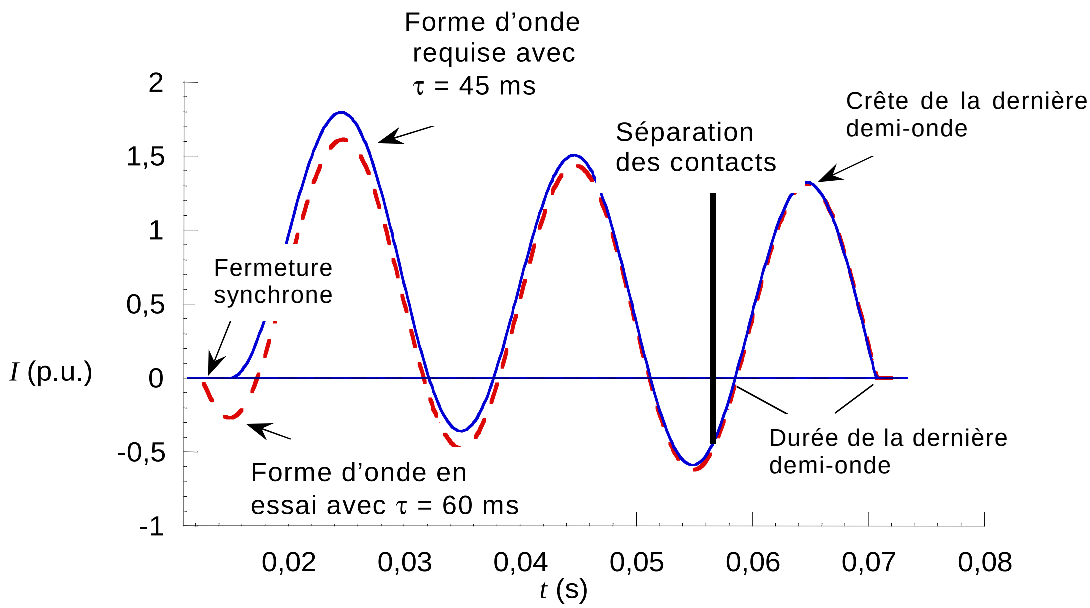


En raison de la constante de temps réduite du circuit d'essai, il est nécessaire d'établir le courant de court-circuit plus tard (méthode du déclenchement anticipé, voir NOTE 1 de 6.106.6.3) et de choisir l'angle d'enclenchement, de façon à obtenir la composante apériodique requise au zéro du courant (fermeture synchrone).

Figure Q.1 – Essais en triphasé d'un disjoncteur dont la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit est supérieure à la constante de temps du circuit d'essai

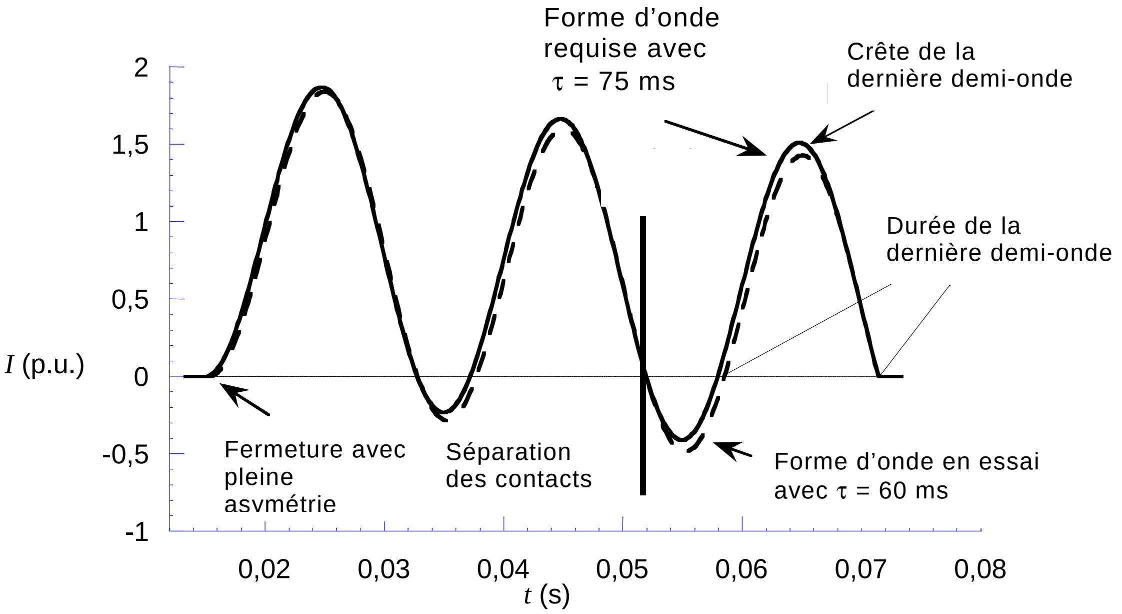


Coupure au zéro de courant après une petite alternance

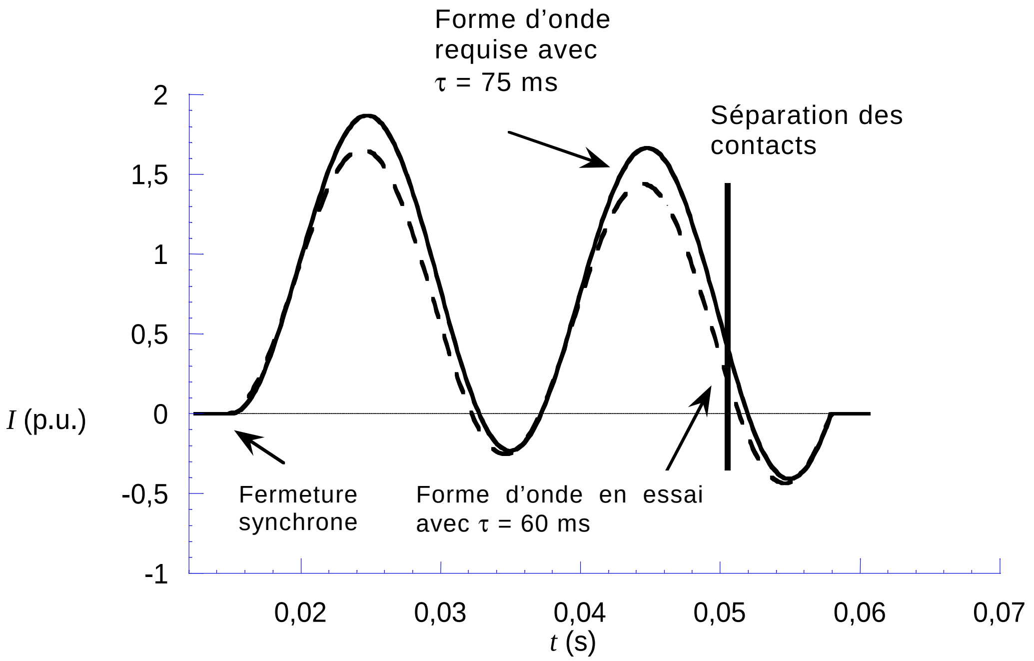


Coupure au zéro de courant à la suite d'une grande alternance

Figure Q.2 – Essais en monophasé d'un disjoncteur dont la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit est inférieure à la constante de temps du circuit d'essai



Coupure au zéro de courant à la suite d'une grande alternance



Coupure au zéro de courant à la suite d'une petite alternance

Figure Q.3 – Essais en monophasé d'un disjoncteur dont la constante de temps de la composante apériodique assignée du pouvoir de coupure assigné en court-circuit est supérieure à la constante de temps du circuit d'essai

Annexe R
(normative)

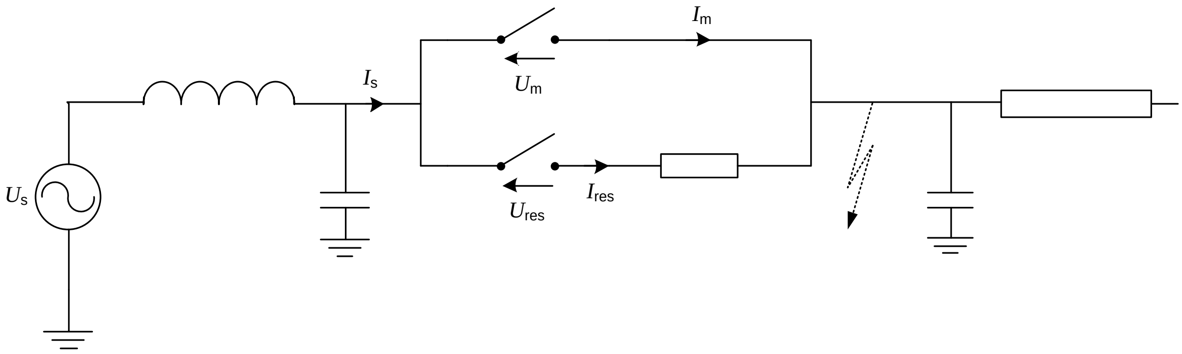
Exigences pour les disjoncteurs avec résistances d'ouverture

R.1 Généralités

Cette annexe est applicable aux disjoncteurs dans lesquels une résistance est insérée en série avec le circuit à couper. Cette résistance est connectée en parallèle avec l'interrupteur principal au moins pour les manœuvres de coupure. Pendant le processus de coupure, l'interrupteur principal transfère le courant à la résistance et l'interrupteur de résistance connecté en série avec la résistance coupe le courant restant.

Les disjoncteurs avec résistances d'ouverture doivent satisfaire à toutes les exigences du texte principal de la présente norme. Cette annexe complète le texte principal et définit des exigences de conception et d'essai spécifiques tenant compte de la présence des résistances d'ouverture.

Une configuration de système type est indiquée à la Figure R.1.



Légende

I_m	Courant traversant l'interrupteur principal	U_m	Tension aux bornes de l'interrupteur principal
I_{res}	Courant traversant l'interrupteur de résistance	U_{res}	Tension aux bornes de l'interrupteur de résistance
I_s	Courant côté alimentation	U_s	Tension côté alimentation

Figure R.1 – Configuration de système type pour coupure par un disjoncteur avec résistances d'ouverture

R.2 Performance d'établissement et de coupure à vérifier

R.2.1 Généralités

La performance d'établissement et de coupure du disjoncteur avec des résistances d'ouverture est vérifiée de manière adéquate si l'on utilise une méthode d'essai directe. En cas de limitations des possibilités d'essai, des méthodes d'essai synthétique doivent être utilisées, se référer à l'Annexe F de la CEI 62271-101:2006.

Une temporisation appropriée des manœuvres mécaniques et électriques incluant la durée de pré-amorçage et les durées d'amorçage à la fois pour l'interrupteur principal et l'interrupteur de résistance doit être obtenue.

NOTE 1 Le nombre de manœuvres consécutives pendant les essais et en service sera limité par la capacité thermique de la résistance et par sa constante de temps de refroidissement.

Il convient que les essais soient effectués de préférence avec résistance d'ouverture. Alternativement, les essais peuvent être effectués sans résistance d'ouverture si la coupure par l'interrupteur principal n'est pas affectée par ou n'affecte pas l'interrupteur de résistance. La résistance est prise en compte en modifiant les paramètres courant et tension qui sont calculés pour les conditions de coupure.

Si les essais sont effectués sans résistance d'ouverture, il convient que les valeurs modifiées de TTR soient calculées au cas par cas, en fonction des conditions de manœuvre telles que le courant de court-circuit et la valeur de résistance ohmique de la résistance d'ouverture. Les calculs de TTR peuvent être faits en utilisant des programmes de calcul de transitoires. Il convient dans ce cas que les valeurs de TTR modifiées soient spécifiées par le concepteur de réseau.

Les paramètres modifiés de TTR peuvent aussi être obtenus en calculant l'influence de la résistance dans des circuits avec des éléments concentrés qui produisent la TTR non influencée.

NOTE 2 Il est courant que les essais d'établissement, de coupure et d'établissement-coupure soient effectués sans résistance d'ouverture et les paramètres d'essai sont réglés en tenant compte des effets de la résistance sur le courant à couper et sur la tension de rétablissement appliquée à l'interrupteur principal et à l'interrupteur de résistance.

NOTE 3 Lorsque les essais sont effectués sans résistance d'ouverture, il est essentiel que la manœuvre et les performances de l'interrupteur principal et de l'interrupteur de résistance ne soient pas mutuellement affectés pendant les manœuvres, par exemple par l'influence des gaz chauds.

Du fait de l'énergie disponible limitée lorsqu'on utilise des circuits synthétiques, les essais synthétiques doivent être effectués en trois parties:

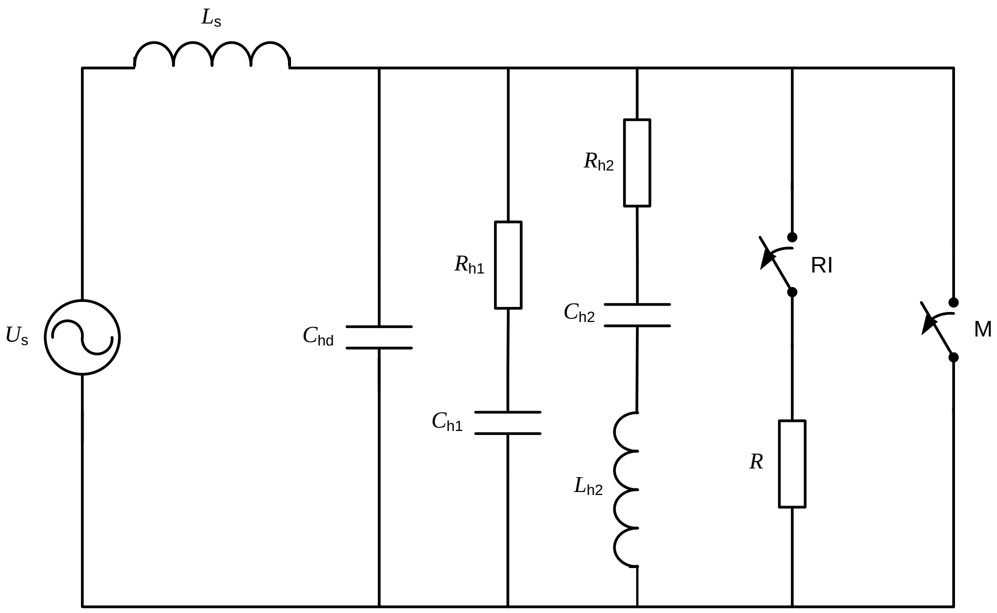
– essais sur l'interrupteur principal;
– essais sur l'interrupteur de résistance;
– essais sur la pile de résistances.

R.2.2 Essais de l'interrupteur principal

R.2.2.1 Essais de défaut aux bornes et essais d'établissement et de coupure en discordance de phases

Ces essais sont normalement effectués en utilisant des méthodes d'essais synthétiques.

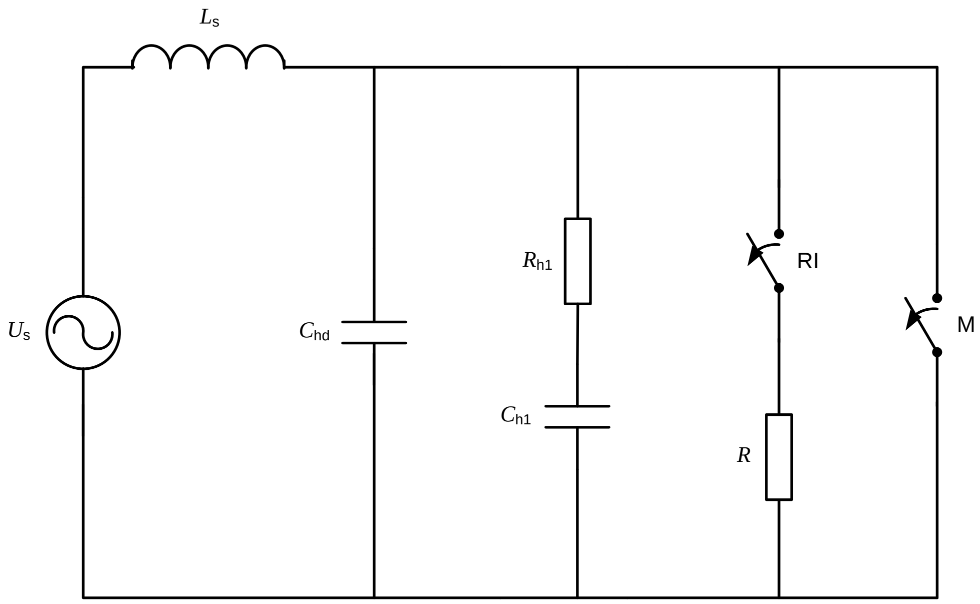
Un exemple de circuit d'essai pour les séquences d'essais T60 et T100 est donné à la Figure R.2. Un exemple de circuit d'essai pour les séquences d'essais T10, T30 et OP2 est donné à la Figure R.3.



Légende

U_s	Tension de source	C_{h2}	Capacité de TTR partie 2
L_s	Inductance de la source	L_{h2}	Inductance de TTR
C_{hd}	Capacité de retard	RI	Interrupteur de résistance
R_{h1}	Résistance de TTR partie 1	R	Résistance
C_{h1}	Capacité de TTR partie 1	M	Contacts principaux
R_{h2}	Résistance de TTR partie 2		

Figure R.2 – Circuit d'essai pour les séquences d'essais T60 et T100



Légende

U_s	Tension de source	C_{h1}	Capacité de TTR
L_s	Inductance de la source	RI	Interrupteur de résistance
C_{hd}	Capacité de retard	R	Résistance
R_{h1}	Résistance de TTR	M	Contacts principaux

Figure R.3 – Circuit d'essai pour les séquences d'essais T10, T30 et OP2

Calcul des paramètres:

$U_s = k_{pp} \times U_r/\sqrt{3}$

$L_s = (U_s/I_s)/\omega$

Calcul des composants de TTR pour T100:

$R_{h1} \approx (du/dt)/(di/dt)$

$C_{h1} \approx 0{,}31 \times L_s/R_{h1}^2$

$R_{h2} \approx 0{,}32 \times R_{h1}$

$C_{h2} \approx 0{,}7 \times C_{h1}$

$L_{h2} \approx 1{,}15 \times L_v$

$C_{hd} \approx t_d/R_{h1}$

Calcul des composants de TTR pour T60:

$R_{h1} \approx 0{,}9 \times (du/dt)/(di/dt)$

$C_{h1} \approx 0{,}3 \times L_s/R_{h1}^2$

$R_{h2} \approx 0{,}1 \times R_{h1}$

$C_{h2} \approx 1{,}16 \times C_{h1}$

$L_{h2} \approx 1{,}38 \times L_v$

$C_{hd} \approx t_d/R_{h1}$

Calcul des composants de TTR pour T30:

$R_{h1} \approx (du/dt)/(di/dt)$

$C_{h1} \approx 0{,}42 \times L_s/R_{h1}^2$

$C_{hd} \approx t_d/R_{h1}$

Calcul des composants de TTR pour T10:

$R_{h1} \approx 1{,}3 \times (du/dt)/(di/dt)$

$C_{h1} \approx 0{,}42 \times L_s/R_{h1}^2$

$C_{hd} \approx t_d/R_{h1}$

Calcul des composants de TTR pour OP2:

$R_{h1} \approx 1{,}85 \times (du/dt)/(di/dt)$

$C_{h1} \approx 2{,}55 \times L_s/R_{h1}^2$

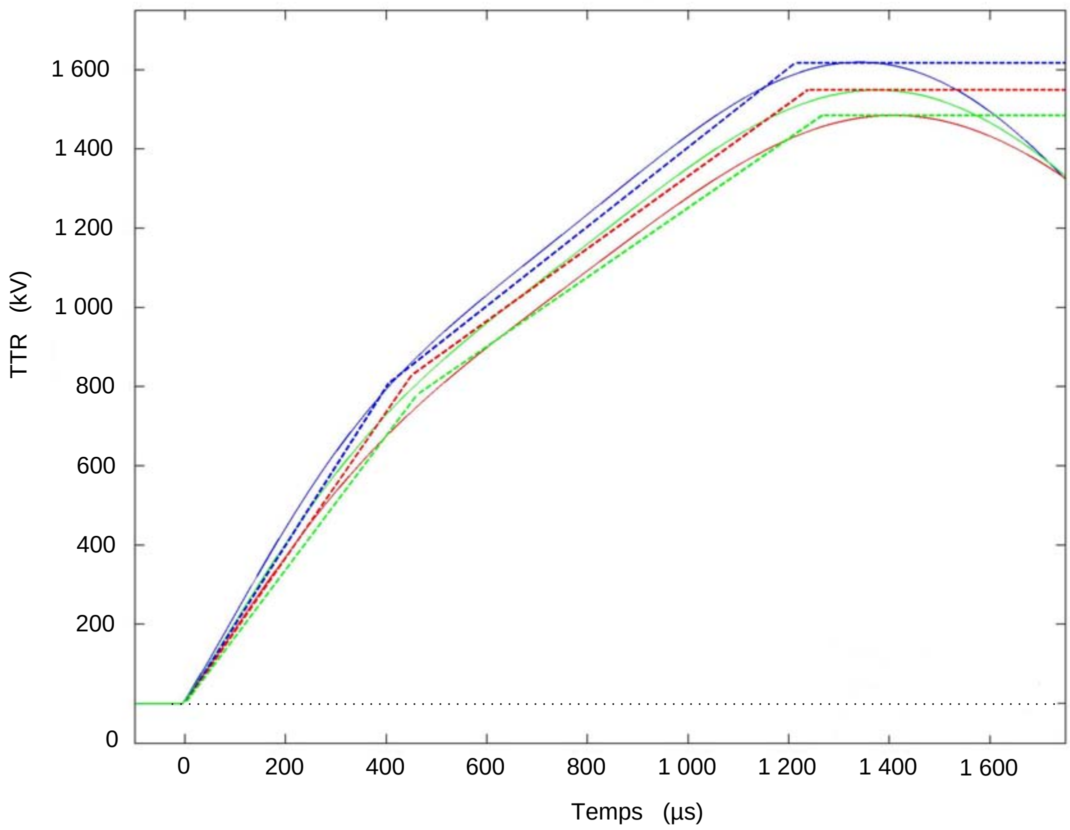
$C_{hd} \approx t_d/R_{h1}$

Le Tableau R.1 énumère les résultats des calculs effectués en utilisant les deux circuits. La réduction de la valeur crête de TTR est indiquée dans la colonne u_{cred}.

Tableau R.1 – Résultats du calcul de TTR pour les défauts aux bornes et discordance de phases

U_r (kV)	I_{sc} (kA)	f (Hz)	**Séquence**	R (Ω)	u_1 (kV)	t_1 (µs)	u_c (kV)	t_2 ou t_3 (µs)	u_{cred} (%)	**Résultat**
1 100	50	50	T100s(b)	∞	808	404	1 617	1 212	0	-
1 100	50	50	T100s(b)	1 000	830	451	1 549	1 238	-4	Sous-amortie
1 100	50	50	T100s(b)	500	780	461	1 485	1 267	-8	Sous-amortie
1 100	50	50	T60	∞	808	269	1 617	1 212	0	-
1 100	50	50	T60	1 000	740	320	1 508	1 210	-7	Sous-amortie
1 100	50	50	T60	500	660	340	1 410	1 237	-13	Sous-amortie
1 100	50	50	T30	∞	-	-	1 660	332	0	-
1 100	50	50	T30	1 000	-	-	1 163	407	-30	Sous-amortie
1 100	50	50	T30	500	-	-	1 036	531	-38	Sur-amortie
1 100	50	50	T10	∞	-	-	1 897	271	0	-
1 100	50	50	T10	1 000	-	-	971	624	-49	Sur-amortie
1 100	50	50	T10	500	-	-	853	935	-55	Sur-amortie
1 100	50	50	OP2	∞	-	-	2 245	1 344	0	-
1 100	50	50	OP2	1 000	-	-	1 877	1 435	-16	Sous-amortie
1 100	50	50	OP2	500	-	-	1 639	1 502	-27	Sur-amortie

Les Figures R.4 et R.5 montrent respectivement des exemples de TTR sous-amorties et sur-amorties.



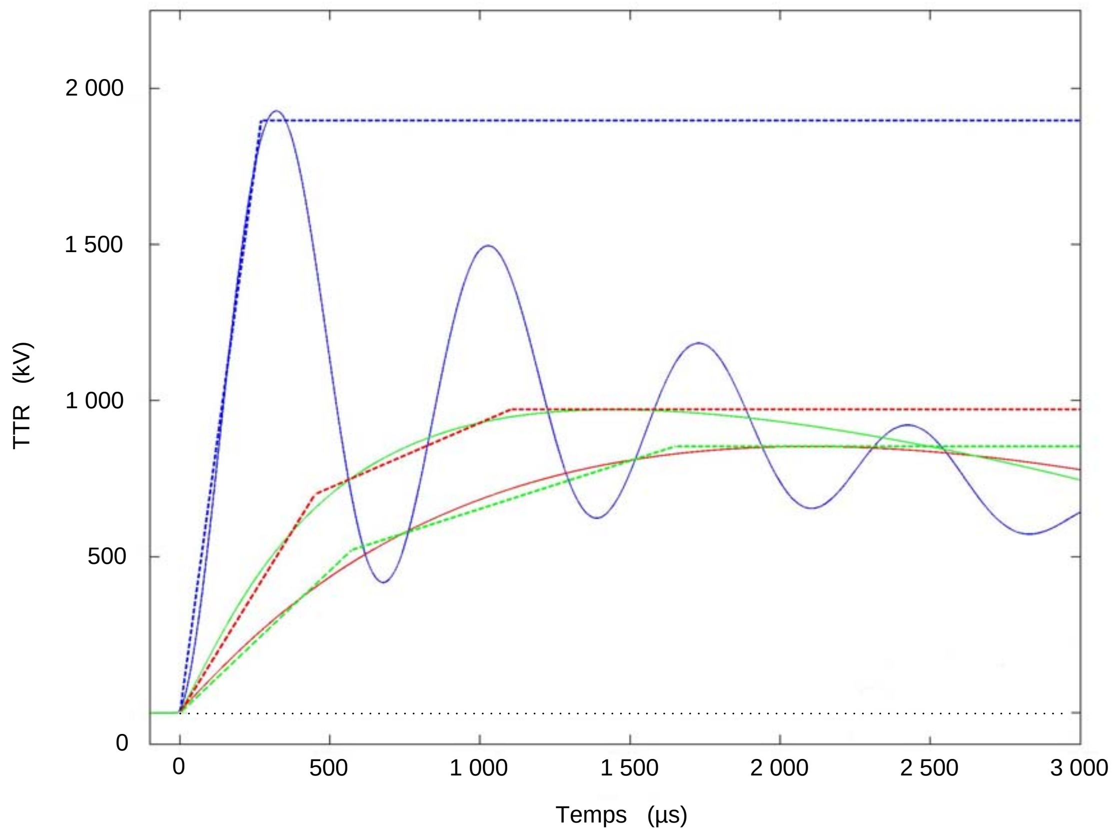
Légende

Ligne bleue $R = \infty$

Ligne rouge R = 1 000 Ω

Ligne verte R = 500 Ω

Figure R.4 – Exemple de TTR sous-amortie pour T100s(b), U_r = 1 100 kV I_{sc} = 50 kA, f_r = 50 Hz



Légende

Ligne bleue $R = \infty$

Ligne rouge $R = 1\,000\ \Omega$

Ligne verte $R = 500\ \Omega$

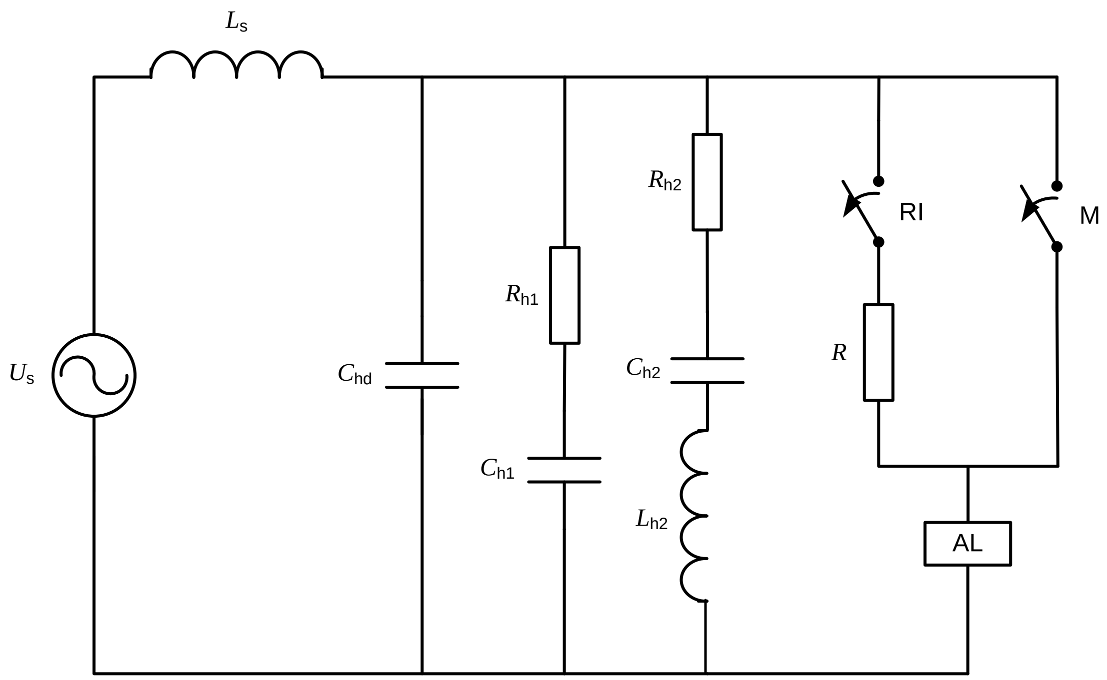
Figure R.5 – Exemple de TTR sur-amortie pour T10,
U_r = 1 100 kV I_{sc} = 50 kA, f_r = 50 Hz

R.2.2.2 Essais de défaut proche en ligne

Ces essais sont normalement effectués en utilisant des méthodes d'essais synthétiques.

Un exemple de circuit d'essai pour la séquence d'essais L_{90} est donné à la Figure R.6.

La contribution côté ligne de la TTR équivalente doit être calculée en simulant une ligne par au moins 10 sections en π avec l'impédance d'onde spécifiée. Un exemple de calcul de ce type est donné à la Figure R.7.



Légende

U_s	Tension de source	C_{h2}	Capacité de TTR partie 2
L_s	Inductance de la source	L_{h2}	Inductance de TTR
C_{hd}	Capacité pour retard	RI	Interrupteur de résistance
R_{h1}	Résistance de TTR partie 1	R	Résistance
C_{h1}	Capacité de TTR partie 1	M	Interrupteur principal
R_{h2}	Résistance de TTTR partie 2	AL	Ligne artificielle

Figure R.6 – Exemple de circuit d'essai pour la séquence d'essais de défaut proche en ligne L_{90}

Le Tableau R.2 énumère les résultats des calculs effectués en utilisant le circuit d'essai représenté à la Figure R.6. La réduction de la valeur crête de TTR est indiquée dans la colonne u_{cred}.

Calcul des composants de TTR pour L_{90}:

– Côté source

$R_{h1} \approx (du/dt)/(di/dt)$

$C_{h1} \approx 0{,}31 \times L_s/R_{h1}^2$

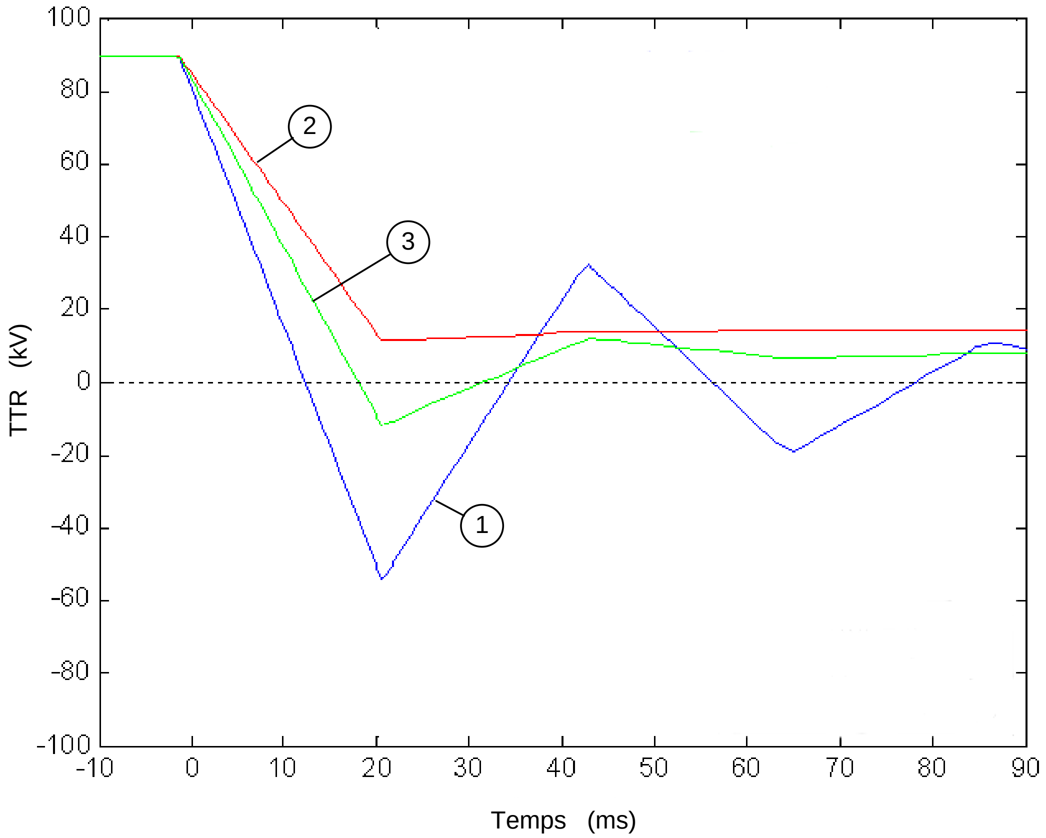
$R_{h2} \approx 0{,}32 \times R_{h1}$

$C_{h2} \approx 0{,}7 \times C_{h1}$

$L_{h2} \approx 1{,}15 \times L_v$

$C_{hd} \approx t_d/R_{h1}$

– Simulation côté ligne par lignes réelles comme indiqué à la Figure R.7.



Légende

1 Ligne bleue: CEI 62271-100 ($R = \infty$): k = 1,6 et Z = 330 Ω

2 Ligne rouge: R = 500 Ω: k = 0,87 et Z = 173 Ω

3 Ligne verte: R = 1 000 Ω: k = 1,13 et Z = 224 Ω

Figure R.7 – Exemple de simulation par lignes réelles pour la séquence d'essais de défaut proche en ligne L_{90} fondée sur U_r = 1 100 kV, I_{sc} = 50 kA et f_r = 50 Hz

Tableau R.2 – Résultats du calcul de TTR pour la séquence d'essais L_{90}

U_r (kV)	I_{sc} (kA)	f (Hz)	**Séquence**	R (Ω)	u_1 (kV)	t_1 (us)	u_c (kV)	t_2 (us)	u_{cred} (%)	k	Z (Ω)
					Source					**Ligne**	
1100	50	50	L90	∞	674	337	1 347	1 011	0	1,6	330
1100	50	50	L90	1 000	635	350	1 302	1 050	-3	1,13	224
1100	50	50	L90	500	605	360	1 251	1 076	-7	0,87	173

R.2.2.3 Essais d'établissement et de coupure de courants capacitifs

L'application de disjoncteurs avec résistances d'ouverture est limitée à l'établissement et la coupure de lignes aériennes seulement.

La forme d'onde de la tension de rétablissement pendant la période d'insertion est exprimée comme suit:

$$U(t) = \frac{\sqrt{2}\ U_s R}{Z}\left[\cos\varphi \times e^{-(1/RC)t} - \cos(\omega t + \varphi)\right] \tag{R.1}$$

où U_s est la tension de source incluant le facteur de tension capacitive k_c exprimé en valeur efficace (kV);

C est la capacité côté ligne (F);

R est la valeur de la résistance d'ouverture (Ω);

$Z = \sqrt{R^2 + (1/\omega C)^2}$;

$\varphi = \tan^{-1}(1/\omega RC)$.

Les essais d'établissement et de coupure de courant de ligne sur l'interrupteur principal sont effectués en deux parties:

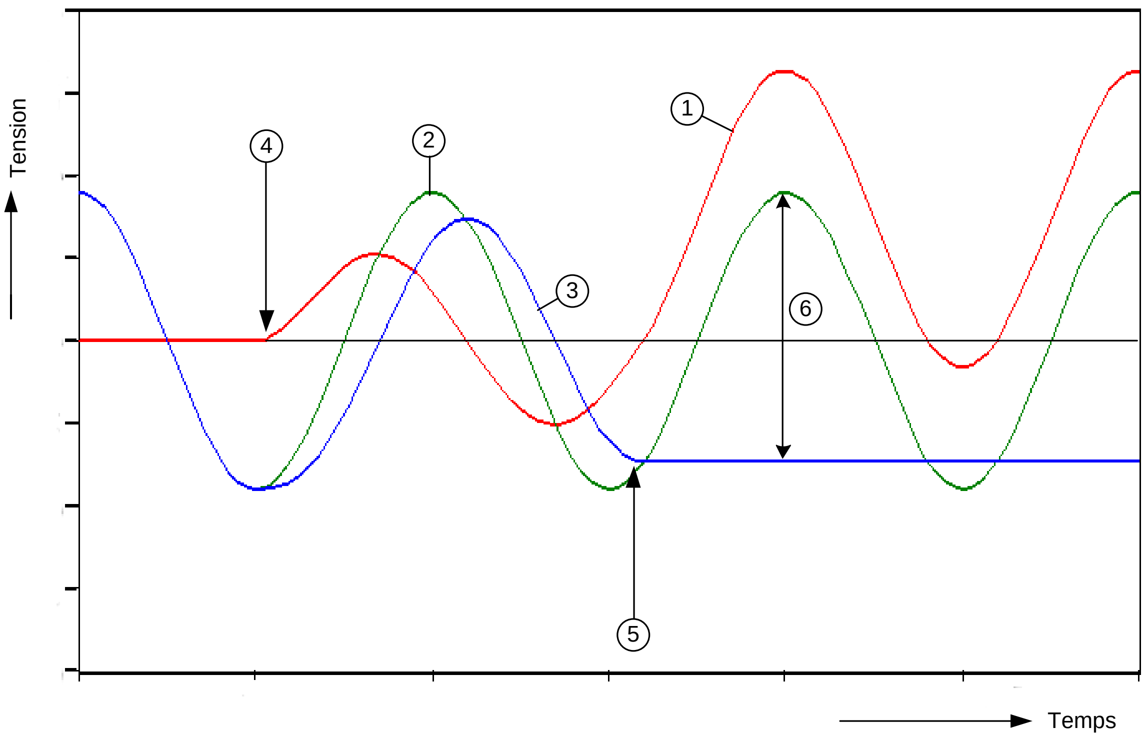
a) Séquence d'essais LC2 avec une tension de rétablissement sinusoïdale destinée à vérifier qu'il n'y a pas de réamorçage ni de réallumage pendant la période d'insertion de la résistance. Si un ou plusieurs réallumages se produisent, on considère que les essais sont invalides et des essais directs doivent être effectués pour confirmer le bon comportement de l'interrupteur principal.

b) Séquence d'essais LC1 avec une forme d'onde en ″1 – cos″ modifié pour vérifier la tenue en tension pour la crête de tension de rétablissement la plus élevée. La forme d'onde en ″1 – cos″ modifié doit être appliquée à un instant correspondant à une durée après le passage par zéro du courant qui est inférieure ou égale à la durée d'insertion de la résistance d'ouverture assignée.

NOTE La forme d'onde de la tension de rétablissement après la période d'insertion est considérée comme étant sans réduction. Une autre manière consiste à effectuer les essais avec un essai unique traitant les deux conditions avec le même nombre d'essais que décrit en 6.111.9.

La performance de réamorçage de l'interrupteur principal doit être conforme au 6.111.11.

Une forme d'onde type de tension de rétablissement pour établissement et coupure de courants capacitifs est représentée à la Figure R.8.



Légende

1	ligne rouge	Tension aux bornes de l'interrupteur principal U_m
2	ligne verte	Tension côté alimentation U_s
3	ligne bleue	Tension côté charge U_l
4		Coupure de l'interrupteur principal
5		Coupure de l'interrupteur de résistance
6		Tension aux bornes de l'interrupteur de résistance U_{res}

Figure R.8 – Forme d'onde type de tension de rétablissement d'établissement et coupure de courants capacitifs sur un disjoncteur équipé de résistances d'ouverture

R.2.3 Essais sur l'interrupteur de résistance

R.2.3.1 Essais d'établissement et de coupure de défaut aux bornes et en discordance de phases

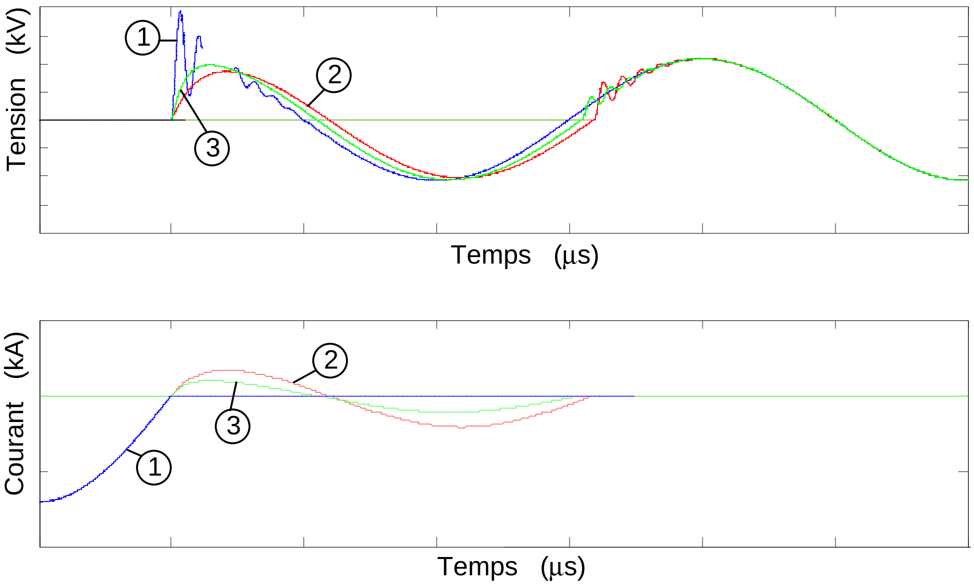
La valeur du courant de coupure de l'interrupteur de résistance est généralement de l'ordre de 1,5 kA ou moins, même dans le cas de tensions assignées supérieures à 800 kV, car la valeur ohmique de la résistance d'ouverture se situe dans la plage de 500 Ω à 2 000 Ω. On suppose que le courant de court-circuit se situe dans la plage de 40 kA à 63 kA. Le courant circulant dans l'interrupteur de résistance est alors de l'ordre de 1 % à 4 % du courant de court-circuit assigné. Dans le cas d'établissement et de coupure en discordance de phases seulement, le courant peut être de l'ordre de 3 kA.

Comme pour l'interrupteur principal, les valeurs de TTR modifiées doivent être calculées pour chaque cas particulier.

Les calculs de TTR peuvent être effectués en utilisant un programme de calcul de transitoire électromagnétique approprié.

Les paramètres de TTR modifiés peuvent également être obtenus en calculant l'influence de la résistance sur les circuits avec des composants concentrés. Un exemple de circuit d'essai est indiqué à la Figure R.3.

Une forme d'onde type de tension de rétablissement et le courant traversant l'interrupteur de résistance sont représentés à la Figure R.9.



Légende

1 Ligne bleue: Interrupteur principal, $R = \infty$

2 Ligne rouge: R = 500 Ω

3 Ligne verte: R = 1 000 Ω

Figure R.9 – Forme d'onde type de tension de rétablissement de T10 (fondée sur U_r = 1 100 kV, I_{sc} = 50 kA et f_r = 50 Hz) sur l'interrupteur de résistance d'un disjoncteur équipé de résistances d'ouverture

Le Tableau R.3 énumère les résultats des calculs effectués en utilisant le circuit représenté à la Figure R.3.

Tableau R.3 – Résultats des calculs de TTR pour la séquence d'essais T10

U_r (kV)	I_{sc} (kA)	f (Hz)	Séquence	R (Ω)	U_c (kV)	t_3 (µs)	I_r (kA)
1 100	50	50	T10	∞			
1 100	50	50	T10	1 000	408	295	0,754
1 100	50	50	T10	500	673	287	1,46

Lorsque la séquence d'essais de défaut aux bornes T10 est exécutée, il est inutile de répéter les autres séquences d'essais de défaut aux bornes sur l'interrupteur de résistance (T30, T60, T100a et T100s).

R.2.3.2 Essais de défaut proche en ligne

Pour la valeur du courant de coupure de l'interrupteur de résistance, se référer à R.2.3.1.

Comme pour l'interrupteur principal, les valeurs de TTR modifiées doivent être calculées pour chaque cas particulier.

Les calculs de TTR peuvent être effectués en utilisant un programme de calcul de transitoire électromagnétique approprié.

Lorsque la séquence d'essais de défaut aux bornes T10 est effectuée, aucun essai de SLF n'est requis sur l'interrupteur de résistance.

R.2.3.3 Essais d'établissement et de coupure de courants capacitifs

Deux séries d'essais d'établissement et de coupure de courant de lignes à vide sont requises.

a) LC1: en utilisant une forme d'onde en ″1 – cos″ comme défini pour les disjoncteurs non équipés de résistances d'ouverture;
b) LC2: avec une forme d'onde en ″1 – cos″ modifié sur un disjoncteur équipé de résistances d'ouverture. L'équation suivante donne la tension de rétablissement instantanée modifiée et de crête de l'interrupteur de résistance dans un circuit avec une résistance R en série:

$$U(t) = \sqrt{2}\, U_{\mathrm{S}} \left[\cos(\theta) - \cos(\omega t + \theta)\right] \tag{R.2}$$

où

$$\theta = \tan^{-1}(\omega CR)$$

La performance de réamorçage de l'interrupteur de résistance doit être conforme au 6.111.11.

R.2.4 Essais de la pile de résistances

La pile de résistances doit supporter les contraintes thermiques provoquées par la circulation du courant dans la résistance pendant la durée d'insertion. Ceci fait l'objet d'un essai en effectuant une opération de coupure T100s, suivie par une séquence d'établissement-coupure en discordance de phases (manœuvre CO). À la fois les niveaux d'énergie et de courant doivent être obtenus dans les éléments de résistance pendant l'essai. Par accord du constructeur, il est admis de raccourcir la durée du courant pendant l'essai si le courant utilisé dans un essai réel est supérieur au courant circulant dans la résistance pendant un état de discordance de phases. Ces essais peuvent être effectués avec les contacts réels du disjoncteur ou avec un interrupteur auxiliaire.

Des essais sur des sections thermiquement équivalentes contenant au moins 20 éléments de résistance connectés en série peuvent être exécutés. Les sections équivalentes doivent simuler des conditions thermiques et diélectriques égales ou plus rigoureuses que celles du module complet.

On considère que les durées d'insertion présumées sont de 10 ms pour une manœuvre d'établissement et 30 ms pour une manœuvre de coupure.

NOTE Une ou plusieurs durées d'insertion différentes peuvent être utilisées si la ou les durées d'insertion assignées sont différentes de celles mentionnées ci-dessus.

La durée entre deux injections d'énergie assignées doit être mentionnée par le constructeur.

Pour vérifier la capacité thermique des piles de résistances, une deuxième séquence d'essais après la durée de refroidissement prescrite doit être effectuée. Le refroidissement de l'ensemble de résistances entre les deux séquences d'essais ne doit pas être plus favorable que dans les conditions de service. Aucune détérioration significative ne doit être observée sur les éléments de résistance après la deuxième séquence d'essais.

La mesure des valeurs ohmiques de l'ensemble de résistances et de chaque élément de résistance individuel doit être telle que les valeurs ohmiques après essai, et après une durée de refroidissement suffisante, ne varient pas de plus de 2,5 % par rapport aux valeurs mesurées avant l'essai.

R.3 Durée d'insertion de la résistance

La résistance doit être insérée dans le circuit au cours des manœuvres de coupure pendant une certaine période. La durée d'insertion mécanique de la résistance doit être plus longue que la durée d'arc maximale de l'interrupteur principal et une valeur située autour de 30 ms est généralement suffisante (on doit également tenir compte de la durée d'arc de l'interrupteur de résistance).

Selon la conception, on peut utiliser les mêmes résistances et interrupteurs de résistance pour la fermeture et l'ouverture. La résistance doit être insérée dans le circuit pendant la durée de préinsertion définie en 3.7.145, en tenant compte du pré-amorçage des interrupteurs de résistance et principal.

R.4 Capacité de tenue au courant

La résistance doit être capable de conduire son courant pendant une période spécifiée sans aucune anomalie telle qu'un arc, un amorçage sur les parties adjacentes, des fissures ou de quelconques dommages mécaniques. Leurs surfaces de contact électrique ne doivent présenter aucun signe d'arc tel que des marques de brûlure.

Toute matière isolante supportant les éléments de résistance s'il y a lieu doit supporter les contraintes thermiques et électriques provoquées par le courant traversant les résistances pendant les manœuvres de coupure et d'établissement.

R.5 Performance diélectrique

Voir 6.2 de la présente norme.

R.6 Performance mécanique

L'essai de manœuvre mécanique (voir 6.101.2) doit être effectué sur un ou plusieurs pôles de disjoncteur entièrement équipés d'interrupteurs principal et de résistance et d'un assemblage de résistances.

Les éléments de résistance doivent satisfaire aux conditions énoncées en 6.101.1.4 pendant et après un essai mécanique. De plus, les éléments de résistance ne doivent présenter aucun dommage tel que des copeaux, des fissures, etc. La résistance ohmique de l'assemblage de résistances mesurée après les essais ne doit pas différer de plus de 2,5 % de la valeur mesurée avant les essais.

R.7 Exigences pour la spécification des résistances d'ouverture

Pour les disjoncteurs équipés de résistance d'ouverture, les points suivants doivent être spécifiés:

– valeur de résistance
– durée d'insertion des résistances;
– cycle de séquences.

La durée comprise entre deux cycles de séquences consécutifs identifiés en R.2.3 (un cycle de séquences étant un O sous défaut aux bornes et un CO sous discordance de phases) doit être mentionnée par le constructeur.

R.8 Exemples de formes d'onde de tension de rétablissement

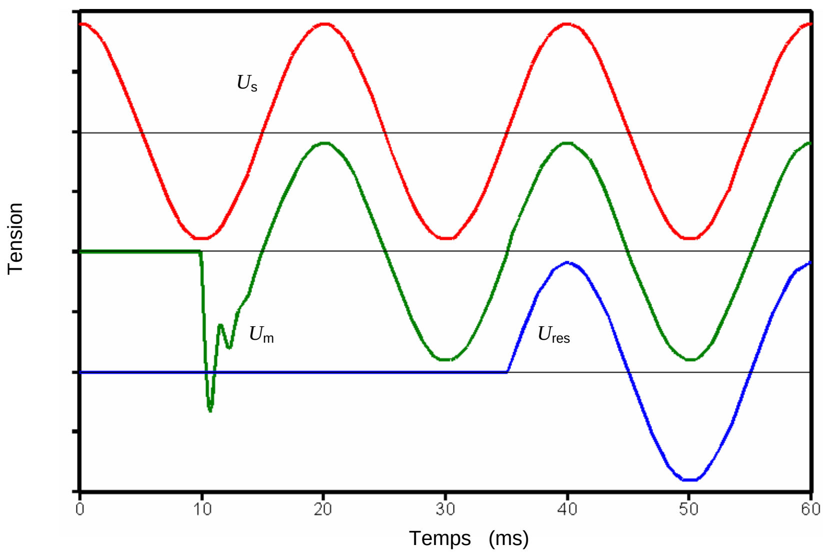
R.8.1 Généralités

Les Figures R.10 à R.15 donnent les formes d'onde pour diverses conditions de coupure et d'établissement et de coupure. Le but est de montrer une représentation graphique et d'illustrer les effets d'une résistance d'ouverture.

R.8.2 Défauts aux bornes

Un exemple type de formes d'onde de la TTR pour les interrupteurs principal et de résistance en cas de coupure de forts courants de court-circuit tels que T100s est donné à la Figure R.10 et les courants correspondants sont représentés à la Figure R.11.

Dans le cas de courants de court-circuit relativement faibles tels que T30 et T10, les formes d'ondes de TTR sont représentées à la Figure R.12 et les formes de courant sont illustrées à la Figure R.13.



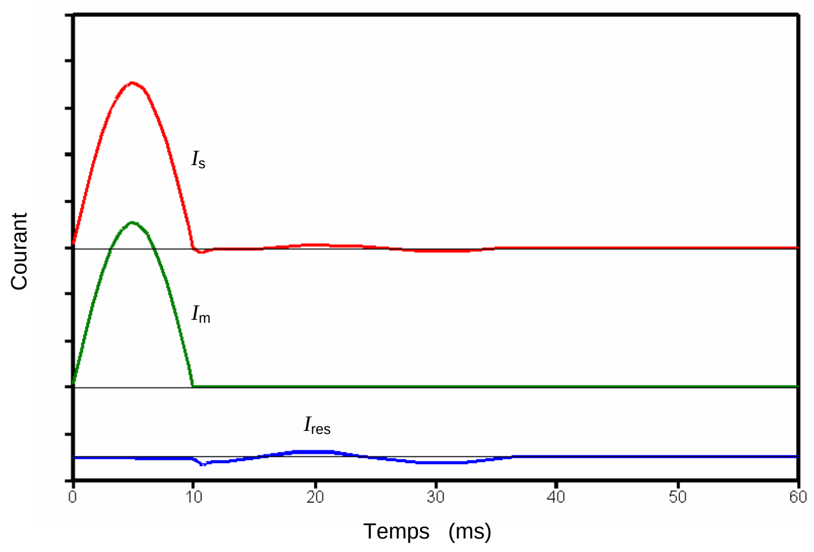
Légende

U_m Tension aux bornes de l'interrupteur principal

U_{res} Tension aux bornes de l'interrupteur de résistance

U_s Tension de source

Figure R.10 – Formes d'onde de TTR pour manœuvre de coupure de fort courant de court-circuit



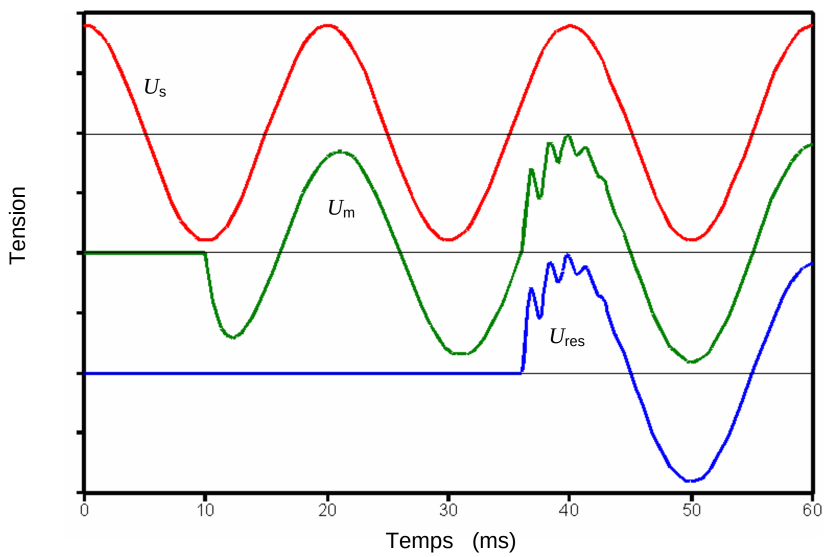
Légende

I_m Courant traversant l'interrupteur principal

I_{res} Courant traversant l'interrupteur de résistance

I_s Courant de source

Figure R.11 – Courants en cas de manœuvre de coupure de fort courant de court-circuit



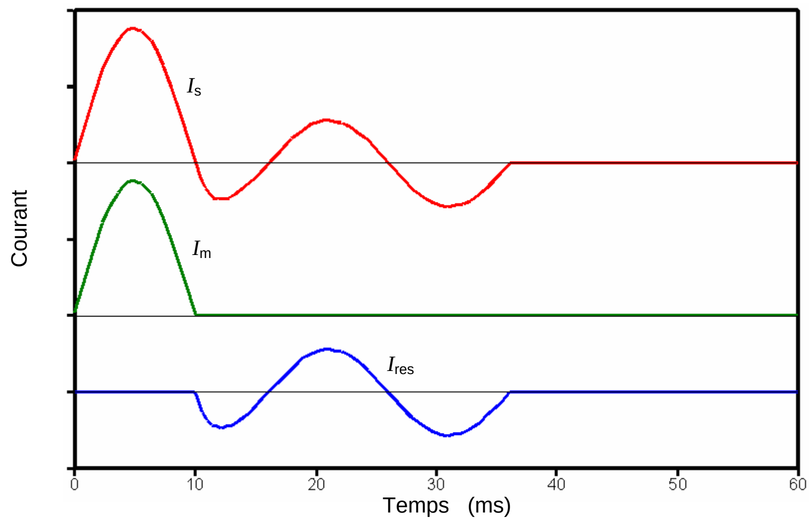
Légende

U_m Tension aux bornes de l'interrupteur principal

U_{res} Tension aux bornes de l'interrupteur de résistance

U_s Tension de source

Figure R.12 – Formes d'onde de TTR pour manœuvre de coupure de faible courant de court-circuit



Légende

I_m Courant traversant l'interrupteur principal

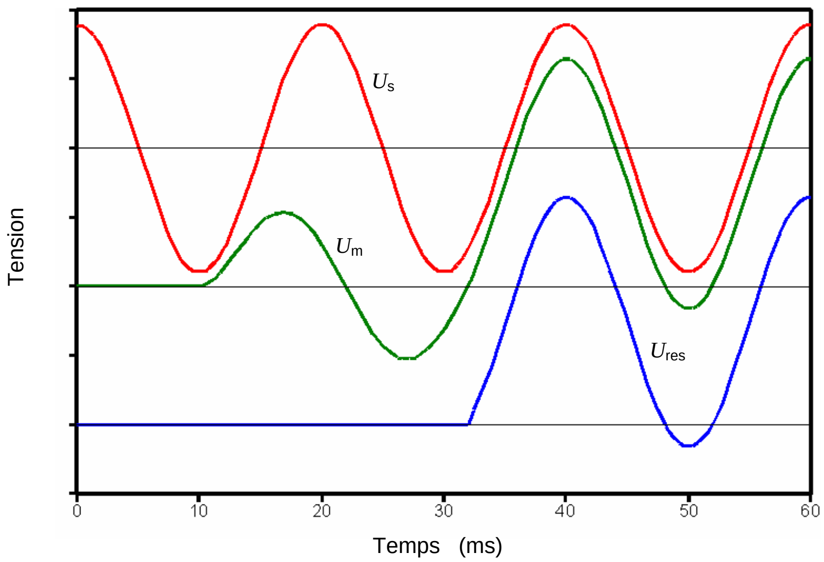
I_{res} Courant traversant l'interrupteur de résistance

I_s Courant de source

Figure R.13 – Courants en cas de manœuvre de coupure de faible courant de court-circuit

R.8.3 Coupure de courant de lignes à vide

Les formes d'ondes types de tension de rétablissement pour manœuvres de coupure de courant de lignes à vide sont données à la Figure R.14, les formes d'ondes de courant sont représentées à la Figure R.15.



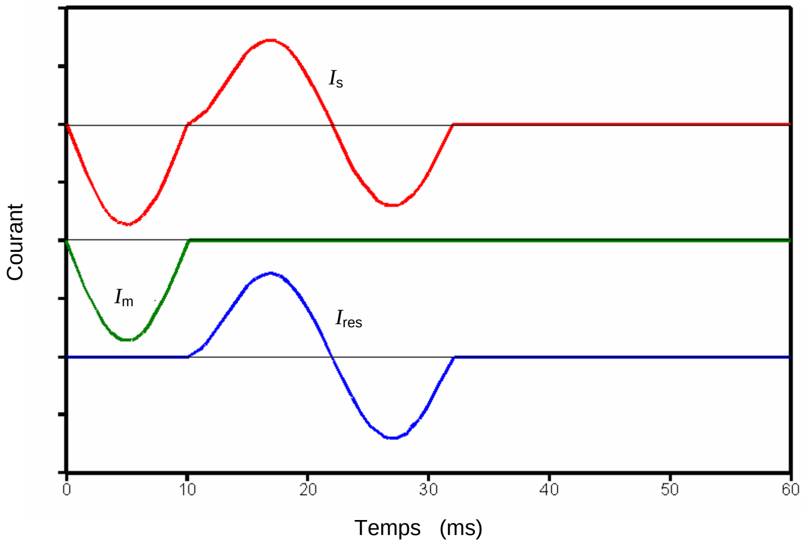
Légende

U_m Tension aux bornes de l'interrupteur principal

U_{res} Tension aux bornes de l'interrupteur de résistance

U_s Tension de source

Figure R.14 – Formes d'ondes de tension pour manœuvre de coupure de courant de lignes à vide



Légende

I_m Courant traversant l'interrupteur principal

I_{res} Courant traversant l'interrupteur de résistance

I_s Courant de source

Figure R.15 – Formes d'ondes de courant pour manœuvre de coupure de courant de lignes à vide

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(Vide)

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3 La CEI 60186 et ses amendements restent en vigueur pour les transformateurs capacitifs de tension. En ce qui concerne les transformateurs inductifs de tension, cette norme est remplacée par la CEI 60044-2.

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