IEC/IEEE 62271-37-013

Edition 1.0 2015-10

INTERNATIONAL STANDARD

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High-voltage switchgear and controlgear – Part 37-013: Alternating-current generator circuit-breakers

IEC/IEEE 62271-37-013:2015-10(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.130.10

ISBN 978-2-8322-2871-5

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 37-013: Alternating-current generator circuit-breakers

FOREWORD

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International Standard IEC/IEEE 62271-37-013 has been prepared by a joint working group comprised of members both from IEC 17A/WG 52 representing subcommittee 17A: High-voltage switchgear and controlgear, of IEC technical committee 17: Switchgear and controlgear, in cooperation with IEEE WG P62271-37-013[1] representing the Switchgear Committee of the Power and Energy Society of the IEEE, under the IEC/IEEE Dual Logo Agreement.

This publication is published as an IEC/IEEE Dual Logo standard.

The text of this standard is based on the following documents:

FDIS	Report on voting
17A/1074/FDIS	17A/1101/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

International standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

This standard shall be read in conjunction with IEC 62271-1: 2007, to which it refers and which is applicable unless otherwise specified in this standard. In order to simplify and clarify the structure of this document, the numbering of clauses and subclauses used here is the same as in IEC 62271-1. Amendments to these clauses and subclauses are given under the same numbering, while additional subclauses are numbered from 101.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website 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- withdrawn,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
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1 A list of IEEE participants can be found at the following address: http://standards.ieee.org/downloads/62271/62271-37-013-2015/62271-37-013-2015_wg-participants.pdf.

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 37-013: Alternating-current generator circuit-breakers

1 General

1.1 Scope

This part of IEC 62271 is applicable to three-phase a.c. high-voltage generator circuit-breakers, hereafter called generator circuit-breaker, designed for indoor or outdoor installation and for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 kV and up to 38 kV.

It is applicable to generator circuit-breakers that are installed between the generator and the transformer terminals. Requirements relative to generator circuit-breakers intended for use with generators and transformers rated 10 MVA or more are covered specifically. Generator circuits rated less than 10 MVA and pumped storage installations are considered special applications, and their requirements are not completely covered by this standard.

This standard is also applicable to the operating mechanisms of generator circuit-breakers and to their auxiliary equipment.

1.2 Normative references

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

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

IEC 60060-1:2010, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60296:2012, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

IEC 60480:2004, *Guidelines for the checking and treatment of sulphur hexafluoride* (SF_6) *taken from electrical equipment and specification for its re-use*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code)*
IEC 60529:1989/AMD1:1999
IEC 60529:1989/AMD2:2013

IEC 61180-1, *High-voltage test techniques for low voltage equipment – Part 1: Definitions, test and procedure requirements*

IEC 62262:2002, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)*

IEC 62271-1:2007, *High-voltage switchgear and controlgear – Part 1: Common specifications*
IEC 62271-1:2007/AMD1:2011

IEC IEEE 62271-37-082:2012, *High-voltage switchgear and controlgear – Part 37-082: Standard practice for the measurement of sound pressure levels on alternating current circuit-breakers*

IEC 62271-100:2008, *High-voltage switchgear and controlgear – Part 100: Alternating current circuit-breakers*
IEC 62271-100:2008/AMD1:2012

IEC 62271-101:2012, *High-voltage switchgear and controlgear – Part 101: Synthetic testing*

IEC TR 62271-306:2012, *High-voltage switchgear and controlgear – Part 306: Guide to IEC 62271-100, IEC 62271-1 and other IEC standards related to alternating current circuit-breakers*

IEEE Std C37.011™-2011, *IEEE Guide for the Application of Transient Recovery Voltage for AC High-Voltage Circuit Breakers (ANSI)*[2]

IEEE Std C37.23™-2003 (Reaff 2008), *IEEE Standard for Metal-Enclosed Bus (ANSI)*

IEEE Std C37.59™-2007, I*EEE Standard Requirements for Conversion of Power Switchgear Equipment*

2 Normal and special service conditions

NOTE Normal and special service conditions are sometimes called usual and unusual service conditions respectively.

2.1 Normal service conditions

Subclause 2.1 of IEC 62271-1:2007 is applicable.

2.2 Special service conditions

Subclause 2.2 of IEC 62271-1:2007 is applicable.

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in IEC 60050-441 and IEC 62271-1, as well as the following, apply.

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

The IEEE Standards Dictionary Online[3] should be referenced for terms and definitions not defined in this clause.

For clarity, ease of reference and convenience of the user, definitions of selected terms as used in this standard are given below.

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3 IEEE Standards Dictionary Online subscription is available at: http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

3.1 General terms

3.1.101
switchgear and controlgear
general term covering switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures

Note 1 to entry: Since generator circuit-breakers are used only in switchgear, this document will refer only to “switchgear” and not to “switchgear and controlgear”.

[SOURCE: IEC 60050-441:1984, 441-11-01, modified – Addition of a new note to entry.]

3.1.102
short-circuit current
over-current resulting from a short circuit due to a fault or an incorrect connection in an electric circuit

[SOURCE: IEC 60050-441:1984, 441-11-07]

3.1.103
moment of inertia
sum (integral) of the products of the mass elements of a body and the squares of their distances (radii) from a given axis

3.1.104
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 generator circuit-breaker in which, at the instant of operation of the generator circuit-breaker, the phase angle between rotating vectors, representing the generated voltages on either side, exceeds the normal value

3.1.105
out-of-phase (as prefix to a characteristic quantity)
qualifying term indicating that the characteristic quantity is applicable to operation of the generator circuit-breaker in out-of-phase conditions

3.1.106
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 generator 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 generator circuit-breaker

3.1.107
loop (of an a.c. current wave)
part of the wave of the a.c. current between two successive current zero crossings

SEE: Figure 1 *n* and *p*.

Note 1 to entry: When a d.c. component (see Figure 1 *d*) is present, a distinction is made between a major loop (see Figure 1 *n*) and a minor loop (see Figure 1 *p*) depending on the time interval between two successive current zero crossings being longer or shorter, respectively, than the half-period of the alternating component of the current.

3.1.108
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

3.1.109
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 conditions such as pollution, humidity, vermin, etc.

[SOURCE: IEC 60050-604:1987, 604-03-02, modified – replacement of "atmospheric air" by "air"]

3.1.110
self-restoring insulation
insulation which completely recovers its insulating properties after a disruptive discharge

[SOURCE: IEC 60050-604:1987, 604-03-04]

3.1.111
non-self-restoring insulation
insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge

[SOURCE: IEC 60050-604:1987, 604-03-05]

3.1.112
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 to entry: This term applies to discharges in solid, liquid and gaseous dielectrics and to combinations of these.

Note 2 to entry: 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 to entry: 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.

3.1.113
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 1 to entry: 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 earth of nearby equipment.

3.1.114
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

Note 1 to entry: Normally such systems are solidly earthed (neutral) systems or low impedance earthed (neutral) systems.

Note 2 to entry: 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.

3.1.115
non-effectively earthed neutral system
system other than effectively earthed neutral system and not meeting its conditions

Note 1 to entry: Normally such systems are isolated neutral systems, high impedance earthed (neutral) systems or resonant earthed (neutral) systems.

Note 2 to entry: 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.

3.1.116
re-ignition (of an a.c. mechanical switching device)
resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of less than a quarter cycle of power frequency

[SOURCE: IEC 60050-441:1984, 441-17-45]

3.1.117
restrike (of an a.c. mechanical switching device)
resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of a quarter cycle of power frequency or longer

[SOURCE: IEC 60050-441:1984, 441-17-46]

3.1.118
isolated-phase bus
bus in which each phase conductor is enclosed by an individual earthed metal housing separated from adjacent conductor housings by an air space

Note 1 to entry: The bus may be self-cooled or may be forced-cooled by means of circulating gas or liquid.

3.2 Assemblies of switchgear and controlgear

No particular definitions.

3.3 Parts of assemblies

No particular definitions.

3.4 Switching devices

3.4.101
switching device
device designed to make or break the current in one or more electric circuits

[SOURCE: IEC 60050-441:1984, 441-14-01]

3.4.102
mechanical switching device
switching device designed to close and open one or more electric circuits by means of separable contacts

Note 1 to entry: Any mechanical switching device may be designated according to the medium in which its contacts open and close, e.g. air, SF_6, oil.

[SOURCE: IEC 60050-441:1984, 441-14-02]

3.4.103
circuit-breaker
mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short circuit, as well as capable of withstanding specified voltages across the gap between the contacts when open

[SOURCE: IEC 60050-441:1984, 441-14-20, modified – addition of a new capability]

3.4.104
generator circuit-breaker
circuit-breaker installed between generator and associated step-up transformer

3.4.105
air circuit-breaker
circuit-breaker in which the contacts open and close in air at atmospheric pressure

[SOURCE: IEC 60050-441:1984, 441-14-27]

3.4.106
oil circuit-breaker
circuit-breaker in which the contacts open and close in oil

Note 1 to entry: Typical examples of oil circuit-breakers are live tank minimum oil circuit-breakers and dead tank bulk oil circuit-breakers.

[SOURCE: IEC 60050-441:1984, 441-14-28]

3.4.107
vacuum circuit-breaker
circuit-breaker in which the contacts open and close within a highly evacuated envelope

[SOURCE: IEC 60050-441:1984, 441-14-29]

3.4.108
gas-blast circuit-breaker
circuit-breaker in which the arc develops in a blast of gas

Note 1 to entry: Where the gas is moved by a difference in pressure established by mechanical means during the opening operation of the circuit-breaker, it is termed a single pressure gas-blast circuit-breaker. Where the gas is moved by a difference in pressure established before the opening operation of the circuit-breaker, it is termed a double pressure gas-blast circuit-breaker.

[SOURCE: IEC 60050-441:1984, 441-14-30]

3.4.109
(void)

3.4.110
air-blast circuit-breaker
gas-blast circuit-breaker in which the gas used is air

[SOURCE: IEC 60050-441:1984, 441-14-32]

3.4.111
generator circuit-breaker class M1
generator circuit-breaker with normal mechanical endurance

3.4.112
generator circuit-breaker class M2
frequently operated generator circuit-breaker for special service requirements and designed so as to require only limited maintenance as demonstrated by specific type tests

3.4.113
generator circuit-breaker class G1
generator circuit-breaker having a rated generator-source short-circuit breaking current characterized at contact separation by a degree of asymmetry of 110 % with the assigned a.c. component of the rated generator-source short-circuit breaking current and a degree of asymmetry of 130 % with a current having an a.c. component equal to 74 % of the assigned a.c. component of the rated generator-source short-circuit breaking current

3.4.114
generator circuit-breaker class G2
generator circuit-breaker having a rated generator-source short-circuit breaking current characterized at contact separation by a degree of asymmetry of 130 % with the assigned a.c. component of the rated generator-source short-circuit breaking current

3.5 Parts of generator circuit-breakers

3.5.101
pole
portion of a switching device associated exclusively with one electrically separated conducting path of its main circuit and excluding those portions which provide a means for mounting and operating all poles together

Note 1 to entry: A switching device is called single-pole if it has only one pole. If it has more than one pole, it may be called multipole (two-pole, three-pole, etc.) provided the poles are or can be coupled in such a manner as to operate together.

[SOURCE: IEC 60050-441:1984, 441-15-01]

3.5.102
main circuit
all the conductive parts of a switching device included in the circuit which it is designed to close or open

[SOURCE: IEC 60050-441:1984, 441-15-02]

3.5.103
control circuit
all the conductive parts (other than the main circuit) of a switching device which are included in a circuit used for the closing operation or opening operation, or both, of the device

[SOURCE: IEC 60050-441:1984, 441-15-03]

3.5.104
auxiliary circuit
all the conductive parts of a switching device which are intended to be included in a circuit other than the main circuit and the control circuits of the device

Note 1 to entry: Some auxiliary circuits fulfil supplementary functions such as signalling, interlocking, etc., and, as such, they may be part of the control circuit of another switching device.

[SOURCE: IEC 60050-441:1984, 441-15-04]

3.5.105
contact
conductive parts designed to establish circuit continuity when they touch and which, due to their relative motion during an operation, open or close a circuit or, in the case of hinged or sliding contacts, maintain circuit continuity

[SOURCE: IEC 60050-441:1984, 441-15-05]

3.5.106
main contact
contact included in the main circuit of a mechanical switching device, intended to carry, in the closed position, the current of the main circuit

[SOURCE: IEC 60050-441:1984, 441-15-07]

3.5.107
arcing contact
contact on which the arc is intended to be established

Note 1 to entry: An arcing contact may serve as a main contact; it may be a separate contact so designed that it opens after and closes before another contact which it is intended to protect from injury.

[SOURCE: IEC 60050-441:1984, 441-15-08]

3.5.108
control contact
contact included in a control circuit of a mechanical switching device and mechanically operated by this device

[SOURCE: IEC 60050-441:1984, 441-15-09]

3.5.109
auxiliary contact
contact included in an auxiliary circuit and mechanically operated by the switching device

[SOURCE: IEC 60050-441:1984, 441-15-10]

3.5.110
auxiliary switch
switch containing one or more control and/or auxiliary contacts mechanically operated by a switching device

[SOURCE: IEC 60050-441:1984, 441-15-11]

3.5.111
“a” contact
make contact
control or auxiliary contact which is closed when the main contacts of the mechanical switching device are closed and open when they are open

[SOURCE: IEC 60050-441:1984, 441-15-12]

3.5.112
“b” contact
break contact
control or auxiliary contact which is open when the main contacts of a mechanical switching device are closed and closed when they are open

[SOURCE: IEC 60050-441:1984, 441-15-13]

3.5.113
release
device, mechanically connected to a mechanical switching device, which releases the holding means and permits the opening or the closing of the switching device

[SOURCE: IEC 60050-441:1984, 441-15-17]

3.5.114
arc control device
device, surrounding the arcing contacts of a mechanical switching device, designed to confine the arc and to assist in its extinction

[SOURCE: IEC 60050-441:1984, 441-15-18]

3.5.115
position indicating device
part of a mechanical switching device which indicates whether it is in the open, closed, or where appropriate, earthed position

[SOURCE: IEC 60050-441:1984, 441-15-25]

3.5.116
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

3.5.117
terminal
component provided for the connection of a device to external conductors

3.5.118
making (or breaking) unit
part of a generator 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 generator circuit-breaker

Note 1 to entry: Making units and breaking units may be separate or combined. Each unit may have several contacts.

Note 2 to entry: The means controlling the voltage distribution between units may differ from unit to unit.

3.5.119
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 generator circuit-breaker

3.5.120
enclosure
part of a generator circuit-breaker providing a specified degree of protection 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

Note 1 to entry: A three-phase enclosed generator circuit-breaker has all three phases in a common enclosure.

Note 2 to entry: A single-phase enclosed generator circuit-breaker has each phase in a single independent enclosure.

Note 3 to entry: For degrees of protection specified by IP coding see IEC 60529:1989 and for degrees of protection specified by IK coding see IEC 62262:2002.

[SOURCE: IEC 60050-441:1984, 441-13-01, modified – addition of new notes to entry and replacement of "assembly" by "generator circuit-breaker" in the definition]

3.5.121
operating mechanism
part of the generator circuit-breaker that actuates the main contacts

3.5.122
power kinematic chain
mechanical connecting system from and including the operating mechanism up to and including the moving contacts

3.5.123
alternative operating mechanism
mechanism 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 to entry: Mechanical characteristics are defined in 6.101.1.1. The use of mechanical characteristics and related requirements are described in Annex D.

Note 2 to entry: 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 to entry: A change in the secondary equipment does not lead to an alternative operating mechanism. However, changes in the opening time can entail differences for asymmetrical switching conditions.

3.6 Operation

3.6.101
operation
transfer of the moving contact(s) from one position to an adjacent position

Note 1 to entry: For a generator circuit-breaker, this can be a closing operation or an opening operation.

Note 2 to entry: If distinction is necessary, an operation in the electrical sense, e.g. make or break, is referred to as a switching operation, and an operation in the mechanical sense, e.g. close or open, is referred to as a mechanical operation.

[SOURCE: IEC 60050-441:1984, 441-16-01]

3.6.102
operating cycle
succession of operations from one position to another and back to the first position through all other positions, if any

[SOURCE: IEC 60050-441:1984, 441-16-02]

3.6.103
operating sequence
succession of specified operations with specified time intervals

[SOURCE: IEC 60050-441:1984, 441-16-03]

3.6.104
closing operation
C
operation by which the device is brought from the open position to the closed position

[SOURCE: IEC 60050-441:1984, 441-16-08]

3.6.105
opening operation
O
operation by which the device is brought from the closed position to the open position

[SOURCE: IEC 60050-441:1984, 441-16-09]

3.6.106
stored energy operation
operation by means of energy stored in the mechanism itself prior to the completion of the operation and sufficient to complete it under predetermined conditions

Note 1 to entry: This kind of operation may be subdivided according to:

a) The manner of storing the energy (spring, weight, etc.);

b) The origin of the energy (manual, electric, etc.);

c) The manner of releasing the energy (manual, electric, etc.).

3.6.107
closed position
position in which the predetermined continuity of the main circuit of the device is secured

[SOURCE: IEC 60050-441:1984, 441-16-22]

3.6.108
open position
position in which the predetermined clearance between open contacts in the main circuit of the device is secured

[SOURCE: IEC 60050-441:1984, 441-16-23]

3.6.109
trip-free mechanical switching device
mechanical switching device, the moving contacts of which return to and remain in the open position when the opening operation is initiated after the initiation of the closing operation, even if the closing command is maintained

Note 1 to entry: To ensure proper breaking of the current which may have been established, it may be necessary that the contacts momentarily reach the closed position.

Note 2 to entry: If the release circuit is completed through an auxiliary switch, electrical release will not take place until such auxiliary switch is closed.

[SOURCE: IEC 60050-441:1984, 441-16-31, modified – addition of a second note to entry]

3.6.110
shunt release
release energized by a source of voltage

[SOURCE: IEC 60050-441:1984, 441-16-41]

3.6.111
anti-pumping device
device which prevents reclosing after a close-open operation as long as the device initiating closing is maintained in the position for closing

[SOURCE: IEC 60050-441:1984, 441-16-48]

3.6.112
interlocking device
device which makes the operation of a switching device dependent upon the position or operation of one or more other pieces of equipment

[SOURCE: IEC 60050-441:1984, 441-16-49]

3.6.113
making operation
closing operation while power is applied to the main circuit

Note 1 to entry: See Figure 1.

3.6.114
breaking operation
opening operation while power is applied to the main circuit

Note 1 to entry: See Figure 1.

3.6.115
close-open operation
CO
closing operation followed by an opening operation

3.6.116
make-break operation
close-open operation while power is applied to the main circuit

Note 1 to entry: See Figure 1.

3.7 Characteristic quantities

Figures 1 to 5 illustrate some definitions of this subclause.

Time quantities, see terms and definitions 3.7.126 to 3.7.135, are expressed in milliseconds or in cycles of the rated power frequency. When expressed in cycles, the power frequency should be stated in brackets. In the case of generator 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

3.7.102
prospective current (of a circuit and with respect to a switching device or a fuse)
current that would flow in the circuit if each pole of the switching device or the fuse were replaced by a conductor of negligible impedance

Note 1 to entry: The method to be used to evaluate and to express the prospective current is to be specified in the relevant publications.

[SOURCE: IEC 60050-441:1984, 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 1 to entry: The definition assumes that the current is made by an ideal generator 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

Note 1 to entry: See Figure 1 *a*.

3.7.105
prospective symmetrical current (of an a.c. circuit)
prospective current when it is initiated at such an instant that no transient phenomenon follows the initiation

Note 1 to entry: For polyphase circuits, the condition of non-transient period can only be satisfied for the current in one pole at a time.

Note 2 to entry: The prospective symmetrical current is expressed by its r.m.s.

[SOURCE: IEC 60050-441:1984, 441-17-03]

3.7.106
maximum prospective peak current (of an a.c. circuit)
prospective peak current when initiation of the current takes place at the instant which leads to the highest possible value

Note 1 to entry: For a multiple device in a polyphase circuit, the maximum prospective peak current refers to a single pole only.

[SOURCE: IEC 60050-441:1984, 441-17-04]

3.7.107
prospective making current (for a pole of a switching device)
prospective current when initiated under specified conditions

Note 1 to entry: The specified conditions may relate to the method of initiation, e.g. by an ideal switching device, or to the instant of initiation, e.g. leading to the maximum prospective peak current in an a.c. circuit, or to the highest rate of rise. The specification of these conditions is found in the relevant publications.

[SOURCE: IEC 60050-441:1984, 441-17-05]

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

Note 1 to entry: 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 to entry: 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.

Note 3 to entry: See Figure 1 *a*.

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 (of a switching device or a fuse)
current in a pole of a switching device or in a fuse at the instant of initiation of the arc during a breaking process

[SOURCE: IEC 60050-441:1984, 441-17-07]

3.7.111
making current (of a switching device or a fuse)
value of prospective making current that a switching device is capable of making at a stated voltage under prescribed conditions of use and behaviour

Note 1 to entry: The voltage to be stated and the conditions to be prescribed are dealt with in the relevant specifications.

[SOURCE: IEC 60050-441:1984, 441-17-09, modified – replacement of "capacity" by "current"]

3.7.112
short-circuit making current
making current for which the prescribed conditions include a short circuit at the terminals of the switching device

Note 1 to entry: See Figure 1 *a*.

[SOURCE: IEC 60050-441:1984, 441-17-10, modified – replacement of "capacity" by "current"]

3.7.113
short-circuit breaking current
breaking current for which the prescribed conditions include a short circuit at the terminals of the switching device

Note 1 to entry: See Figure 1 *b*.

[SOURCE: IEC 60050-441:1984, 441-17-11, modified – replacement of "capacity" by "current"]

3.7.114
short-time withstand current
current that a circuit or a switching device in the closed position can carry during a specified short time under prescribed conditions of use and behaviour

[SOURCE: IEC 60050-441:1984, 441-17-17]

3.7.115
peak withstand current
value of peak current that a circuit or a switching device in the closed position can withstand under prescribed conditions of use and behaviour

[SOURCE: IEC 60050-441:1984, 441-17-18]

3.7.116
applied voltage (for a switching device)
voltage which exists across the terminals of a pole of a switching device just before the making of the current

[SOURCE: IEC 60050-441:1984, 441-17-24]

3.7.117
recovery voltage
voltage which appears across the terminals of a pole of a switching device or a fuse after the breaking of the current

Note 1 to entry: This voltage may be considered in two successive intervals of time, one during which a transient voltage exists, followed by a second one during which the power frequency or the steady-state recovery voltage alone exists.

[SOURCE: IEC 60050-441:1984, 441-17-25]

3.7.118
transient recovery voltage
TRV
recovery voltage during the time in which it has a significant transient character

Note 1 to entry: The transient recovery voltage may be oscillatory or non-oscillatory or a combination of these depending on the characteristics of the circuit and the switching device. It includes the voltage shift of the neutral of a polyphase circuit.

Note 2 to entry: The transient recovery voltages in three-phase circuits is, unless otherwise stated, that across the first-pole-to-clear, because this voltage is generally higher than that which appears across each of the other two poles.

[SOURCE: IEC 60050-441:1984, 441-17-26]

3.7.119
prospective transient recovery voltage (of a circuit)
transient recovery voltage following the breaking of the prospective symmetrical current by an ideal switching device

Note 1 to entry: The definition assumes that the switching device or the fuse, for which the prospective transient recovery voltage is sought, is replaced by an ideal switching device, i.e. having instantaneous transition from zero to infinite impedance at the very instant of zero current, i.e. at the "natural" zero. For circuits where the current can follow several different paths, e.g. a polyphase circuit, the definition further assumes that the breaking of the current by the ideal switching device takes place only in the pole considered.

[SOURCE: IEC 60050-441:1984, 441-17-29]

3.7.120
power frequency recovery voltage
recovery voltage after the transient voltage phenomena have subsided

[SOURCE: IEC 60050-441:1984, 441-17-27]

3.7.121
peak arc voltage (of a mechanical switching device)
maximum instantaneous value of voltage which under prescribed conditions appears across the terminals of a pole of a switching device during the arcing time

[SOURCE: IEC 60050-441:1984, 441-17-30]

3.7.122
clearance
distance between two conductive parts along a string stretched the shortest way between these conductive parts

[SOURCE: IEC 60050-441:1984, 441-17-31]

3.7.123
clearance between poles
clearance between any conductive parts of adjacent poles

[SOURCE: IEC 60050-441:1984, 441-17-32]

3.7.124
clearance to earth
clearance between any conductive parts and any parts which are earthed or intended to be earthed

[SOURCE: IEC 60050-441:1984, 441-17-33]

3.7.125
clearance between open contacts
total clearance between the contacts, or any conductive parts connected thereto, of a pole of a mechanical switching device in the open position

[SOURCE: IEC 60050-441:1984, 441-17-34]

3.7.126
opening time
opening time is the interval of time between the instant of energising the opening release, the generator circuit-breaker being in the closed position, and the instant when the arcing contacts have separated in all poles

Note 1 to entry: The opening time may vary with the breaking current.

Note 2 to entry: For generator 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 to entry: The opening time includes the operating time of any auxiliary equipment necessary to open the generator circuit-breaker and forming an integral part of the generator circuit-breaker.

Note 4 to entry: See Figure 1 *j*.

3.7.127
arcing time (of a pole)
interval of time between the instant of the first initiation of an arc and the instant of final arc extinction

Note 1 to entry: See Figure 1 *k*.

[SOURCE: IEC 60050-441:1984, 441-17-38, modified – deletion of the words "in all poles" at the end of the definition]

3.7.128
break-time
maximum interval of time between the energizing of the trip circuit at rated control voltage and rated fluid pressure of the operating mechanism and the end of the arcing time

Note 1 to entry: See Figure 1 *l*.

[SOURCE: IEC 60050-441:1984, 441-17-39, modified – the entire definition has been rephrased]

3.7.129
closing time
interval of time between energising the closing circuit, the generator circuit-breaker being in the open position, and the instant when the contacts touch in all poles

Note 1 to entry: The closing time includes the operating time of any auxiliary equipment necessary to close the generator circuit-breaker and forming an integral part of the generator circuit-breaker.

3.7.130
make-time
interval of time between energising the closing circuit, the generator circuit-breaker being in the open position, and the instant when the current begins to flow in the first pole

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

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

Note 3 to entry: See Figure 1 *m*.

[SOURCE: IEC 60050-441:1984, 441-17-40, modified – the entire definition has been rephrased]

3.7.131
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 to entry: The pre-arcing time depends on the instantaneous value of the applied voltage during a specific closing operation and therefore may vary considerably.

3.7.132
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

Note 1 to entry: Unless otherwise stated, it is assumed that the opening release incorporated in the generator circuit-breaker is energised at the instant when the contacts touch in the first pole during closing. This represents the minimum close-open time.

[SOURCE: IEC 60050-441:1984, 441-17-42, modified – addition of a new note]

3.7.133
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 to entry: Unless otherwise stated, it is assumed that the opening release of the generator circuit-breaker is energised one half-cycle after current begins to flow in the main circuit during making. Here it is noted that the use of relays with shorter operating time can subject the circuit-breaker to higher asymmetrical currents.

Note 2 to entry: The make-break time can vary due to the variation of the pre-arcing time.

3.7.134
minimum trip signal duration
minimum time the auxiliary power is applied to the opening release to ensure complete opening of the generator circuit-breaker

3.7.135
minimum close signal duration
minimum time the auxiliary power is applied to the closing device to ensure complete closing of the generator circuit-breaker

3.7.136
normal current
current in r.m.s. amperes at power frequency that a generator circuit-breaker is capable of carrying continuously under specified conditions of use and behaviour without exceeding any of its designated limitations

3.7.137
first-pole-to-clear factor
<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

3.7.138
amplitude factor
ratio between the maximum excursion of the transient recovery voltage to the crest value of the power frequency recovery voltage

3.7.139
insulation level
for a generator circuit-breaker, a characteristic defined by two values indicating the insulation withstand voltages

[SOURCE: IEC 60050-604:1987, 604-03-47, modified – replacement of "particular item of equipment" by "generator circuit-breaker" and removal of “one or”]

3.7.140
power frequency withstand voltage
r.m.s. value of sinusoidal power frequency voltage that the generator circuit-breaker can withstand during tests made under specified conditions and for a specified time

[SOURCE: IEC 60050-604:1987, 604-03-40, modified – replacement of "equipment" by "generator circuit-breaker"]

3.7.141
impulse withstand voltage
peak value of the standard impulse voltage wave which the insulation of the generator circuit-breaker withstands under specified test conditions

3.7.142
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 1 to entry: This pressure is often designated as interlocking pressure (refer to 3.6.5.6 of IEC 62271-1:2007).

3.7.143
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 generator circuit-breaker are maintained and at which a replenishment of the interrupting and/or insulating fluid becomes necessary

Note 1 to entry: See also 3.6.5.5 of IEC 62271-1:2007.

Note 2 to entry: For generator 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 generator circuit-breaker are maintained taking into account the pressure drop at the end of the expected operating life.

3.7.144
degree of asymmetry (of a current at any time)
ratio (expressed as a percentage) of the d.c. component to the peak value of the a.c. component determined from the envelope of the current wave at that time

Note 1 to entry: This value is 100 % when the d.c. component equals the peak value of the a.c. component.

3.7.145
generator-source short-circuit current
short-circuit current when the source of the short-circuit current is entirely from a generator through no transformation

3.7.146
system-source short-circuit current
short-circuit current when the source of the short-circuit current is from the power system through at least one transformation

3.7.147
intermediate level of asymmetry
when in a three-phase system the short-circuit current is initiated simultaneously in all phases and maximum asymmetry is obtained in one of the phases, the intermediate asymmetry is the level of asymmetry in the other two phases having an intermediate (reduced) level of asymmetry

Note 1 to entry: See Figure 6.

3.7.148
earliest possible interruption in a phase with intermediate level of asymmetry after a major loop
the interruption with the shortest time (t_1) from fault current initiation to the first current zero after a major loop in the phase with intermediate level of asymmetry, taking into account:

- the minimum relay time (0,5 cycle of power frequency);
- the minimum opening time;
- the minimum arcing time;
- and that the subsequent current zero crossing of the prospective three-phase current occurs in the phase with maximum level of asymmetry after a major loop

Note 1 to entry: This definition is to be used only for the determination of the test parameters during asymmetrical short-circuit breaking tests. (TD2 – System-source fault)

Note 2 to entry: See Figure 7.

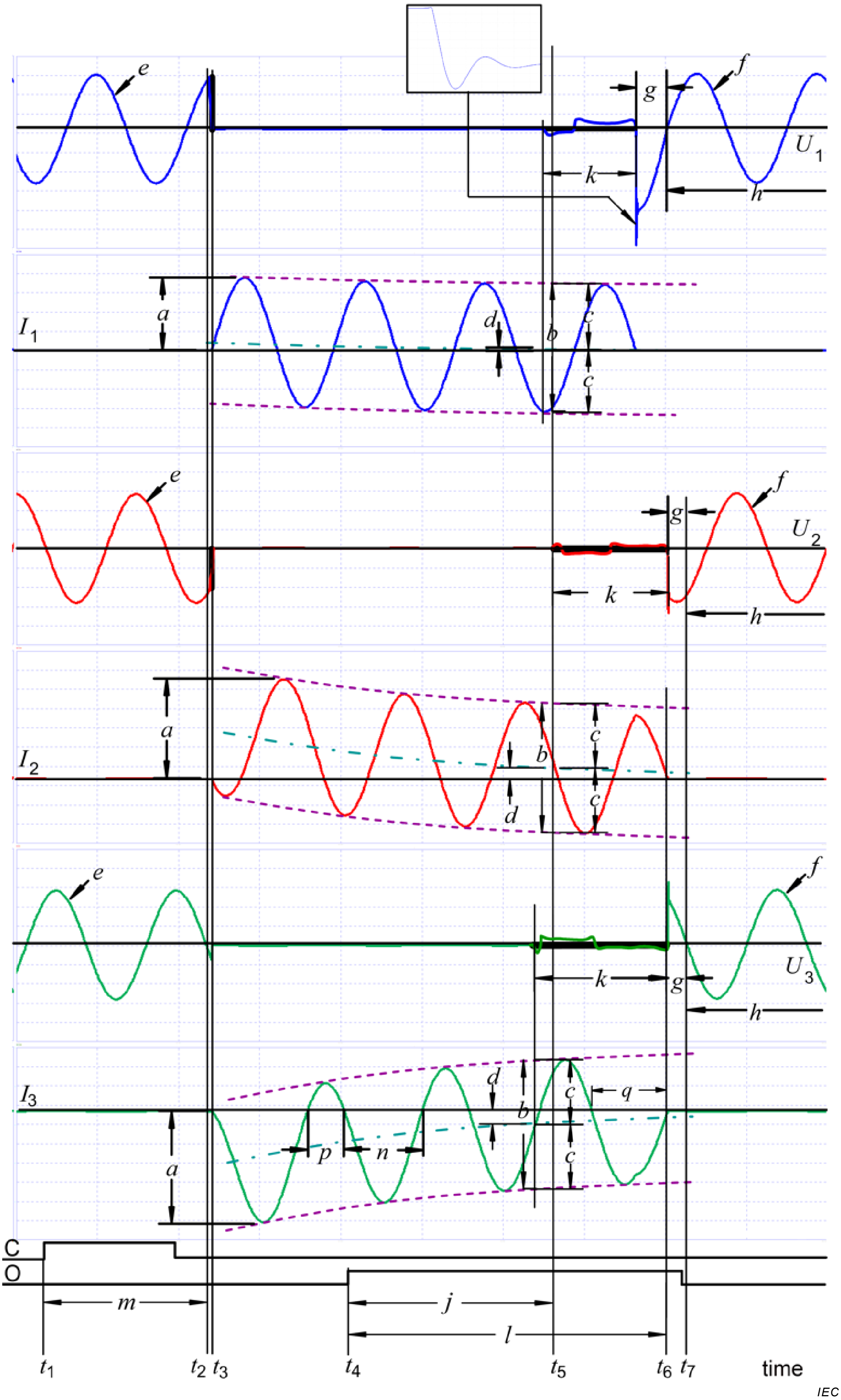
3.7.149
earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop
the interruption with the shortest time (t_2) from fault current initiation to the first current zero after a minor loop in the phase with intermediate level of asymmetry, taking into account:

- the minimum relay time (0,5 cycle of power frequency);
- the minimum opening time;
- the minimum arcing time;
- and that the subsequent current zero crossing of the prospective three-phase current occurs in the other phase with intermediate level of asymmetry after a major loop

Note 1 to entry: This definition is to be used only for the determination of the test parameters during asymmetrical short-circuit breaking tests. (TD2 – System-source fault)

Note 2 to entry: See Figure 8.

3.7.150
minimum arcing time (of a switching device)
shortest interval of time between the instant of the initiation of an arc and the instant of arc extinction


e
f
g
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U1
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I2
U3
I3
p
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q
C
O
m
j
l
t1
t2 t3
t4
t5
t6 t7
time
IEC

U_1	voltage across the terminals of the first-pole-to-clear	*a*	(peak) making current
I_1	current in the first-pole-to-clear	*b*	peak-to-peak value of the a.c. component
U_2, U_3	voltage across the terminals of the two other poles	*c*	peak value of the a.c. component
I_2, I_3	current in the two other poles	*d*	d.c. component
C	closing command, e.g. voltage across the terminals of the closing circuit	*e*	applied voltage
O	opening command, e.g. voltage across the terminals of the opening release	*f*	recovery voltage
t_1	the instant of initiation of the closing operation	*g*	transient recovery voltage
t_2	the instant when the current begins to flow in the main circuit	*h*	power frequency recovery voltage
t_3	the instant when the current is established in all poles	*j*	opening time
t_4	the instant of energizing the opening release	*k*	arcing time
t_5	the instant when the arcing contacts have separated (or instant of initiation of the arc) in all poles	*l*	break time
t_6	the instant of final arc extinction in all poles	*m*	make time
t_7	the instant when the transient voltage phenomena have subsided in the last-pole-to-clear	*n*	major loop
		p	minor loop
		q	major extended loop

NOTE 1 Indicators *i* and *o* are not used.

NOTE 2 The rms value of the a.c. component of the breaking current is $c/\sqrt{2}$.

Figure 1 – Typical oscillogram of a three-phase short-circuit make-break cycle

Notes to the following Figures 2 to 5:

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.

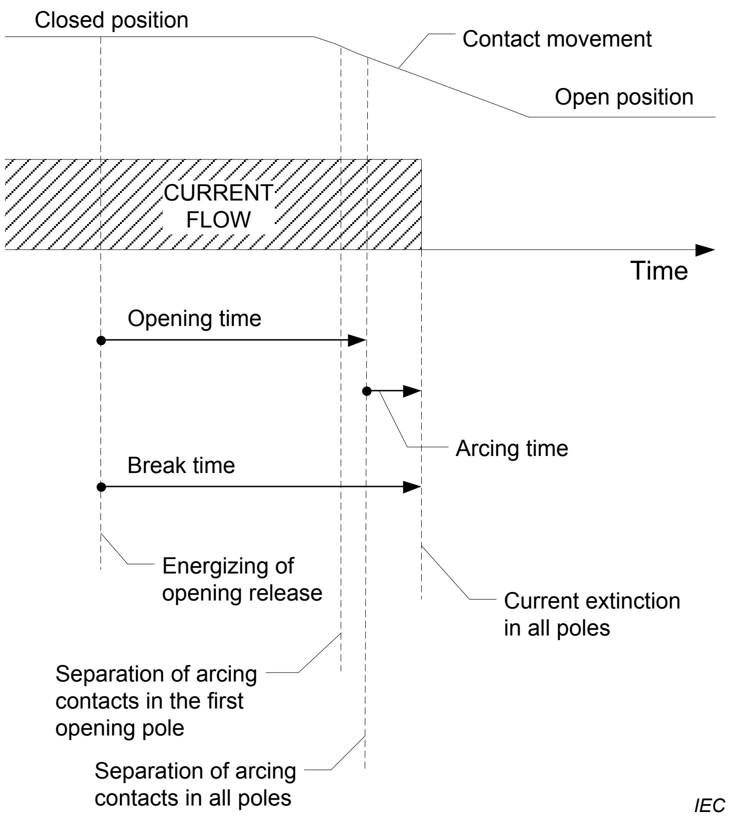


Figure 2 – Generator circuit-breaker without resistors – Opening operation

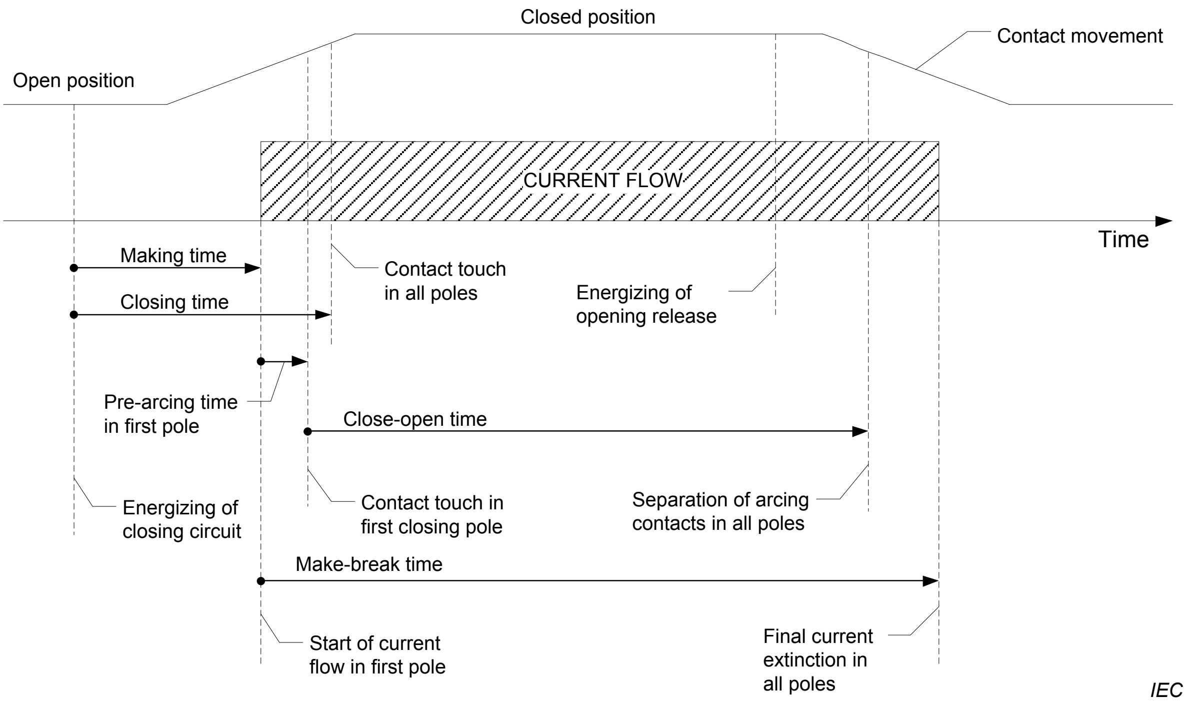


Figure 3 – Generator circuit-breaker without resistors – Close-open cycle

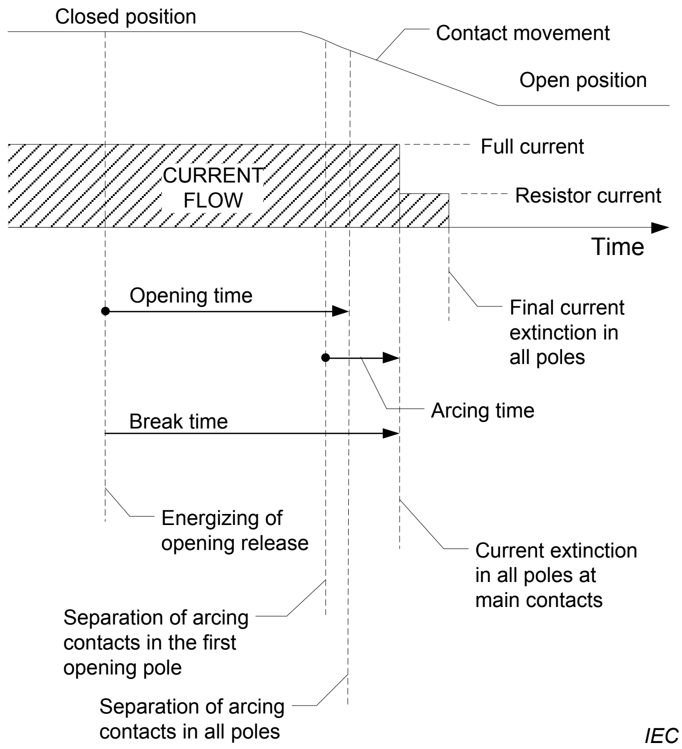


Figure 4 – Generator circuit-breaker with opening resistors – Opening operation

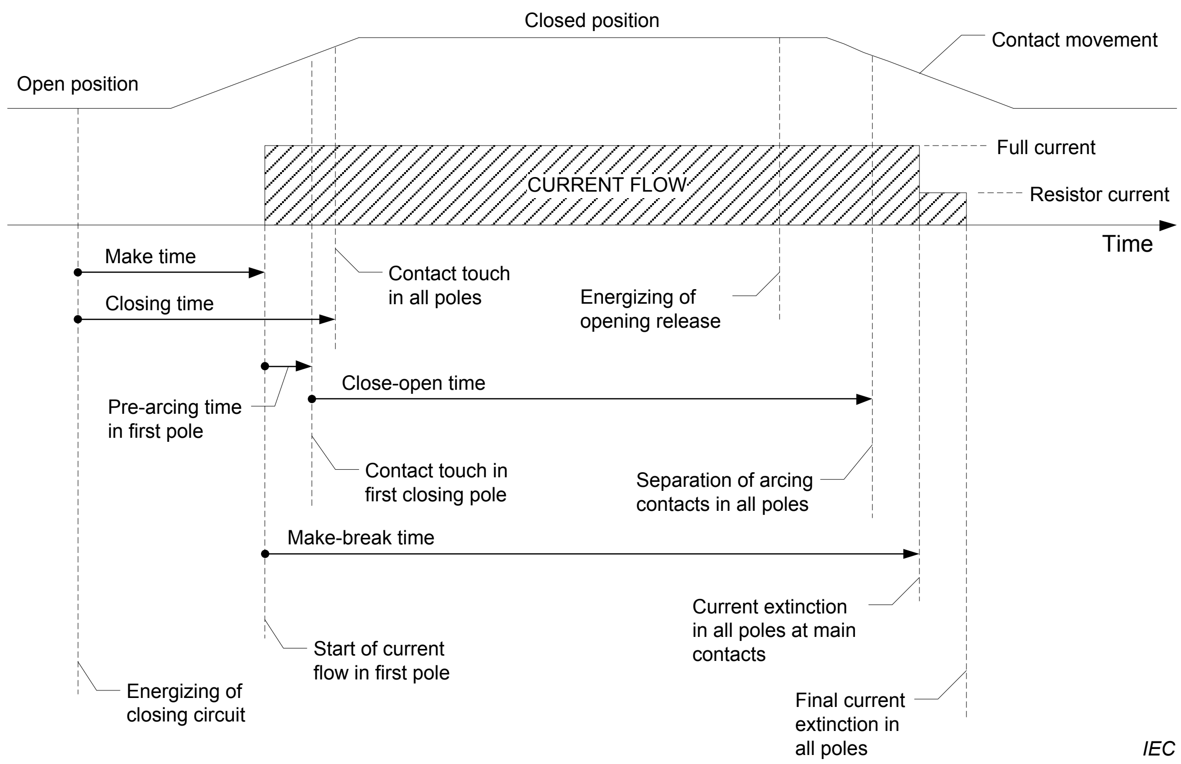


Figure 5 – Generator circuit-breaker with opening resistors – Close-open cycle

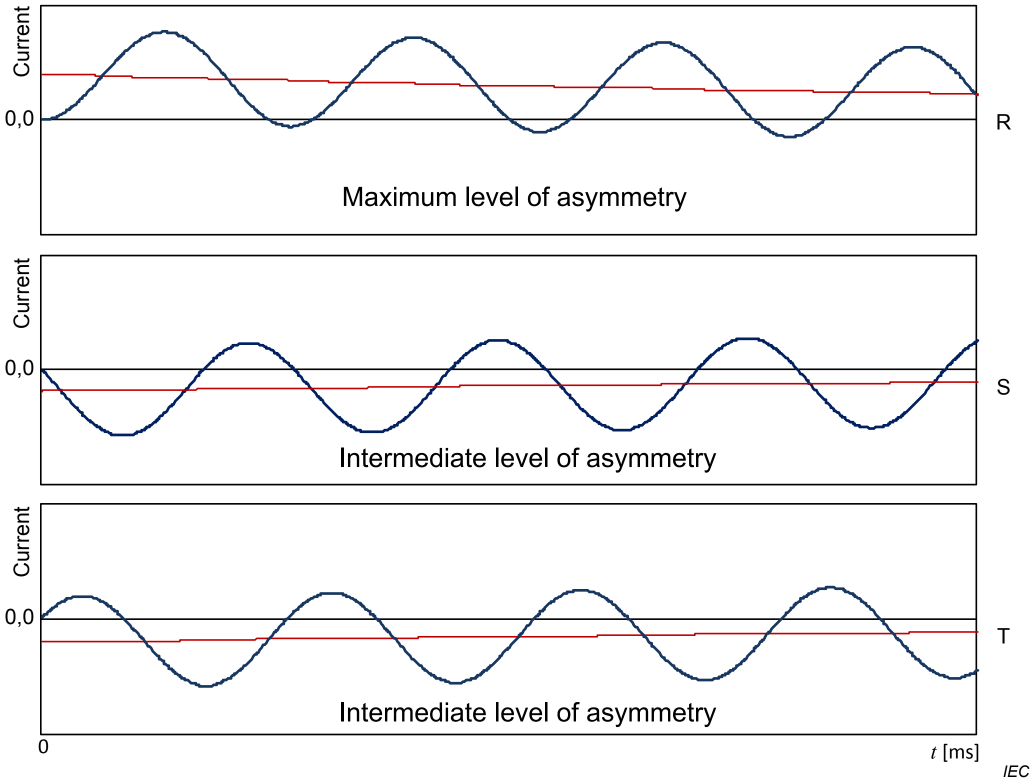


Figure 6 – Example of a three-phase asymmetrical current

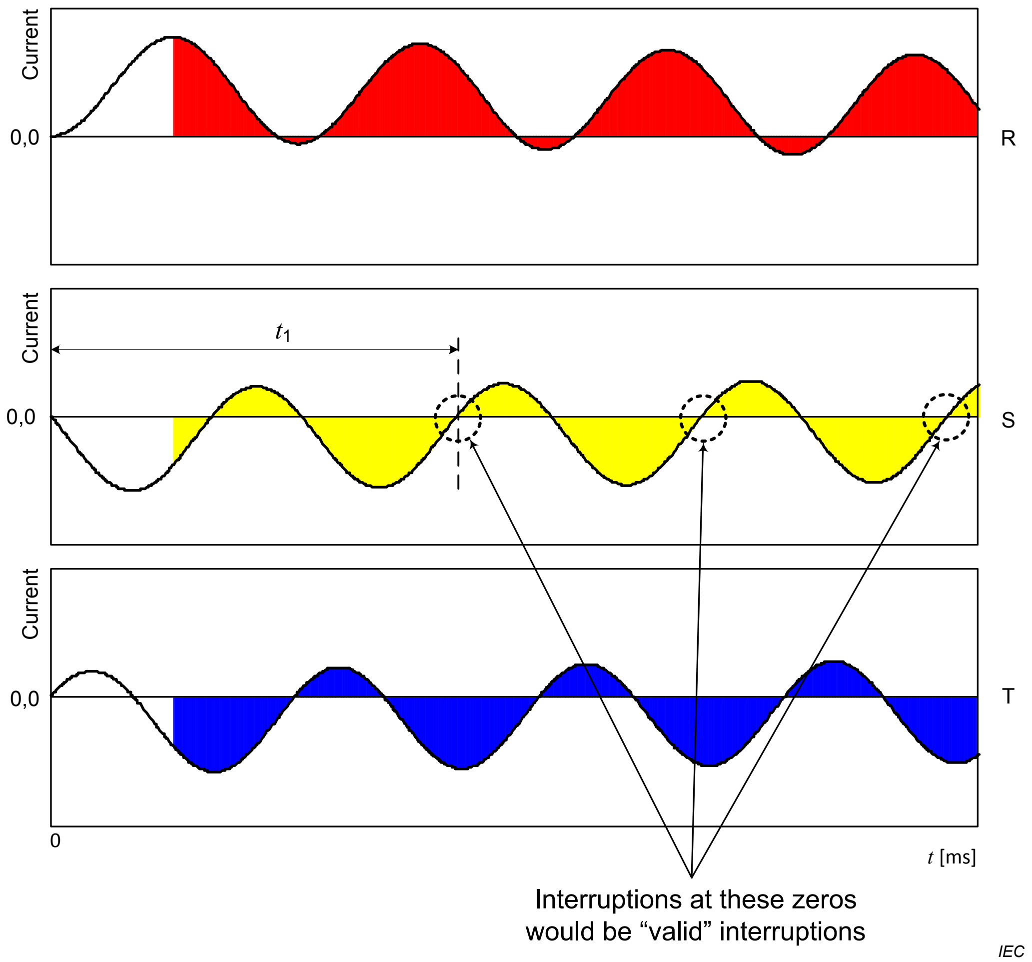


Figure 7 – Examples of possible valid interruptions in a phase with intermediate level of asymmetry after a major loop and a corresponding time t_1

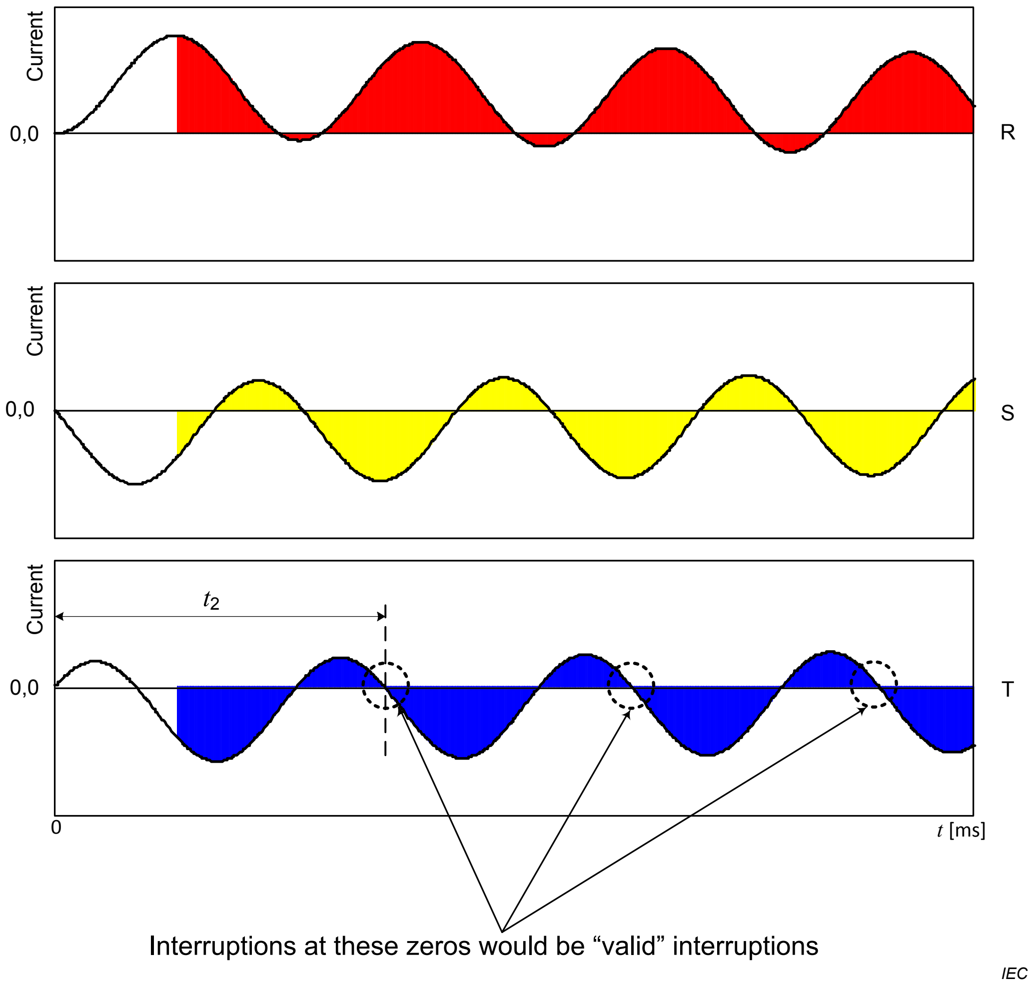


Figure 8 – Examples of possible valid interruptions in a phase with intermediate level of asymmetry after a minor loop and a corresponding time t_2

3.8 Index of definitions

A

B

4 Ratings

Clause 4 of IEC 62271-1:2007 is replaced by the following:

The ratings and required capabilities of a generator circuit-breaker are the designated limits of operating characteristics based on definite conditions and shall include the following items, where applicable:

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 system-source short-circuit breaking current;
l) rated short-circuit making current;
m) rated load making and breaking current;
n) rated transient recovery voltage (TRV);
o) rated operating sequence;
p) rated time quantities.

The following characteristics are not mandatory but shall be given on request if assigned.

q) rated out-of-phase making and breaking current;
r) rated generator-source short-circuit breaking current.

4.1 Rated voltage U_r

Subclause 4.1 of IEC 62271-1:2007 is replaced by the following:

The rated voltage of a generator circuit-breaker is the highest r.m.s. voltage for which the generator circuit-breaker is designed and is the upper limit for operation.

NOTE 1 The rated voltage can also be referred to as rated maximum voltage.

NOTE 2 The rated voltage is equal to the maximum operating voltage of the generator (usually equal to 1,05 times the rated voltage of the generator) to which the generator circuit-breaker is applied.

4.2 Rated insulation level

NOTE The rated insulation level can also be referred to as rated dielectric strength.

Subclause 4.2 of IEC 62271-1:2007 is replaced by the following:

The rated insulation level of a generator circuit-breaker is its voltage withstand capability with specified magnitudes and waveshapes.

4.2.101 Dielectric strength

Dielectric strength shall conform to the performance requirements of this standard. Requirements for the rated dielectric strength of the generator circuit-breakers are given in Table 1.

Table 1 – Rated insulation levels for a.c. generator circuit-breakers

	Insulation withstand voltages	
(1)	**(2)**	**(3)**
Rated voltage U_r kV (r.m.s. value)	**Rated power-frequency withstand voltage** U_d kV (r.m.s. value)	**Rated lightning impulse withstand voltage** U_p kV (peak value)
$U_r \leq 7,2$	20	60
$7,2 < U_r \leq 12$	28	75
$12 < U_r \leq 15$	38	95
$15 < U_r \leq 17,5$	50	110
$17,5 < U_r \leq 27$	60	125
$27 < U_r \leq 38$	80	150
These values are applicable for indoor and outdoor generator circuit-breakers.		

4.2.102 Rated power frequency withstand voltage U_d

The rated power frequency withstand voltage is the voltage that a new generator circuit-breaker shall be capable of withstanding for 1 min (see Column (2) of Table 1 and 6.2.6.1).

4.2.103 Rated lightning impulse withstand voltage U_p

The rated lightning impulse withstand voltage is the peak value of a standard $1,2 \times 50$ µs impulse voltage wave that a new generator circuit-breaker shall be capable of withstanding (see Column (3) of Table 1 and 6.2.6.2).

4.3 Rated frequency f_r

Subclause 4.3 of IEC 62271-1:2007 is applicable with the following modification:

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

If rated for both 50 Hz and 60 Hz, the nameplate may be marked 50/60 Hz.

Applications at other frequencies require special considerations.

NOTE The rated frequency can also be referred to as rated power frequency.

4.4 Rated normal current I_r and temperature rise

4.4.1 Rated normal current I_r

Subclause 4.4.1 of IEC 62271-1:2007 is applicable with the following addition.

Values from the R 10 series are preferred values only. Manufacturers and users are free to choose any other values.

NOTE The rated normal current can also be referred to as rated continuous current.

4.4.2 Temperature rise

Subclause 4.4.2 of IEC 62271-1:2007 is applicable with the following addition:

Generator circuit-breaker parts handled by the operator in the normal course of work duties shall have a maximum temperature no greater than 50 °C.

4.4.3 Particular points of Table 3 of IEC 62271-1:2007

Subclause 4.4.3 of IEC 62271-1:2007 is applicable.

4.4.101 Emergency current ratings during loss of cooling

The operating considerations for generator circuit-breakers require that emergency ratings are established to enable the circuit-breaker to remain in service following loss of normally required cooling systems.

The following provisions shall be observed:

a) It is possible to operate the generator circuit-breaker for limited time periods with circuit-breaker parts at a higher total temperature than the limits specified for the normal current rating;

b) The difference between the emergency temperature limits and the normal operating temperatures provide a definite allowable time period during which full load may be carried before the reduction in load current shall be accomplished;

c) The generator circuit-breaker may remain in service at a reduced load current, the value of which will depend on the type of emergency condition prevailing;

d) Where the circuit-breaker normal current rating is affected by several independent systems (e.g., interrupting medium, cooling medium, forced air cooling of isolated phase bus, etc.), the effect of losing each system individually and in combination should be established;

e) In addition to a) through d), certain generating station designs (e.g., single generator output connected by two generator circuit-breakers to two unit step-up transformers) may also require special emergency operating conditions and ratings.

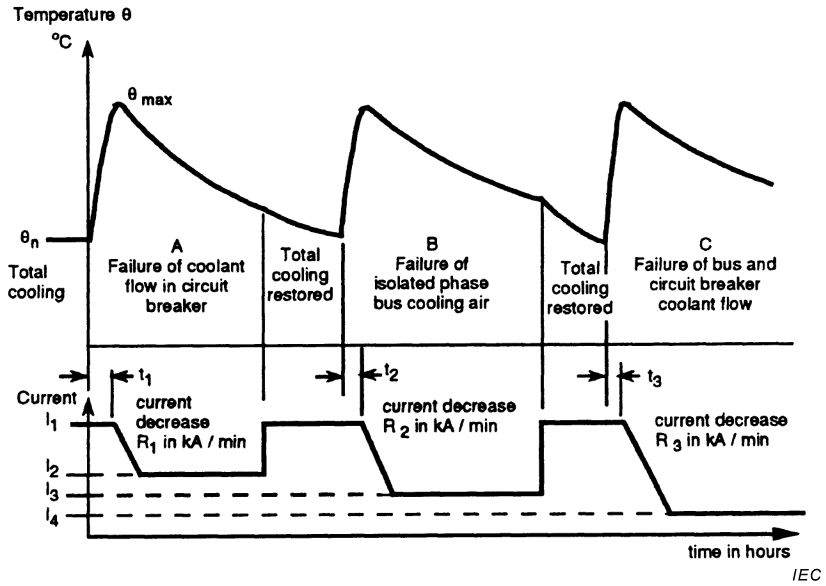
For each emergency condition the following parameters shall be given:

t_e The time available at rated current before the load shall be reduced;

R_e The rate at which the load current shall be reduced in kA/min;

I_e The emergency current assigned to the generator circuit-breaker for operating under each emergency condition for an unlimited period of time.

Figure 9 illustrates typical emergency conditions in which the loss of two cooling systems, that of the generator circuit-breaker and that of the bus, have been studied separately and simultaneously.



Key

I_1	is the rated current with all cooling systems in operation
I_2	is the allowable load current if failure (A) of coolant in circuit-breaker occurs
I_3	is the allowable load current if failure (B) of isolated phase bus cooling air occurs
I_4	is the allowable load current if failure (C) of isolated bus and circuit-breaker coolant flow occurs
θ_{max}	is the allowable hottest spot total temperature in °C
θ_n	is the hottest spot total temperature at rated continuous current
t_1, t_2, t_3	are the allowable times without a reduction in rated continuous current and without exceeding θ_{max}

Figure 9 – Effect of various cooling failures and subsequent load reductions on generator circuit-breaker temperature

The following are the parameters that are required for correct operation under each type of emergency condition and for which values shall be determined by the manufacturer:

t_1, t_2, t_3 are the times available at rated current before the load shall be reduced.

R_1, R_2, R_3 are the rates at which the load current shall be reduced in kA/min.

I_2, I_3, I_4 are the emergency currents assigned to the generator circuit-breaker for operating under each emergency condition for an unlimited period of time.

4.5 Rated short-time withstand current I_k

Subclause 4.5 of IEC 62271-1:2007 is applicable.

4.6 Rated peak withstand current I_p

Subclause 4.6 of IEC 62271-1:2007 is applicable with the following modification:

A d.c. time constant of 133 ms covers the majority of cases and corresponds to a rated peak withstand current equal to 2,74 times the rated short-time withstand current.

4.7 Rated duration of short circuit t_k

Subclause 4.7 of IEC 62271-1:2007 is applicable with the following change.

The minimum value of t_k shall be 1 s.

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

4.8.1 General

Subclause 4.8.1 of IEC 62271-1:2007 is applicable with the following addition:

In general the supply voltage is measured at the control power terminals of the operating mechanism at the peak operating current.

4.8.2 Rated supply voltage U_a

Subclause 4.8.2 of IEC 62271-1:2007 is not applicable and is replaced by the following:

Preferred values of supply voltages are given in Table 2.

4.8.3 Tolerances

Subclause 4.8.3 of IEC 62271-1:2007 is not applicable and is replaced by the following:

Preferred ranges of the supply voltages are given in Table 2.

Table 2 – Preferred values of supply voltages and their ranges for closing and opening devices and of auxiliary and control circuits of generator circuit-breakers

Direct current voltage ranges [a, b, c, d, g, h]			Alternating current voltage ranges [a, b, c, g]	
Preferred supply voltage U_a V	Closing and auxiliary functions V	Tripping functions V	Preferred supply voltage U_a V	Closing and auxiliary functions V
			Single-phase	
48 [e]	36 – 56	28 – 56	120	104 – 127 [f]
110 – 125	90 – 140	70 – 140	240	208 – 254 [f]
220 – 250	180 – 280	140 – 280	Three-phase	
			208 Y/120	180 Y/104 – 220 Y/127
			240	208 – 254

[a] Relays, motors, or other auxiliary equipment that function as part of the control for a device shall be subject to the voltage limits imposed by this standard, whether mounted at the device or at a remote location.

[b] Mechanism devices in some applications may be exposed to supply voltages exceeding those specified here due to abnormal conditions, such as abrupt changes in line loading. Such applications require study, and the manufacturer should be consulted. Also, application of switchgear devices containing solid-state control exposed continuously to control voltages approaching the upper limits of ranges specified herein require specific attention, and the manufacturer should be consulted before application is made.

[c] Includes supply for pump or compressor motors. Note that rated voltages for motors and their operating ranges are covered in the related standards.

[d] It is recommended that the coils of closing, auxiliary, and tripping devices that are connected continually to one d.c. potential should be connected to the negative control bus so as to minimize electrolytic deterioration.

[e] 48 V tripping, closing, and auxiliary functions are recommended only when the device is located near the battery or where special effort is made to ensure the adequacy of conductors between battery and control terminals.

[f] Includes heater circuits.

[g] Extended voltage ranges apply to all closing and auxiliary devices when cold. Mechanisms utilizing standard auxiliary relays for control functions may not comply at lower extremes of voltage ranges when relay coils are hot, as after repeated or continuous operation.

[h] DC supply voltage sources, such as those derived from rectified alternating current, may contain sufficient inherent ripple to modify the operation of control devices to the extent that they may not function over the entire specified voltage ranges.

4.8.4 Ripple voltage

Subclause 4.8.4 of IEC 62271-1:2007 is applicable.

4.8.5 Voltage drop and supply interruption

Subclause 4.8.5 of IEC 62271-1:2007 is applicable.

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

Subclause 4.9 of IEC 62271-1:2007 is applicable.

4.10 Rated pressure of compressed gas supply for controlled pressure systems

Subclause 4.10 of IEC 62271-1:2007 is applicable.

4.11 Rated filling levels for insulation, interruption and/or operation

Subclause 4.11 of IEC 62271-1:2007 is applicable.

4.101 Rated short-circuit current

4.101.1 General

The rated short-circuit current of a generator circuit-breaker is the r.m.s. value of the three-phase earthed short-circuit current to which all required short-circuit capabilities are related. Procedures for determining the symmetrical short-circuit current duties that compare with ratings and related required capabilities are found in Clause 8. It is to be noted that, if the performance capability of a generator circuit-breaker design has been demonstrated for a certain generator short-circuit current rating or transformer short-circuit current rating, then that performance capability is automatically demonstrated for a generator or a transformer of lower short-circuit current rating respectively.

4.101.2 Rated system-source short-circuit breaking current

4.101.2.1 General

The rated system-source short-circuit breaking current is the highest system-source short-circuit current at contact separation, which the generator 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 generator circuit-breaker and having a transient recovery voltage equal to the value specified in 4.105. For three-pole generator circuit-breakers, the a.c. component relates to a three-phase earthed short-circuit. The source of the short-circuit current is from the power system through at least one transformation.

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

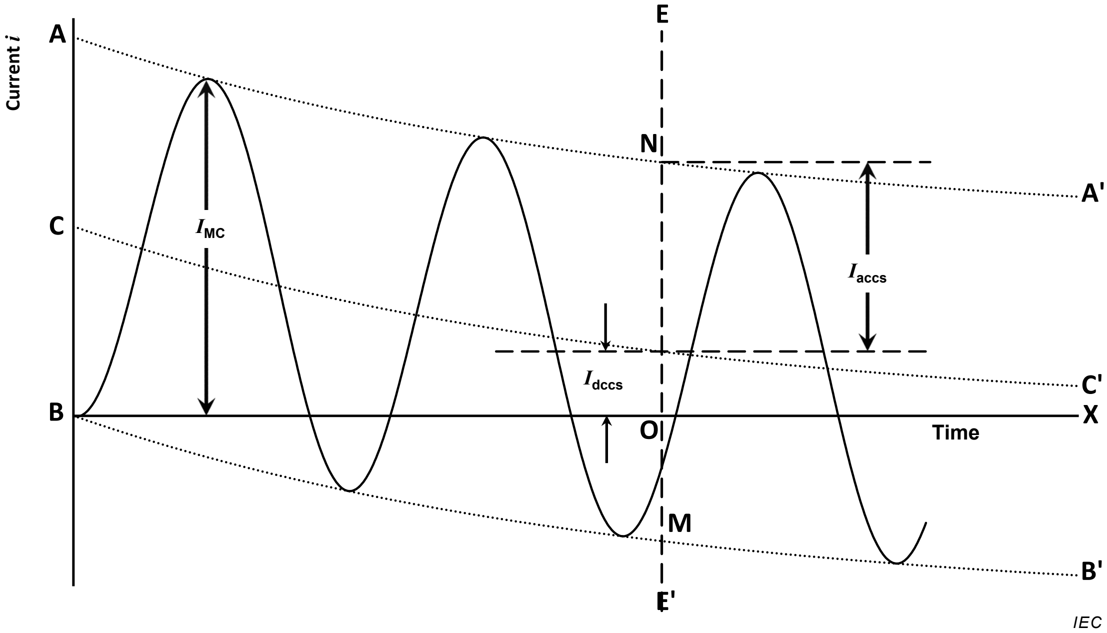
a) the r.m.s. value of its a.c. component I_{sc};
b) the d.c. time constant of the rated system-source short-circuit breaking current which results in a certain degree of asymmetry at contact separation.

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

NOTE 2 The degree of asymmetry is a function of the d.c. time constant of the rated system-source short-circuit breaking current (see 4.101.2.3) and of the instant of initiation of the system-source short-circuit current.

NOTE 3 In case of the rated system-source short-circuit breaking current the degree of asymmetry does not exceed 100 %.

For determination of the a.c. component, the d.c. component and the degree of asymmetry at any time following current initiation, see Figures 10 and 11.



Key

AA'
BB' is the envelope of current-wave

BX is the current zero line

CC' is the centre line of the envelope of current-wave

EE' is the instant of contact separation (initiation of the arc)

I_{MC} is the peak value of making current

I_{accs} is the peak value of a.c. component of current at instant of contact separation, EE'

I_{dccs} is the d.c. component of current at instant of contact separation, EE'

Figure 10 – Typical asymmetrical system-source short-circuit current

$\frac{I_{accs}}{\sqrt{2}}$ is the r.m.s. value of the a.c. component of current I_{sc} at instant of contact separation, EE'

Asy_{cs} is the degree of asymmetry at instant of contact separation, EE',

$$Asy_{cs} = 100\ \% \times \frac{I_{dccs}}{I_{accs}} = 100\ \% \times \frac{\overline{ON} - \overline{OM}}{\overline{MN}} = 100\ \% \times \left(\frac{2 \times \overline{ON}}{\overline{MN}} - 1 \right)$$

Figure 11 – Degree of asymmetry as a function of time after fault initiation

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

The following applies:

a) at voltages below and equal to the rated voltage, the generator circuit-breaker 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.

4.101.2.2 R.M.S. value of the a.c. component of the rated system-source short-circuit breaking current I_{sc}

The standard r.m.s. value of the a.c. component of the rated system-source short-circuit breaking current should be selected from the R10 series specified in IEC 60059 [33][4]. Values from the R 10 series are preferred values only. Manufacturers and users are free to choose any other values.

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.

4.101.2.3 DC time constant of the rated system-source short-circuit breaking current τ

The standard d.c. time constant is 133 ms.

4.101.3 Rated generator-source short-circuit breaking current

4.101.3.1 General

The rated generator-source short-circuit breaking current is the highest generator-source short-circuit current at contact separation, which the generator 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

4 Numbers in square brackets refer to the Bibliography.

to the rated voltage of the generator circuit-breaker and having a transient recovery voltage equal to the value specified in 4.105. For three-pole generator circuit-breakers, the a.c. component relates to a three-phase earthed short-circuit. The source of the short-circuit current is entirely from a generator through no transformations.

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

a) the r.m.s. value of its a.c. component at contact separation I_{scg};

b) the degree of asymmetry at contact separation Asy_{cs}.

If the degree of asymmetry exceeds 100 % then this leads to delayed current zero crossings.

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

A typical generator-source short-circuit current wave form including the a.c. component, the d.c. component and the degree of asymmetry as a function of time after fault initiation is depicted in Figure 12.

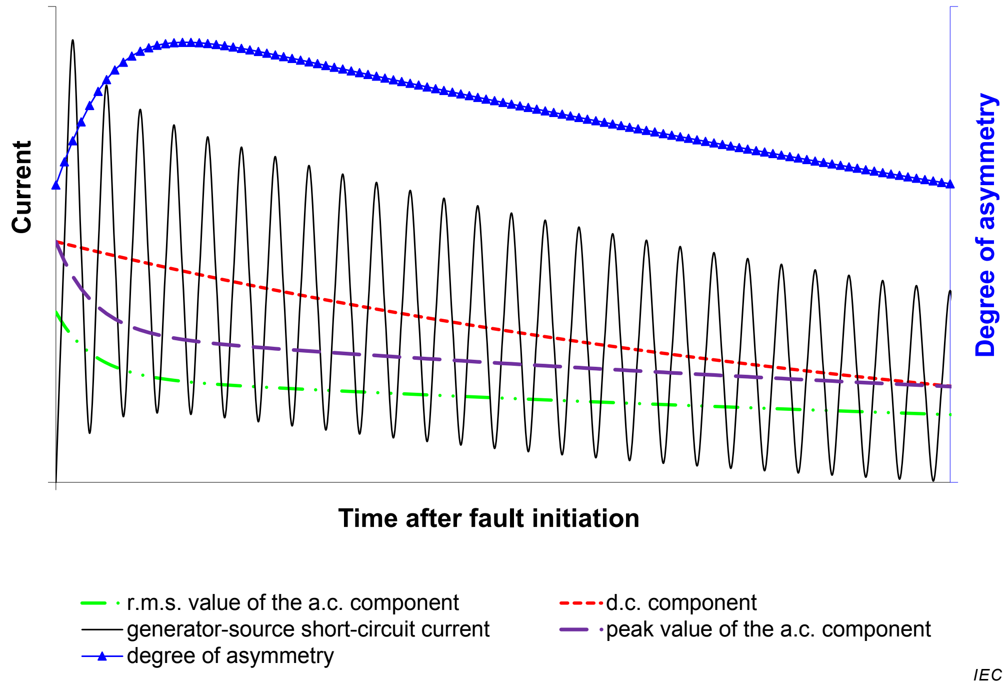


Figure 12 – Typical asymmetrical generator-source short-circuit current with a strong decrement of the a.c. component

For determination of the a.c. component and the degree of asymmetry at any time following current initiation, see Annex E.

The following applies:

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

b) at voltages above the rated voltage, no short-circuit breaking current is guaranteed.

It should be noted that the a.c. component of this short-circuit current can decay rapidly, depending on the subtransient and transient time constants of the generator while the d.c. component decays with the armature time constant. The a.c. component and the degree of asymmetry of the generator-source short-circuit current can vary depending if the generator is unloaded or delivering power prior to fault.

The capability of a generator circuit-breaker to interrupt short-circuit currents with delayed current zero crossings occurring in actual service conditions, may be difficult to demonstrate in high power testing stations. Therefore the capability of a generator circuit-breaker to interrupt a short-circuit current with delayed current zero crossings shall be ascertained by calculations (see 8.103.6.3.6.4) taking into account results derived from test-duties in 6.105.12.

4.101.3.2 R.M.S. value of the a.c. component of the rated generator-source short-circuit breaking current I_{scg}

This standard does not give preferred values for the a.c. component of the generator-source short-circuit breaking current because its maximum value is usually less than the a.c. component of the short-circuit breaking current from the power system. If a rating is assigned by the manufacturer, then the generator circuit-breaker shall be tested for the related capabilities (see 6.105).

4.101.3.3 Degree of asymmetry of the rated generator-source short-circuit breaking current

For a generator circuit-breaker of class G1 the degree of asymmetry is 110 % with the assigned a.c. component of the rated generator-source short-circuit breaking current and 130 % with a current having an a.c. component equal to 74 % of the assigned a.c. component of the rated generator-source short-circuit breaking current irrespectively of the time that contact separation occurs (see Annex H).

For generator circuit-breaker of class G2 the degree of asymmetry is 130 % with the assigned a.c. component of the rated generator-source short-circuit breaking current irrespectively of the time that contact separation occurs (see Annex H).

4.101.4 Rated single-phase-to-earth fault breaking current

No specific rating is assigned to cover the single-phase-to-earth fault breaking current because generator circuit-breakers are designed for use on systems earthed through a high-impedance where the single-phase-to-earth fault current will not exceed 50 A. In no case are the capabilities for single-phase-to-earth faults required to exceed this value. Generator circuit-breakers can easily break this current.

4.102 Rated peak short-circuit making current I_{MC}

The rated short-circuit making current (see Figure 10) of a generator circuit-breaker having simultaneity of poles is based on a d.c. time constant of 133 ms. This is 2,74 times the r.m.s. value of the a.c. component of its rated system-source short-circuit breaking current.

If a generator-source short-circuit current rating is assigned and its making current is higher than the value above, then the rated making current shall be assigned by the manufacturer.

This value is applicable both for 50 Hz and 60 Hz.

NOTE The short-circuit making current can also be referred to as closing current.

4.103 Rated load making and breaking current

The rated load making and breaking current is the highest load current which the generator circuit-breaker shall be capable of making and 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 4.105.

The capability of the generator circuit-breaker to interrupt the load current shall be demonstrated by tests according to 6.104.

4.104 Rated out-of-phase making and breaking current

The rated out-of-phase making and breaking current is the highest out-of-phase current which the generator circuit-breaker shall be capable of making and 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 4.105.

The r.m.s. value of the assigned out-of-phase current switching rating I_d shall be 50 % of the r.m.s. value of the a.c. component of the rated system-source short-circuit breaking current.

NOTE The out-of-phase making and breaking current can also be referred to as out-of-phase switching current.

4.105 Rated transient recovery voltage (TRV) related to the breaking currents

4.105.1 Representation of TRV waves

The waveform of transient recovery voltages approximates a damped single frequency oscillation. Two straight lines adequately represent the upper and lower bounds of the rising part of the TRV waveform. The upper line begins at the origin, rises up and to the right and is tangent to the TRV curve, with a slope equal to the TRV rate of rise. The lower line has the same slope as the upper, and begins on the time axis at the point of the time delay t_d and ends at the point with coordinates (t', u') as illustrated in Figure 13. The upper line ends where it intersects a horizontal line drawn tangent to the highest point, u_c, of the TRV waveform. The time at the point where these two lines intersect, t_3, is called the rise time, and the coordinates of this point are (t_3, u_c). It is clear from Figure 13 that this time, t_3, is earlier than the time when the TRV waveform actually reaches its peak. Methods of drawing TRV envelopes are given in 8.103.7.3.

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

The two parameters used for the representation of TRV are u_c and t_3.

u_c is the reference voltage (the TRV peak value), and is calculated as follows

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

where

k_{pp} is the first-pole-to-clear factor with a value of 1,5 (see 8.103.7.4) and

k_{af} is the amplitude factor with a value of 1,5 (see 8.103.7.5)

t_3 is the time to the intersection point of the upper line and the horizontal reference line. The method for determining the value for the time t_3 for a given TRV waveform is described in 8.103.7.3.

The preferred value of u' is chosen to be $u_c/3$ and t' is chosen to be $t_d + t_3/3$.

The ratio of u_c/t_3 is called the “Rate-of-Rise-of-Recovery-Voltage” [RRRV].

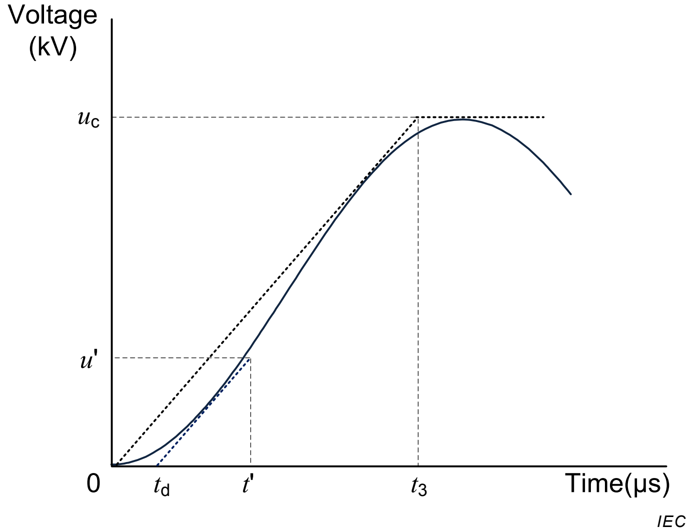


Figure 13 – 2-parameter representation of prospective TRV waveform for interrupting three-phase symmetrical faults

4.105.2 Rated values of TRV

Standard values for TRV parameters are listed in Table 3, Table 4, Table 5, and Table 6. The equation and method for determining the time t_3 are given in 8.103.7.3 and Figure 13. Table 3, Table 4, Table 5, and Table 6 provide the values of the prospective TRV parameters. U_r is expressed in kV (r.m.s. value).

The values for the TRV parameters t_3 and u_c given in Tables 3 through 6 are expressed in microseconds and kV (peak value) respectively, and are calculated as functions of U_r, which is expressed in units of kV (r.m.s. value).

The ratings given in Table 3 and Table 4 are determined for the first-pole-to-clear and for symmetrical current interruption in case of three-phase earthed faults. If the generator circuit-breaker requires that the prospective TRV be modified by the addition of capacitors, then the amount of equivalent capacitance required shall be given in the test report and on the nameplate.

Table 3 – TRV parameters for system-source faults

Transformer rating	**Prospective TRV**		
	Time t_3	**TRV peak value u_c**	**RRRV**
MVA	μs	kV	kV/μs
10 – 50	0,58 U_r	1,84 U_r	3,2
51 – 100	0,53 U_r	1,84 U_r	3,5
101 – 200	0,46 U_r	1,84 U_r	4,0
201 – 400	0,41 U_r	1,84 U_r	4,5
401 – 600	0,37 U_r	1,84 U_r	5,0
601 – 1 000	0,34 U_r	1,84 U_r	5,5
1 001 or more	0,31 U_r	1,84 U_r	6,0
The time delay t_d shall be equal to 1 μs.			

Table 4 – TRV parameters for generator-source faults

Generator rating MVA	Prospective TRV		
	Time t_3 µs	TRV peak value u_c kV	RRRV kV/µs
10 – 50	1,23 U_r	1,84 U_r	1,5
51 – 100	1,15 U_r	1,84 U_r	1,6
101 – 400	1,02 U_r	1,84 U_r	1,8
401 – 800	0,92 U_r	1,84 U_r	2,0
801 or more	0,84 U_r	1,84 U_r	2,2
The time delay t_d shall be equal to 0,5 µs.			

Table 5 – TRV parameters for load current switching

Generator rating MVA	Prospective TRV		
	Time t_3 µs	TRV peak value u_c kV	RRRV kV/µs
10 – 50	1,03 U_r	0,92 U_r	0,9
51 – 100	0,92 U_r	0,92 U_r	1,0
101 – 400	0,77 U_r	0,92 U_r	1,2
401– 800	0,66 U_r	0,92 U_r	1,4
801 or more	0,58 U_r	0,92 U_r	1,6
The time delay t_d shall be equal to 1 µs.			

Table 6 – TRV parameters for out-of-phase current switching

Generator rating MVA	Prospective TRV		
	Time t_3 µs	TRV peak value u_c kV	RRRV kV/µs
10 – 50	0,87 U_r	2,6 U_r	3,0
51 – 100	0,79 U_r	2,6 U_r	3,3
101 – 400	0,64 U_r	2,6 U_r	4,1
401 – 800	0,56 U_r	2,6 U_r	4,7
801 or more	0,50 U_r	2,6 U_r	5,2
The time delay t_d shall be equal to 1 µs.			

4.106 Standard operating sequence

4.106.1 General

The standard operating sequence of a generator circuit-breaker shall be CO – 30 min – CO (without any intentional delay between C and O).

4.106.2 Rated short-circuit current operating sequence

The rated short-circuit current operating sequence of a generator circuit-breaker shall be the standard operating sequence.

NOTE The rated short-circuit current operating sequence can also be referred to as rated short-circuit duty cycle.

4.106.3 Rated load current operating sequence

The rated load current operating sequence of a generator circuit-breaker shall be the standard operating sequence unless the manufacturer assigns shorter time intervals between operations.

4.106.4 Rated out-of-phase current operating sequence

The rated out-of-phase current operating sequence of a generator circuit-breaker shall be the standard operating sequence unless the manufacturer assigns shorter time intervals between operations.

4.107 Rated time quantities

4.107.1 General

Refer to Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5.

Rated values shall be assigned to the following time quantities:

– opening time (no-load);
– break-time;
– closing time (no-load);
– close-open 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 and 4.11);
– rated pressure of hydraulic supply for operation;
– an ambient air temperature of 20 °C ± 5 °C.

NOTE Usually, it is not necessary to assign a rated value of make-time since it is approximately the same as the closing time.

In addition the minimum opening time shall be stated by the manufacturer.

4.107.2 Rated break-time

The rated break-time of a generator circuit-breaker is the maximum interval between the energizing of the trip circuit and the interruption of the current in all poles in the main circuit during test-duty 1 of Tables 16 or 17 (see 6.103.12) 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 breaking tests, shall be carried out at the minimum auxiliary supply voltage, at the minimum pressure for operation and at the minimum pressure for interruption. 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:

$$t_{\mathrm{b\ max}} = t_1 + T \times 132°/360° - (t_2 - t_3)$$

where

$t_{\mathrm{b\ max}}$ is the maximum determined break-time;

t_1 is the minimum recorded break-time for symmetrical system-source short-circuit breaking tests;

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

t_2 is the maximum recorded opening time on no-load, with auxiliary supply voltage, pressure for operation and pressure for interruption as used during test-duties in 6.103;

t_3 is the rated opening time.

NOTE 1 The rated break-time can also be referred to as rated interrupting time.

NOTE 2 Typical values are approximately 60 ms to 90 ms with the actual time being dependent on the rated system-source short-circuit breaking current.

NOTE 3 The rated break-time can slightly differ from the maximum determined break-time as the minimum break time can additionally be slightly influenced by the pressure for operation and the pressure for interruption. In order to show this influence, the test to show the minimum break time can be repeated at rated auxiliary supply voltage, rated pressure for operation and rated pressure for interruption.

NOTE 4 For single-phase tests simulating a three-phase operation, the recorded break-time can exceed the rated break-time by 30 electrical degrees because in these cases the current zeros occur less frequently than in the three-phase case.

NOTE 5 For generator circuit-breakers equipped with resistors, the time until final extinction of the resistor current will be longer.

4.107.3 Rated minimum opening time

The rated minimum opening time of a generator circuit-breaker is the shortest possible interval between the instant of energizing the opening release and the instant when the arcing contacts have separated in all poles.

NOTE Typically the minimum opening time will occur when the opening release is energized at upper limit of the supply voltage and if applicable at maximum functional pressure for operation.

4.108 Mechanical operation endurance capability classes M1 and M2

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

Standard generator circuit-breaker (normal mechanical endurance) **class M1**	1 000 operating cycles
Generator circuit-breaker for special service requirements (extended mechanical endurance) **class M2**	3 000 operating cycles

5 Design and construction

5.1 Requirements for liquids in generator circuit-breakers

Subclause 5.1 of IEC 62271-1:2007 is applicable.

5.2 Requirements for gases in generator circuit-breakers

Subclause 5.2 of IEC 62271-1:2007 is applicable.

5.3 Earthing of generator circuit-breakers

Subclause 5.3 of IEC 62271-1:2007 is applicable with the following modification.

For non-enclosed or three-phase enclosed generator circuit-breakers subclause 5.3 of IEC 62271-1:2007 is applicable.

For single-phase enclosed generator circuit-breakers earthing connection is made by connecting the enclosure of the generator circuit-breaker to the earthed enclosure of the busbar.

5.4 Auxiliary and control equipment

Subclause 5.4 of IEC 62271-1:2007 is applicable with the following additions:

a) where shunt opening and closing releases are used, appropriate measures shall be taken in order to avoid damage to the releases when a continuous or sustained closing or opening command signal is applied. For example, those measures may include the use of series control contacts arranged so that:
   - when the generator 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 generator circuit-breaker is open, the open release control contact (“a”) is open and the close release control contact (“b”) is closed;

   NOTE Systems other than contacts are possible and can be used.

b) 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 (3.7.135) provided by the circuit-breaker and no later than the rated closing time. If the current of the shunt closing release is interrupted by the control contact, the closing command shall be positively longer than the rated closing time.

c) for shunt opening releases the protecting measures for the shunt opening releases as mentioned in indent a) above shall operate no sooner than the minimum trip duration (3.7.134) required by the circuit-breaker and no later than 20 ms after separation of the main contacts;

d) for short close-open time requirements the protective measures for the shunt releases as mentioned in indent a) above shall operate no sooner than when main contacts close and no later than one half-cycle after main contacts close;

e) 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;

f) connections shall withstand the stresses imposed by the generator circuit-breaker, especially those due to mechanical forces during operations;

g) in the case of outdoor generator circuit-breakers, all auxiliary equipment including the wiring shall be adequately protected against rain and humidity;

h) 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 generator circuit-breaker manufacturer;

i) 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;

j) the power consumption of heaters at rated voltage shall be within the tolerance of ± 10 % of the value specified by the manufacturer;

k) where anti-pumping devices are part of the generator circuit-breaker control scheme, they shall act on each control circuit, if more than one is installed.

5.5 Dependent power operation

Subclause 5.5 of IEC 62271-1:2007 is not applicable for generator circuit-breakers.

5.6 Stored energy operation

Subclause 5.6 of IEC 62271-1:2007 is applicable.

5.7 Independent manual or power operation (independent unlatched operation)

Subclause 5.7 of IEC 62271-1:2007 is not applicable for generator circuit-breakers.

5.8 Operation of releases

5.8.1 Shunt closing release

Subclause 5.8.1 of IEC 62271-1:2007 is applicable.

5.8.2 Shunt opening release

Subclause 5.8.2 of IEC 62271-1:2007 is applicable with the following addition.

The operating mechanism shall be trip-free as defined in 3.6.109 of this document. That is, whenever an opening command is given it shall have priority over a closing command.

5.8.3 Capacitor operation of shunt releases

Subclause 5.8.3 of IEC 62271-1:2007 is applicable.

5.8.4 Under-voltage release

Subclause 5.8.4 of IEC 62271-1:2007 is not applicable.

5.8.101 Multiple releases

If a generator 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.

5.8.102 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.

5.8.103 Power consumption of releases

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

5.9 Low- and high-pressure interlocking devices

Subclause 5.9 of IEC 62271-1:2007 is replaced by the following:

All generator circuit-breakers having an energy storage in gas receivers or hydraulic accumulators (see 5.6.1 of IEC 62271-1:2007) and all generator circuit-breakers except sealed pressure devices, using compressed gas for interruption (see 5.103) shall be fitted with a low-pressure or low-density interlocking device, and can also be fitted with a high-pressure or high-density interlocking device, set to operate at, or within, the appropriate limits of pressure or density stated by the manufacturer.

5.10 Nameplates

Subclause 5.10 of IEC 62271-1:2007 is applicable with the following modifications: the nameplates of a generator circuit-breaker and its operating devices shall be marked in accordance with Table 7 below.

The nameplate shall be visible when the generator circuit-breaker is in the position of normal service and installation.

Coils of operating devices and releases shall be marked with the manufacturer's name and part number.

Table 7 – Nameplate information

Information to be listed on nameplates	Abbreviation	Unit	Generator 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 frequency	f_r	Hz	X		
Rated normal current	I_r	A	Y		external forced cooling is not required
Rated normal current with external forced cooling	$I_{r, efc}$	A	Y		external forced cooling is required
Rated short-time withstand current	I_k	kA	X		
Rated duration of short-circuit	t_k	s	X		
Rated short-circuit peak making current	I_{MC}	kA	X		
R.M.S. value of the a.c. component of the rated system-source short-circuit breaking current	I_{SC}	kA	X		
Degree of asymmetry at contact separation of the rated system-source short-circuit breaking current		%	X		

Information to be listed on nameplates	Abbreviation	Unit	Generator circuit-breaker	Operating device	Condition: Marking only required if
(1)	(2)	(3)	(4)	(5)	(6)
R.M.S. value of the a.c. component of the rated out-of-phase breaking current	I_d	kA	(X)		
Rated filling pressure for operation at 20 °C	p_{rm}	MPa [psi][2]		(X)	
Kind and mass[3] of fluid for insulation and/or interruption		kg [weight lb][3]	Y		sealed tank contains fluid
Rated filling pressure for insulation and/or interruption at 20 °C	p_{re}	MPa [psi] [3]	(X)		
Rated voltage of closing devices		V		(X)	
Rated voltage of opening devices		V		(X)	
Rated frequency of closing devices		Hz		(X)	
Rated frequency of opening devices		Hz		(X)	
Rated current of closing devices		A		(X)	
Rated current of opening devices		A		(X)	
Rated voltage of auxiliary circuits	U_a	V		(X)	
Rated frequency of auxiliary circuits		Hz		(X)	
Rated current of auxiliary circuits		A		(X)	
Mass[3] (including fluids)	M	kg [weight lb][3]	X	X	
Standard operating sequence			X		
Rated break-time		ms	X		
Capacitance value per phase at the generator side		nF	Y		equipped with capacitor at the generator side
Capacitance value per phase at the transformer side		nF	Y		equipped with capacitor at the transformer side
Resistance value per phase in parallel to the interrupting chamber		Ω	Y		equipped with opening resistor in parallel to the interrupting chamber
Year of manufacture			X	X	
Instruction book number			X	X	
Relevant standard with date of issue			X	X	

Key

X = the marking of these values is mandatory; blanks indicate the value zero.

(X) = if a rating is assigned the marking of these values is mandatory.

Y = the marking of these values is mandatory if the conditions in column (6) are met.

NOTE 1 The abbreviation in column (2) can be used instead of the terms in column (1). When terms in column (1) are used, the word "rated" need not appear.

NOTE 2 In column (3) in addition to the preferred SI units listed:

– masses may also be given as weights [weight lb]

and

– pressures may also be given as pounds per square inch [psi]

NOTE 3 When alternative units are given, the alternative amount and the unit are given [in brackets] in column (3).

For example, a mass of 200 kg can be listed as "200 kg" or as "200 kg [weight 440 lb]".

A pressure of 1,0 MPa can be listed as "1,0 MPa" or as "1,0 MPa [145 psi].

5.10.101 Accessories

Nameplates of all accessories shall include the following:

a) identification;
b) pertinent operating characteristics.

5.10.102 Modification of generator circuit-breakers

Revised nameplates shall be furnished when modification is involved. IEEE Std C37.59™-2007 provides guidance regarding nameplates for modified generator circuit-breakers.

5.11 Interlocking devices

Subclause 5.11 of IEC 62271-1:2007 is applicable.

5.12 Position indication

Subclause 5.12 of IEC 62271-1:2007 is applicable.

5.13 Degrees of protection provided by enclosures

Subclause 5.13 of IEC 62271-1:2007 is replaced by the following:

Degrees of protection provided by enclosures of generator circuit-breakers:

- against allowing penetration from outside for the (IP coding) assigned according to IEC 60529,

and

- against external mechanical impacts for the (IK coding) assigned according to IEC 62262,

shall be specified for all enclosures containing parts of the main circuit of the generator circuit-breaker, as well as for enclosures containing appropriate low-voltage control and/or auxiliary circuits and for enclosures containing mechanical operating mechanisms.

The degrees of protection apply to the service conditions of the generator circuit-breaker.

NOTE The degrees of protection can be different for other conditions such as maintenance, testing, etc.

5.13.1 Protection of persons against access to hazardous parts and protection of the equipment against ingress of solid foreign objects (IP coding)

Subclause 5.13.1 of IEC 62271-1:2007 is applicable.

5.13.2 Protection against ingress of water (IP coding)

Subclause 5.13.2 of IEC 62271-1:2007 is applicable.

5.13.3 Protection of equipment against mechanical impact under normal service conditions (IK coding)

Subclause 5.13.13 of IEC 62271-1:2007 is applicable.

5.14 Creepage distances for outdoor insulators

Subclause 5.14 of IEC 62271-1:2007 is applicable.

5.15 Gas and vacuum tightness

Subclause 5.15 of IEC 62271-1:2007 is applicable.

5.16 Liquid tightness

Subclause 5.16 of IEC 62271-1:2007 is applicable.

5.17 Fire hazard (flammability)

Subclause 5.17 of IEC 62271-1:2007 is applicable.

5.18 Electromagnetic compatibility (EMC)

Subclause 5.18 of IEC 62271-1:2007 is applicable.

5.19 X-ray emission

Subclause 5.19 of IEC 62271-1:2007 is applicable

5.20 Corrosion

Subclause 5.20 of IEC 62271-1:2007 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.

When no special requirement with respect to simultaneous operation of poles is stated, the maximum difference between the instants of contacts separation 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.

5.102 General requirement for operation

A generator circuit-breaker, including its operating devices, shall be capable of completing its rated short-circuit operating sequence (4.106.2) in accordance with the relevant provisions of 5.6 to 5.9 and 5.103 for the applicable range(s) of ambient temperatures as defined in Clause 2 of IEC 62271-1:2007.

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.

Generator circuit-breakers provided with heaters shall be designed to permit an opening operation at the assigned minimum ambient temperature 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 generator 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 3.7.142 and 3.7.143).

The manufacturer may specify pressure limits at which the generator 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.

The generator 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 generator circuit-breaker during operation.

NOTE These are normally associated with air, air-blast and oil generator circuit-breakers.

Vent outlets of generator circuit-breakers shall be situated such that a discharge of oil or gas or both will not cause electrical breakdown and is directed away from any location where persons are likely to 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 generator circuit-breaker or its auxiliary equipment.

5.105 Warning labels

Markings and warning labels shall be provided to identify possible dangerous conditions related to the generator circuit-breaker and its operating devices and to call special attention to the appropriate precautions.

5.106 Instructions

Instructions essential for maintenance and the safe operation of the generator circuit-breaker shall be provided.

6 Type tests

Clause 6 of IEC 62271-1:2007 is applicable with the following additions:

Type tests are made to determine the adequacy of the design of a particular type, style, or model generator circuit-breaker to meet its assigned ratings and to operate satisfactorily under the specified service conditions. Type tests are made only on representative generator circuit-breakers of basically the same design, i.e., the same interrupters operating at the same contact speeds, and having at least the same dielectric strength. These tests are not intended to be used as a part of normal production. The applicable portions of these type tests may also be used to evaluate modifications of a previous design and to assure that performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate.

The type tests for generator circuit-breakers are listed in Table 8. 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 A. The individual type tests shall, in principle, be performed on a generator circuit-breaker in a new and clean condition. In case of generator 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 60480:2004.

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 %.

Table 8 – 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
Sound pressure level tests		6.101.4
System-source short-circuit current making and breaking tests		6.103
Load current switching tests		6.104
Type tests dependent upon application, rating or design	**Condition requiring type test**	**Subclauses**
Verification of the degree of protection	Assigned IP coding Assigned IK coding	6.7.1 6.7.2
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 generator circuit-breakers for special service conditions	Assigned class M2	6.101.2.4
Low and high temperature tests	In accordance with 6.101.3.1	6.101.3
Generator-source short-circuit current making and breaking tests	Assigned generator-source short-circuit current	6.105
Out-of-phase making and breaking tests	Assigned out-of-phase current	6.106
Mandatory type tests, shown in the upper part of the table, are required for all generator circuit-breakers. Other type tests, shown in the lower part of the table, are required for all generator circuit-breakers where the associated rating is specified.		

6.1 General

6.1.1 Grouping of tests

Subclause 6.1.1 of IEC 62271-1:2007 is applicable.

6.1.2 Information for identification of specimens

Subclause 6.1.2 of IEC 62271-1:2007 is applicable.

6.1.3 Information to be included in type-test reports

Subclause 6.1.3 of IEC 62271-1:2007 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 B.

6.2 Dielectric tests

6.2.1 Ambient air conditions during tests

Subclause 6.2.1 of IEC 62271-1:2007 is applicable.

6.2.2 Wet test procedure

Subclause 6.2.2 of IEC 62271-1:2007 is applicable.

6.2.3 Condition of the generator circuit-breaker during dielectric tests

Subclause 6.2.3 of IEC 62271-1:2007 is applicable with the following addition:

Additional power-frequency voltage tests shall be performed with the insulating gas at atmospheric pressure to simulate the loss of this gas, with a voltage corresponding to 1,5 times the following voltages:

a) the phase opposition voltage across the open contacts;

b) the phase-to-earth voltage between the conductor and earth;

c) the phase-to-phase voltage between phases, if applicable.

In case vacuum interrupters are used in enclosures filled with an insulating gas the additional power-frequency voltage tests are performed with the insulating gas at atmospheric pressure.

In case vacuum interrupters are not used in enclosures filled with an insulating gas the additional power-frequency voltage tests are not required.

It may be difficult to carry out the dielectric tests on generator circuit-breakers equipped with resistors or capacitors. In such cases, they may be disconnected or removed.

If resistors or capacitors have been disconnected or removed during dielectric tests these components shall be tested separately in accordance to the values of Table 1.

If the generator circuit-breaker is equipped with additional components (e.g. surge arresters, voltage transformers, etc.), then those components have to be disconnected or removed prior to the dielectric test.

6.2.4 Criteria to pass the test

Subclause 6.2.4 of IEC 62271-1:2007 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 generator 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 generator circuit-breaker has failed the test.

If the atmospheric correction factor K_t is less than 1,00 but greater than 0,95, it is permissible to test without applying the correction factor. Then, if one or two disruptive discharges out of 15 impulses occur involving the external insulation, the particular test series showing flashover(s) is repeated with the appropriate correction factor. No damage to the non-self-restoring insulation is permitted.

6.2.5 Application of test voltage and test conditions

Subclause 6.2.5 of IEC 62271-1:2007 is applicable.

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

The test voltages specified in Table 1 apply.

6.2.6.1 Power-frequency withstand voltage tests

Subclause 6.2.6.1 of IEC 62271-1:2007 is applicable with the following addition.

Wet tests are required only for outdoor generator circuit-breakers having insulation exposed to outdoor conditions.

6.2.6.2 Lightning impulse voltage test

Subclause 6.2.6.2 of IEC 62271-1:2007 is applicable.

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

These are not applicable for generator circuit-breakers.

6.2.8 Artificial pollution tests for outdoor insulators

Subclause 6.2.8 of IEC 62271-1:2007 is applicable.

6.2.9 Partial discharge tests

Subclause 6.2.9 of IEC 62271-1:2007 is applicable with the following addition:

Partial discharge tests are not normally required to be performed on the complete generator circuit-breaker. However, in the case of generator 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 Dielectric tests on auxiliary and control circuits

Subclause 6.2.10 of IEC 62271-1:2007 is applicable.

6.2.11 Voltage test as a condition check

Subclause 6.2.11 of IEC 62271-1:2007 is not applicable; the tests specified there are replaced with the following:

After mechanical or environmental tests (see 6.101.1.4), if the insulating properties of a generator circuit-breaker across open contacts, to earth or between adjacent poles 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 62271-1:2007 shall be applied as a condition check. The test voltage shall be 80 % of the value in column (2) of Table 1.

After making, breaking or switching tests a 1 min power-frequency withstand voltage test shall be performed as a condition check across the open contacts. If there are any other dielectric gaps subject to the arcing medium (e.g. operating rod), they shall be evaluated either by this test or if that is not practical, then by a separate test. The test voltage shall be 80 % of the value in column (2) of Table 1.

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

Subclause 6.3 of IEC 62271-1:2007 is not applicable.

6.4 Measurement of the resistance of circuits

6.4.1 Main circuit

Subclause 6.4.1 of IEC 62271-1:2007 is applicable with the following modification:

The current during the measurement shall be specified by the manufacturer, but shall not be less than 100 A d.c.

6.4.2 Auxiliary circuits

Subclause 6.4.2 of IEC 62271-1:2007 is applicable.

6.5 Temperature-rise tests

6.5.1 Conditions of the generator circuit-breaker to be tested

Subclause 6.5.1 of IEC 62271-1:2007 is applicable.

6.5.2 Arrangement of the equipment

Subclause 6.5.2 of IEC 62271-1:2007 is applicable with the following additions and modifications according to a), b) or c).

a) For non-enclosed or three-phase-enclosed generator circuit-breakers the following apply.

   Because of the thermal effects of the magnetic influence on the neighbouring poles of the generator circuit-breaker, three-phase tests shall be performed.

   Other apparatus incorporated in series and closely associated with the generator circuit-breaker, such as current transformers, voltage transformers, disconnectors, etc. shall be mounted in their regular positions.

   The inductive heating of adjacent supporting structures such as pole frames shall be taken into account and shall be measured.

b) For single-phase-enclosed generator circuit-breakers the following apply.

   Single-phase tests are permissible for single-phase-enclosed generator circuit-breakers

   – if the single-phase-enclosed generator circuit-breaker will be connected to a single-phase enclosed isolated phase bus (IPB) system whose enclosures carry the rated current;
   – if the tests are made at the phase having the most unfavourable position, which in most cases is the middle phase;
   – if there is no possibility of magnetic influence;
   – if the influence of the neighbouring phases can be simulated by means of heaters, heat insulation or equivalent.

   Single-phase-enclosed generator circuit-breakers which are not connected to single-phase enclosed IPBs or where the enclosure of the single-phase enclosed IPB does not carry the rated current shall be tested three-phase.

   When single-phase enclosed generator circuit-breakers are single-phase tested, the current in the enclosure of the generator circuit-breaker shall be the rated current.

   Other apparatus incorporated in series and closely associated with the generator circuit-breaker, such as current transformers, voltage transformers, disconnectors, etc. shall be mounted in their regular positions.

   As the continuous current-carrying capability of a generator circuit-breaker is influenced by the temperature of the connected IPB, the tests shall be performed with an IPB attached to the generator circuit-breaker. The minimum length of the IPB shall be its enclosure’s outer diameter multiplied by 1,5 or 2 m, whichever of the two numbers is larger.

The temperature rise of the IPB – measured at a distance of 1 m from the terminals of the generator circuit-breaker – shall be kept at the temperatures indicated in Table 9. The temperature shall be measured at a minimum of 2 points for each of the 4 positions (see positions number 8 and 9 in Figure 14). The measuring points shall be distributed equally around the circumference of the IPB conductor and the IPB enclosure. There is no limit on the difference between the temperature rise at the terminals of the generator circuit-breaker or other apparatus incorporated in series and closely associated with the generator circuit-breaker, such as disconnectors, and the IPB at a distance of 1 m from the terminals as specified in IEC 62271-1.

In case the generator circuit-breaker is attached to the IPB by means of connections, those connections shall not be considered part of the generator circuit-breaker.

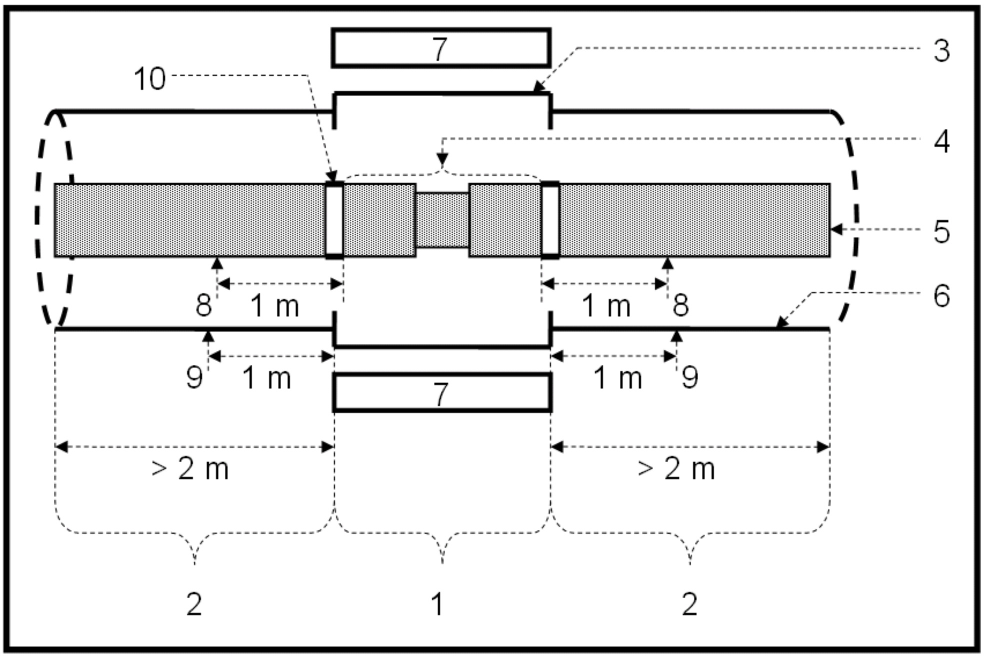
Table 9 – Conditions during temperature rise test

Part	**Ranges of average temperature rise of the IPB at ambient air temperature not exceeding 40 °C** K	
	Option 1	**Option 2**
IPB conductor at position 8 on each side	50	65
IPB enclosure at position 9 on each side	30	40
NOTE Position 8 and position 9 are shown in Figure 14.		

By agreement between user and manufacturer one of the 2 options of Table 9 shall be selected and recorded in the temperature-rise test report.

NOTE Different values of rated normal current can be assigned for option 1 and option 2.

A typical temperature rise test setup for single-phase-enclosed generator circuit-breakers is illustrated in Figure 14.



Key

1 Single-phase enclosed generator circuit-breaker

2 Single-phase enclosed IPB

3 Enclosure of the generator circuit-breaker

4 Interrupting chamber of the generator circuit-breaker

5 Conductor of the IPB

6 Enclosure of the IPB

7 Means to simulate the neighbouring phases of the generator circuit-breaker

8 Position at which the temperature of the conductor of the IPB shall be kept at the values indicated in Table 9

9 Position at which the temperature of the enclosure of the IPB shall be kept at the values indicated in Table 9

10 Connections between the terminals of the generator circuit-breaker and the terminals of the conductor of the IPB

Figure 14 – Typical temperature rise test setup for single-phase-enclosed generator circuit-breakers (top view)

c) For generator circuit-breakers with forced cooling the following apply.

When testing a generator circuit-breaker with a forced-cooled rating, the continuous current-carrying capability shall be determined with the forced cooling system operating. The temperatures in the current-carrying path shall be measured during these tests.

The entrance temperature and the quantity of the coolant (m^3/s) (e.g. air, water, etc.) shall be adjusted to the prevailing rated service conditions and recorded.

If an isolated phase bus is used and is forced cooled, the temperatures of the IPB – as defined in Table 9 – are not applicable since the temperatures of the IPB are dependent on quantity and temperature of the coolant.

6.5.3 Measurement of the temperature and the temperature rise

Subclause 6.5.3 of IEC 62271-1:2007 is applicable.

6.5.4 Ambient air temperature

Subclause 6.5.4 of IEC 62271-1:2007 is applicable.

6.5.5 Temperature-rise tests of the auxiliary and control equipment

Subclause 6.5.5 of IEC 62271-1:2007 is applicable.

6.5.6 Interpretation of the temperature-rise tests

The temperature rise of the various parts of the generator circuit-breaker shall not exceed the values specified in Table 3 of IEC 62271-1:2007.

6.5.101 Demonstrations of emergency conditions

Emergency conditions shall be demonstrated by tests. These tests shall include, if applicable, the following conditions:

a) failure of cooling (loss of cooling fluid, failure of cooling in the IPB, failure of fans, pumps, air circulators, etc.);

b) loss of insulating medium.

Conditions a) and b) shall be tested individually. If the cooling system consists of different independent subsystems, individual failure of each cooling subsystem and simultaneous failure of all subsystems shall be tested.

For each type of test, the following data (refer to Figure 9) shall be determined based on the temperature limits set by the manufacturer:

a) maximum time the emergency condition can persist (t_1, t_2, etc.);

b) a rate of decrease of the continuous current (R_1, R_2, etc.);

c) the lower value of current so that the temperature rise in the generator circuit-breaker will not exceed the values in 6.5.6 (I_1, I_2, etc.).

NOTE If the forced-cooling systems of the isolated-phase bus and the generator circuit-breaker use the same air, the phenomenon becomes complicated when the cooling air is lost. The temperature of the isolated-phase bus does not remain constant but will also rise, and it is suggested that this rise is taken into account during testing. The limit of total temperature of the isolated-phase bus is agreed upon by the user and the manufacturer, and the practical application in the power system are taken into account as well in order to carry out realistic tests.

6.6 Short-time withstand current and peak withstand current tests

Subclause 6.6 of IEC 62271-1:2007 is applicable.

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

Subclause 6.6.1 of IEC 62271-1:2007 is applicable with the following addition.

Single-phase enclosed generator circuit-breakers may be tested single-phase or three-phase. In the case of single-phase testing the enclosure shall carry the full return current. In the case of three-phase testing the return current in the three enclosures can be simulated by short-circuiting both ends of the three enclosures.

6.6.2 Test current and duration

Subclause 6.6.2 of IEC 62271-1:2007 is applicable.

6.6.3 Behaviour of generator circuit-breaker during test

Subclause 6.6.3 of IEC 62271-1:2007 is applicable.

6.6.4 Conditions of generator circuit-breaker after test

Subclause 6.6.4 of IEC 62271-1:2007 is applicable.

6.7 Verification of the degree of protection

6.7.1 Verification of the IP coding

Subclause 6.7.1 of IEC 62271-1:2007 is applicable.

6.7.2 Verification of the IK coding

Subclause 6.7.2 of IEC 62271-1:2007 is applicable.

6.8 Tightness tests

Subclause 6.8 of IEC 62271-1:2007 is applicable with the following addition.

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

6.9 Electromagnetic compatibility (EMC) tests

Subclause 6.9 of IEC 62271-1:2007 is applicable.

6.10 Additional tests on auxiliary and control circuits

6.10.1 General

Subclause 6.10.1 of IEC 62271-1:2007 is applicable.

6.10.2 Functional tests

Subclause 6.10.2 of IEC 62271-1:2007 is applicable with the following addition:

If the mechanical operation tests at ambient air temperature in accordance with 6.101.2 are performed on the complete circuit-breaker equipped with its entire control unit, then the intent of the functional tests according to 6.10.2 of IEC 62271-1:2007 has been demonstrated and additional tests are not required. 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 62271-1:2007 is applicable.

6.10.4 Verification of the operational characteristics of auxiliary contacts

Subclause 6.10.4 of IEC 62271-1:2007 is applicable.

6.10.5 Environmental tests

Subclause 6.10.5 of IEC 62271-1:2007 is applicable with the following addition:

If the mechanical operation tests at ambient air temperature in accordance with 6.101.2, the low and high temperature tests in accordance with 6.101.3 are performed on the complete circuit-breaker equipped with its entire control unit, then the intent of the environmental tests according to 6.10.5 of IEC 62271-1:2007 has been demonstrated and additional tests are not required. 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 is performed by agreement between manufacturer and user.

6.10.6 Dielectric tests

Subclause 6.10.6 of IEC 62271-1:2007 is not applicable and is replaced by the following.

Auxiliary and control circuits of switchgear and controlgear shall be subjected to short duration power-frequency voltage withstand tests.

Each test shall be performed

a) between the auxiliary and control circuits connected together as a whole and the frame of the switching device;
b) if practicable, between each part of the auxiliary and control circuits, which in normal use may be insulated from the other parts, and the other parts connected together and to the frame.

The power frequency tests shall be performed according to IEC 61180-1. The test voltage shall be 2 kV with duration of 1 min.

The auxiliary and control circuits of switchgear and controlgear shall be considered to have passed the tests if no disruptive discharge occurs during each test.

The test voltage of motors and other devices such as electronic equipment used in the auxiliary and control circuits shall be the same as the test voltage of those circuits. If such apparatus has already been tested in accordance with the appropriate specification, it may be disconnected for these tests. If lower test voltages are used, the values shall be stated in the test document.

6.11 X-radiation test procedure for vacuum interrupters

Subclause 6.11 of IEC 62271-1:2007 is applicable.

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 generator circuit-breaker shall be established, for example, by recording no-load travel curves or by the use of characteristic parameters, such as the instantaneous speed at certain positions of the time-travel curve. This may also be done 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 generator 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 filling 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 D gives requirements and explanation on the use of mechanical characteristics.

6.101.1.2 Component tests

When testing of a complete generator 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 generator 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 generator circuit-breaker is tested. Component tests shall cover all different types of components of the complete generator 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 generator circuit-breaker.

Parts of auxiliary and control equipment shall comply with the relevant standards by which they have been manufactured, as applicable. The proper function of such parts in connection with the function of the other parts of the generator circuit-breaker shall be verified.

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

Before and after the tests and according the provisions of 6.101.2.5, the following operating characteristics or settings shall be recorded and evaluated:

a) closing time;
b) opening time;
c) maximum difference between closing times and maximum difference between opening times for units of one pole;
d) maximum difference among closing times and maximum difference among opening times for the poles of a three-pole operated generator circuit-breaker;
e) recharging time of the operating device;
f) power consumption of the control circuit;
g) power 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.

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

During and after the tests, the generator 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 for 1 min at 80 % of the value in column (2) of Table 1.

In general, these requirements are fulfilled if:

– during the tests, the generator circuit-breaker operates on command and does not operate without command;
– the no-load closing operation and the no-load opening operation after the test series, performed at rated supply voltage and at rated filling pressure for operation shall be compared with the corresponding operations before the test series. The requirements of 6.101.1.1 and of Annex D shall be fulfilled;
– after the tests, all parts do not show undue wear;
– 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 without their temperature rise exceeding by more than 10 K the values specified in Table 3 of IEC 62271-1:2007.

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.

For other than sealed for life interrupter units, visual inspection is usually sufficient for verification of the capability of the generator circuit-breaker to carry the rated normal current.

NOTE Experience shows that an increase of the voltage drop across the generator circuit-breaker cannot alone be considered as reliable evidence of an increase in temperature rise.

For sealed for life generator circuit-breakers subclause 6.102.9.1 indent b) procedures A or B apply.

– during and after the tests, any distortion of mechanical parts is not such that it adversely affects the operation of the generator circuit-breaker or prevents the proper fitting of any replacement part;
– after the tests the insulating properties of the generator circuit-breaker in the open position shall be in essentially the same condition as before the tests. Visual inspection of the generator circuit-breaker after the tests is usually sufficient for verification of the insulating properties. In the case of generator circuit-breakers with sealed-for-life interrupter units, a voltage test as a condition check in accordance with 6.2.11 shall be performed.

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 voltage test as a condition check, as requested in 6.2.11 may not be adequate to verify the integrity of the device. In such cases the integrity of the device shall be demonstrated by the methods according to 6.102.9.1 indent c) fourth paragraph.

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, including the trip-free and anti-pumping 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 62271-1:2007 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 62271-1:2007).

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 application of voltage on or current in the main circuit is not required for this test.

NOTE A generator circuit-breaker design can 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 D.

6.101.2.2 Condition of the generator circuit-breaker before the test

The generator 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 multi-pole generator 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 and insulation according to item j) of 6.101.1.3.

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

The mechanical operation test shall consist of 1 000 operating cycles.

The generator circuit-breaker shall be tested in accordance with Table 10.

6.101.2.4 Description of the test on class M2 generator circuit-breakers

The mechanical operation test shall consist of 3 000 operating cycles.

The generator circuit-breaker shall be tested in accordance with Table 10.

Table 10 – Number of operating sequences

Operating sequence	Supply voltage	Number of operating sequences at rated operating pressure	
		class M1 generator circuit-breakers [a, b]	class M2 generator circuit-breakers [a, c]
C – t_a – O – t_a	Minimum	250	750
	Rated	250	750
	Maximum	250	750
CO – t_a	Rated	250	750

Key

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 generator circuit-breaker (this time can be different according to the type of operation);

[a] No functional part shall have been replaced prior to completion of the specified number of operations.

[b] After 500 operating cycles cleaning, tightening, adjusting, lubricating, as recommended by the manufacturer, is allowed.

[c] After each 1 000 operating cycles cleaning, tightening, adjusting, lubricating, as recommended by the manufacturer, is allowed.

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 generator circuit-breakers.

Before and after the total test programme, the operations according Table 11 shall be performed:

Table 11 – Operations to be performed before and after the test programme

		Operating pressure		
		Minimum if applicable	Rated	Maximum if applicable
Supply voltage	Minimum	1 × C 1 × O 1 × CO	1 × C 1 × O 1 × CO	1 × C 1 × O 1 × CO
	Rated	1 × C 1 × O 1 × CO	1 × C 1 × O 1 × CO	1 × C 1 × O 1 × CO
	Maximum	1 × C 1 × O 1 × CO	1 × C 1 × O 1 × CO	1 × C 1 × O 1 × CO

Key

O opening operation;

C closing operation;

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

During these operations, the operating characteristics (see 6.101.1.3) shall be recorded and evaluated. After the total test program the condition of the generator 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 of no importance. For indoor generator circuit-breakers whose minimum ambient temperature is –5 °C and for outdoor generator circuit-breakers whose minimum ambient temperature is –10 °C, no low temperature test is required. For generator circuit-breakers whose maximum ambient temperature is +40 °C, no high temperature test is required.

For generator circuit-breakers with a common operating device, three-phase tests shall be made. Generator circuit-breakers with independent poles, testing of only one complete pole is permitted.

Owing to limitations of the test facilities, multi-enclosure type generator circuit-breakers may be tested using one or more of the following alternatives provided that the generator 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 with the exception of the conditions identified in item f) of 6.101.3.3.

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

No maintenance, replacement of parts, lubrication or readjustment of the generator 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 can apply.

The generator 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 62271-1:2007. In the test report the testing conditions and the condition of the generator 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 generator 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 generator 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 generator circuit-breaker design can 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 in three locations at the distance of 1 m from the generator circuit-breaker shall be measured and reported:

– at the level of the top of the generator circuit-breaker;

– at half the height of the generator circuit-breaker. This is the ambient temperature to be reported;

– at the bottom of the generator circuit-breaker but not less than 0,25 m from the floor.

The maximum temperature deviation over the height of the generator 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 15a.

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 generator circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.

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

c) With the generator circuit-breaker in the closed position, the air temperature shall be decreased to the appropriate, minimum ambient air temperature T_L, according to the value chosen from 2.1.1, 2.1.2 or 2.2.3 of IEC 62271-1:2007. The generator 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 generator circuit-breaker in the closed position at temperature T_L, a tightness test shall be performed if gases are used for operation, interruption and/or insulation. An increased leakage rate is acceptable, provided that it returns to the original value when the generator 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 62271-1:2007. In case of vacuum generator circuit-breakers no tightness test is required. However, if the vacuum generator circuit-breaker is used in an enclosure filled with an insulating gas, for example SF_6, the tightness verification tests shall be performed on this enclosure.

e) After 24 h at temperature T_L, an opening and closing operation at rated supply voltage and at rated filling pressure for operation shall be performed and the results of these operations shall be compared with the results of the corresponding operations before the low temperature test. The requirements of 6.101.1.1 and of Annex D shall be fulfilled.

f) The low temperature behaviour of the generator 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 generator 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 generator circuit-breaker is still operable without auxiliary power to the heaters.

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

h) During the 24 h period with the generator 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 generator 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 62271-1:2007.

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 filling pressure for operation with the generator circuit-breaker at temperature T_L. An interval of least a 3 min shall be allowed for each cycle or sequence. The results of the first closing and opening operation shall be recorded and compared with the results of the corresponding operation before the low temperature test. The requirements of 6.101.1.1 and of Annex D shall be fulfilled.

   Following the first closing operation C and the first opening operation O three CO operating cycles (no intentional time delay between the C and O) 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 10).

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

k) After the generator circuit-breaker has stabilised thermally at ambient air temperature T_A, a recheck shall be made of the generator 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 15b.

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 generator circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.

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

n) With the generator 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 chosen from 2.1.1, 2.1.2 or 2.2.3 of IEC 62271-1:2007 at a rate of change of approximately 10 K per hour. The generator circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at T_H.

   For applications where the generator circuit-breakers are installed outdoors, the effects of solar radiation should be considered. Refer to IEEE C37.24™-2003 (Reaff 2008) [29].

o) During the 24 h period with the generator circuit-breaker in the closed position at the temperature T_H, a tightness test shall be performed if gases are used for operation, interruption and/or insulation. An increased leakage rate is acceptable, provided that it returns to the original value when the generator 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 62271-1:2007. In case of vacuum generator circuit-breakers no tightness test is required. However, if the vacuum generator circuit-breaker is used in an enclosure filled with an insulating gas, for example SF_6, the tightness verification tests shall be performed on this enclosure.

p) After 24 h at the temperature T_H, an opening and closing operation at rated supply voltage and at rated filling pressure for operation shall be performed and the results of these operations shall be compared with the results of the corresponding operations before the high temperature test. The requirements of 6.101.1.1 and of Annex D shall be fulfilled.

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

r) During the 24 h period with the generator 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 generator 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 62271-1:2007.

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 filling pressure for operation with the generator circuit-breaker at the temperature T_H. An interval of at least 3 min shall be allowed for each cycle or sequence. The results of the first closing and opening operation shall be recorded and compared with the results of the corresponding operations before the high temperature test. The requirements of 6.101.1.1 and of Annex D shall be fulfilled.

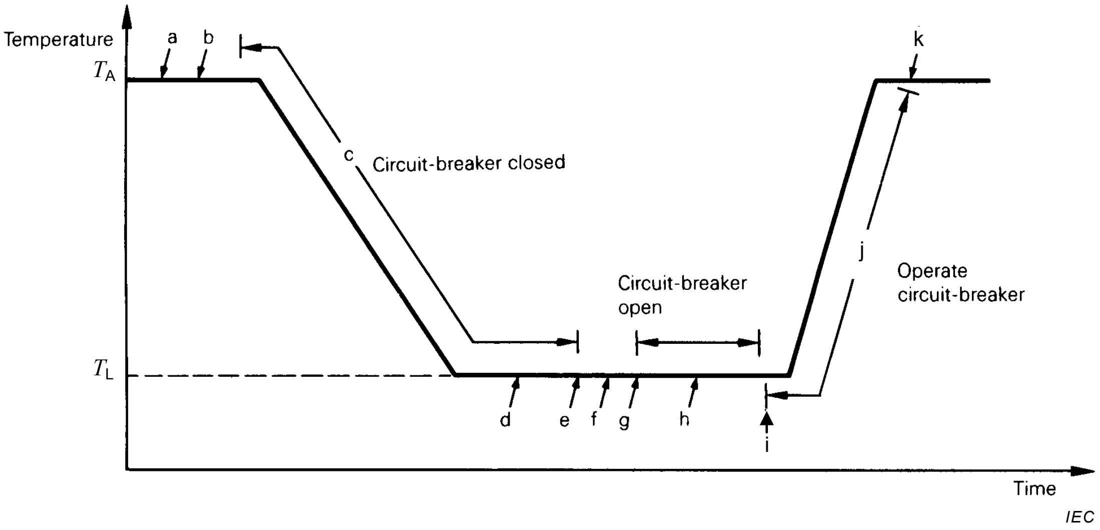
   Following the first closing operation C and the first opening operation O three CO operation cycles (no intentional time delay between the C and O) shall be performed. The additional operations shall be made by performing C – t_a – O – t_a operating sequences (t_a is defined in Table 10).

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 per hour.

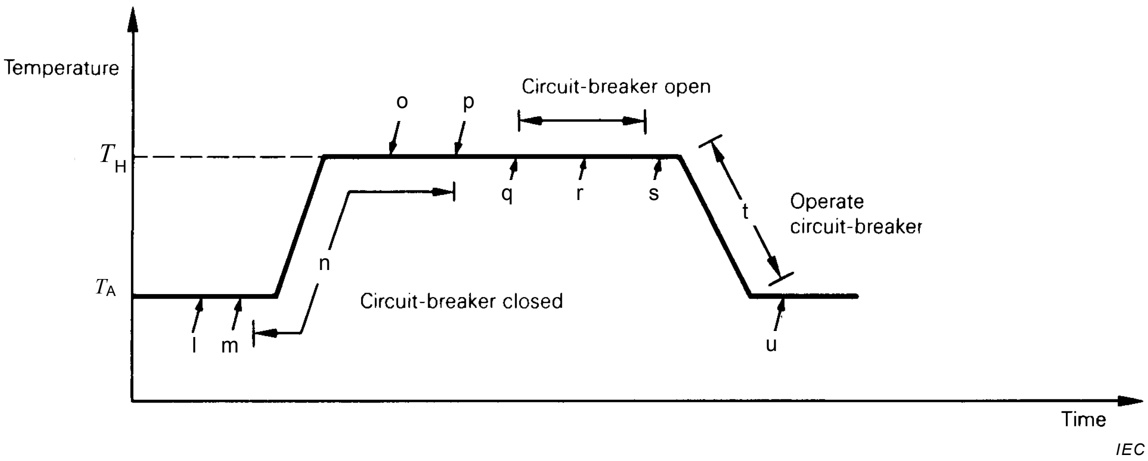
   During the temperature transition period, the generator circuit-breaker shall be subjected to alternate C – t_a – O – t_a – C and O – t_a – C – t_a – O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so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

u) After the generator circuit-breaker has stabilised thermally at ambient air temperature T_A, a recheck shall be made of the generator 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).



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 15 – Test sequences for low and high temperature tests

6.101.4 Sound level tests

Sound level tests can either be performed under three-phase or single-phase no-load conditions. The peak instantaneous sound pressure level at any location accessible to personnel including above and below the generator circuit-breaker shall be measured and reported.

A sufficient number of measurement locations shall be chosen to identify and monitor the highest sound level locations. The test should be made at the site, if feasible, rather than in the laboratory. The tests shall be made taking into account IEC/IEEE 62271-37-082:2012.

6.102 Miscellaneous provisions for making and breaking tests

6.102.1 General

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 generator circuit-breaker).

Generator circuit-breakers shall be capable of making and breaking system-source short-circuit currents. This is demonstrated by the tests as described in 6.103.

In addition, generator circuit-breakers shall be capable of making and breaking load currents. This is demonstrated by the tests as described in 6.104.

Generator circuit-breakers with an assigned generator-source short-circuit current switching rating shall be capable of making and breaking generator-source short-circuit currents. This is demonstrated by the tests as described in 6.105.

Generator circuit-breakers with an assigned out-of-phase current switching rating shall be capable of making and breaking out-of-phase currents. This is demonstrated by the tests as described in 6.106.

It is preferred that three-phase making and breaking capabilities be demonstrated on a complete three-pole generator circuit-breaker in a three-phase test circuit.

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 generator 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 generator circuit-breaker type:

a) single-phase testing (see 6.102.4.1);
b) unit testing (see 6.102.4.2).

6.102.2 Number of test specimens

Subclause 6.1.1 of IEC 62271-1:2007 is applicable with the following addition:

No limitation on the number of test specimens is set for making and breaking tests.

The expendable parts or parts subject to wear may be replaced or refitted between any test-duty, but no parts can be replaced or refitted within each test duty.

6.102.3 Arrangement of generator circuit-breaker for tests

6.102.3.1 General

The generator circuit-breaker under test shall be mounted on its own support or on an equivalent support. A generator 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.

Capacitors can be installed between the step-up transformer and the generator circuit-breaker, or between the generator and the generator circuit-breaker, or at both sides, or capacitors can be part of the generator circuit-breaker assembly. In these cases the tests shall be carried out with the capacitors connected or if these capacitors are not installed during these tests the influence of the capacitors on the prospective TRV shall be taken into account and the modified TRV applied accordingly. Computer simulations may be necessary to establish the TRV affected by these capacitors.

The interrupting capability demonstrated by these tests is valid only if capacitors of the same capacitance value as used during the tests are installed in service according to the tested configuration.

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 (refer to Table 2). To facilitate consistent control of the opening and closing operation, the releases may be supplied at the maximum operating voltage for test-duties 2, 5, 6A, 6B and OP2. 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.

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 generator 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 3.7.143.

The generator 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 generator circuit-breaker having all its arcing contacts supported within a common enclosure shall be tested as a complete three-pole generator circuit-breaker in three-phase circuits, taking Annex O of IEC 62271-100:2008 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 generator 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 generator circuit-breaker not having completely independent switching devices should be tested as a complete three-pole generator circuit-breaker. However, owing to limitation of available testing facilities, one single-pole of the generator circuit-breaker may be tested, provided that mechanical and electrical conditions applied during the tests are equivalent to, or not more favourable than, the complete three-pole generator circuit-breaker over the range of tests with respect to:

- 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.

6.102.4 General considerations concerning testing methods

6.102.4.1 Single-phase testing of one pole of a generator circuit-breaker with a common operating mechanism

According to this method, one pole of a generator circuit-breaker with a common operating mechanism 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 generator circuit-breaker with a common operating mechanism under corresponding conditions.

In those cases where the generator circuit-breaker design permits single-phase testing to simulate three-phase conditions and the generator 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 generator circuit-breaker permits single-phase tests to simulate three-phase conditions, verification tests consisting of a three-phase making operation and a three-phase symmetrical breaking operation shall be performed. Furthermore, it shall be checked that the operating characteristics of the generator circuit-breaker to be single-phase tested correspond to the provisions of 6.101.1.1.

During the verification tests for making and breaking, the course of the contact travel is recorded. The sensor for picking up the course of the contact travel shall be mounted at a suitable location, in order to optimally record the contact travel, either directly or indirectly.

The making and breaking tests shall be performed as follows:

a) The verification test for making shall be performed in a three-phase test circuit which can provide a prospective value of the peak making current equal to at least I_{MC}.

   Due to limitations of test facilities it is not always possible to perform the verification test for making at rated voltage and rated short-circuit current. The making operation at reduced voltage with a minimum of not less than 50 % of the rated voltage is permissible if the pre-arcing time during making at rated voltage in any phase is not more than 1/10 cycle of power frequency with a tolerance of 20 %.

   The pre-arcing time at rated voltage shall be determined by performing making tests at reduced current. The reduced current shall be low enough to avoid contact erosion.

   The verification test for making consists of a three-phase making test at the rated short-circuit current. Tests performed at 50 Hz are also valid for 60 Hz applications and tests performed at 60 Hz are also valid for 50 Hz applications, as long as for both cases the test circuit is such that a prospective value of the peak making current of at least I_{MC} can be provided.

   The three-phase verification test for making is valid independent from the actual closing angle. As a result the peak current value will be at least 93 % of I_{MC} in one of the three phases.

The duration of the current shall be long enough for the generator circuit-breaker to reach its fully closed position.

b) The verification test for breaking consists of a three-phase breaking test at the rated short-circuit breaking current and with the maximum arcing time in the last-pole-to-clear. The breaking operation may be performed at any convenient test voltage. Tests performed at 50 Hz are also valid for 60 Hz applications and tests performed at 60 Hz are also valid for 50 Hz applications, as long as for both cases the maximum arcing time in the last-pole-to-clear of the respective application is covered. The course of the contact travel during the three-phase breaking test shall be used as a reference for the following procedure:

   – Two envelope curves shall be drawn from the instant of contact separation to the end of the contact travel. The distance of the two envelopes from the original course shall be ±5 % of the total travel or ±2 mm whichever is larger evaluated from the three-phase verification test (see Figure 17).

   – During a single-phase test under the same conditions (breaking test at the rated short-circuit breaking current with the maximum arcing time) the contact travel shall be recorded. If 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, single-phase testing to represent three-phase conditions is permitted.

   – 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 % or +4 mm and +0 %, –10 % or –4 mm respectively (see Figure 18 and Figure 19). 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 % or 4 mm.

To achieve the correct contact travel characteristics of the individual poles, depending on the design (single-pole or three-pole 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).

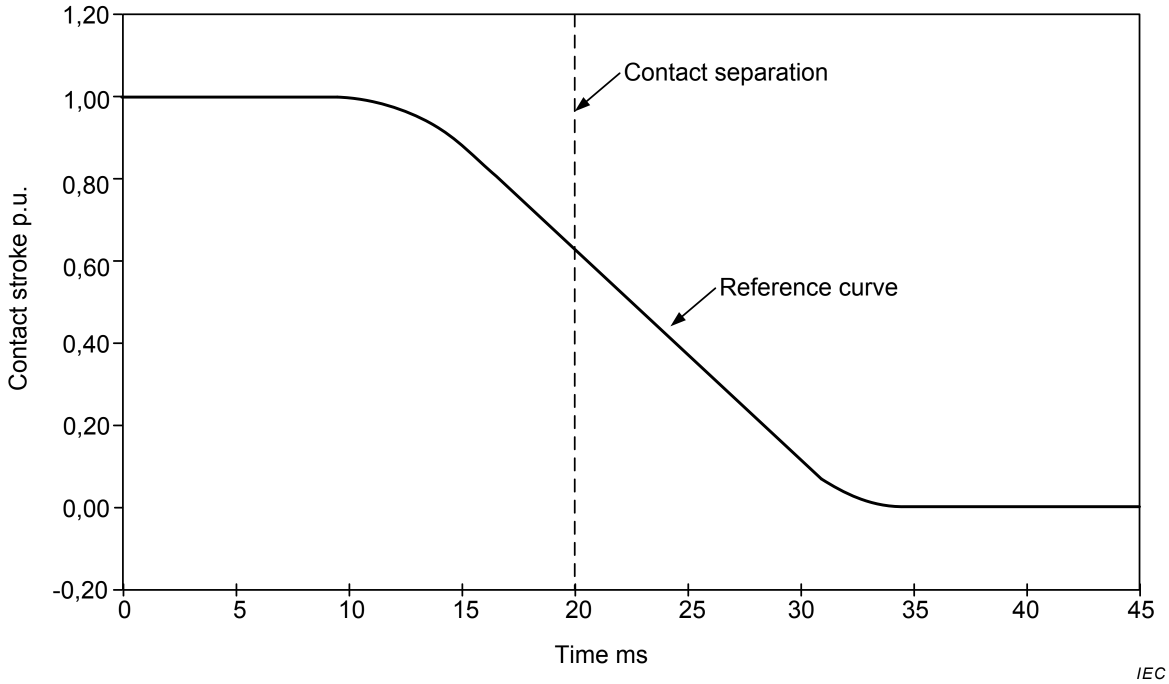


Figure 16 – Reference mechanical travel characteristics (idealised curve)

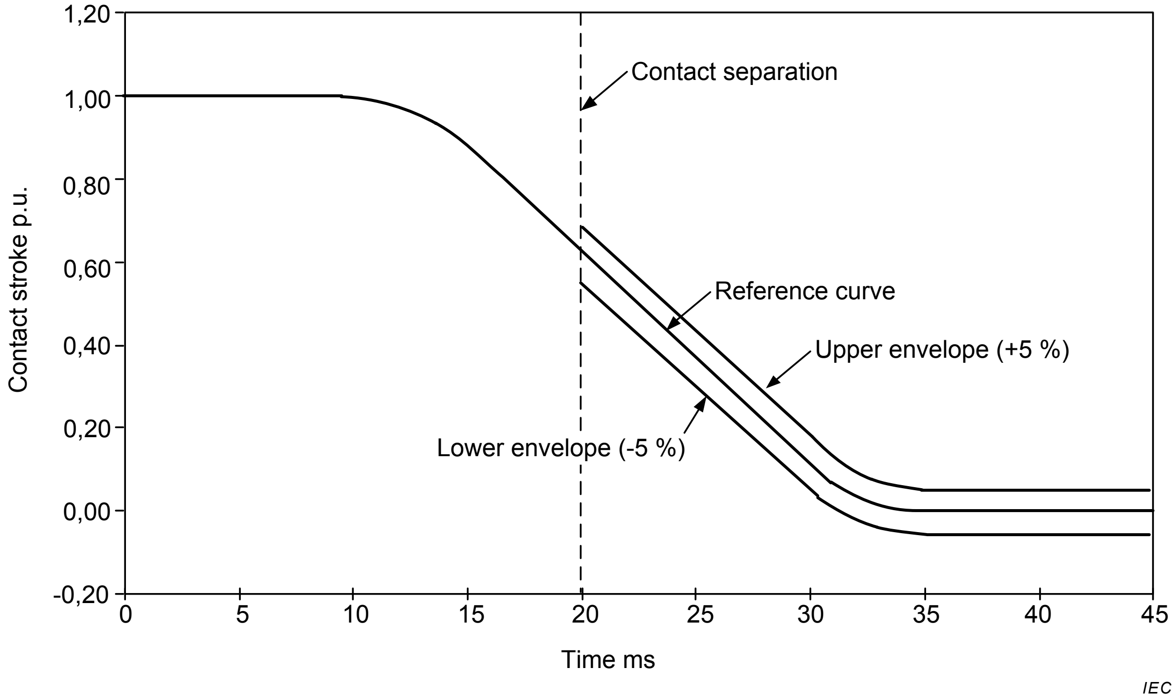


Figure 17 – Reference mechanical travel characteristics (idealised curve) with the prescribed envelopes centered over the reference curve (+5 %, –5 %), contact separation in this example at time *t* = 20 ms

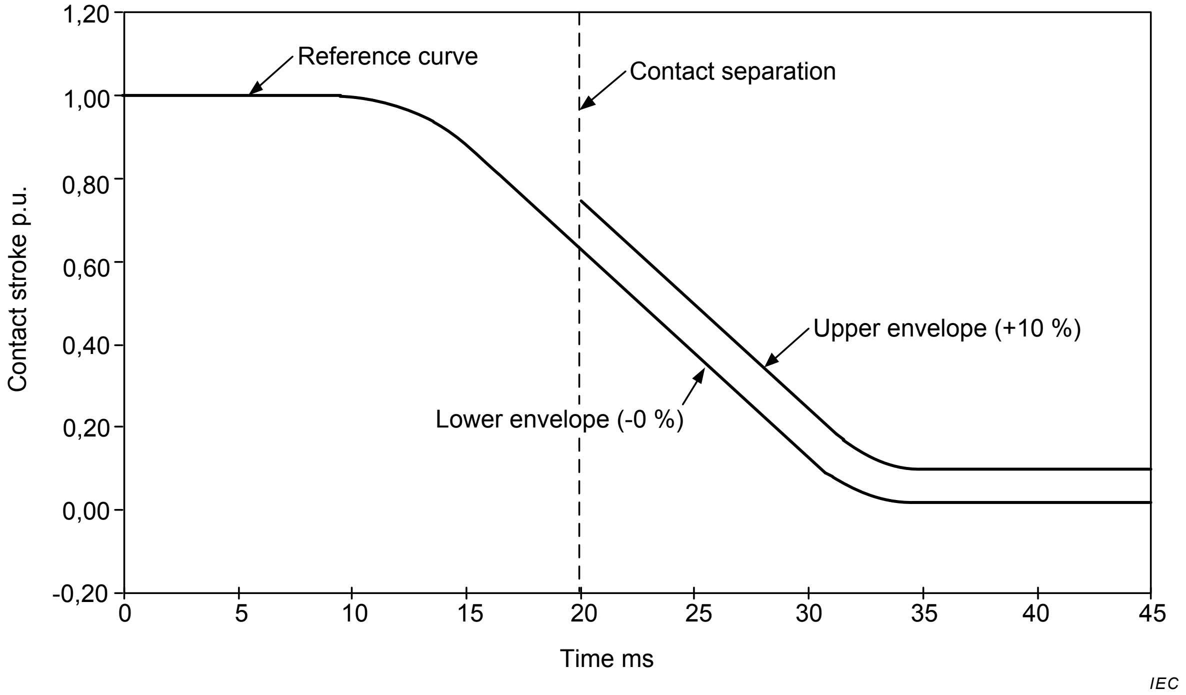


Figure 18 – Reference mechanical travel characteristics (idealised curve) with the prescribed envelopes fully displaced upward from the reference curve (+10 %, –0 %), contact separation in this example at time *t* = 20 ms

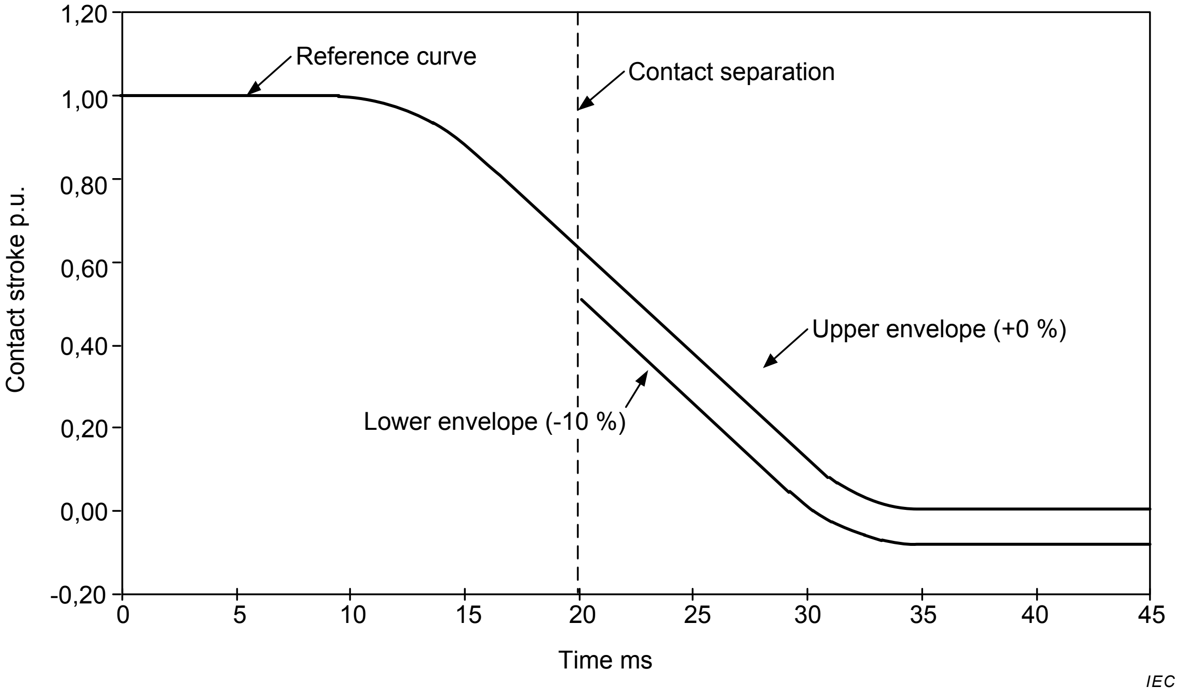


Figure 19 – Reference mechanical travel characteristics (idealised curve) with the prescribed envelopes fully displaced downward from the reference curve (+0 %, –10 %), contact separation in this example at time *t* = 20 ms

6.102.4.2 Unit testing

6.102.4.2.1 General

Certain generator 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 generator 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:

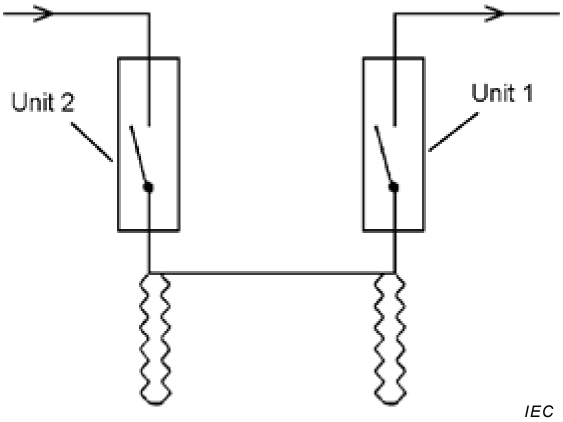
a) The generator circuit-breaker pole consists of units (or assemblies of units) which are separately operated and which have no mutual connections for the arc extinguishing medium. In this case unit testing is acceptable. However, the mutual influence through the electrodynamic forces of the current on the units and the arc in the units should be taken into account (see Figure 20). This may be done by substitution of the second interrupter unit by a conductor with equivalent shape.
b) The generator 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 generator 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 single-unit testing and full-pole testing are the same. The procedure as given in 6.102.4.1 for single-phase testing of a three-pole generator 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 generator circuit-breakers, which have mutual connections for the extinguishing medium between units (see also item b) above) is covered at the same time.

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-phase testing of a three-pole generator circuit-breaker shall be applied accordingly.

When carrying out unit tests it is essential that the units are identical and that the static voltage distribution for the type of test is known.

Pole of a generator 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.

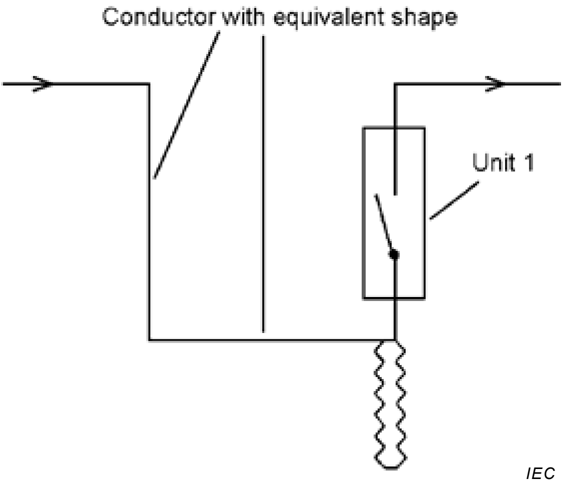


Figure 20 – Equivalent testing set-up for unit testing of generator circuit-breakers with more than one separate interrupter units

6.102.4.2.2 Identical nature of the units

The units of the generator 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

In making tests the closing of the contacts of one pole shall be such that the time interval between the closing of the contacts of the first unit to close and the closing of the contacts of the last unit to close is not more than one-sixth of a cycle of rated frequency. In breaking tests the opening of the contacts of one pole shall be such that the time interval between the opening of the contacts of the first unit to open and the opening of the contacts of the last unit to open 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 generator 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.

6.102.4.2.3 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.

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 generator circuit-breaker. Such calculations and supporting measurements verifying the assumptions used in the calculations are the responsibility of the manufacturer.

If the generator circuit-breaker is fitted with parallel resistors, the voltage distribution shall be calculated or measured statically at the frequency of the TRV.

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 1 It can be taken into account that the voltage distribution is more favourable during the out-of-phase and load current breaking tests than during the short-circuit fault tests.

NOTE 2 The influence of pollution is not considered in determining voltage distribution. In some cases, pollution can affect this voltage distribution.

6.102.4.2.4 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 generator circuit-breaker, determined in accordance with 6.102.4.2.3.

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 6.102.4.2.3.

During unit testing, the insulation to earth is not stressed with the full voltage occurring during a breaking operation of the complete generator circuit-breaker. 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 IEC 62271-100:2008 and in IEC 62271-101:2012.

6.102.5 Synthetic tests

Synthetic testing methods can be applied for making, breaking and switching tests as required in 6.103 to 6.106.

NOTE For synthetic testing techniques and methods IEC 62271-101:2012 can be used as a reference.

6.102.6 No-load operations before tests

Before commencing making, breaking and switching tests, C and O operations shall be made and the mechanical characteristics recorded. Details such as closing time and opening time shall be recorded. For these no-load operations, conditions stated in 6.101.1.1 apply. Additional no-load operations may be necessary.

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. After a change of contacts or any kind of maintenance, these mechanical travel characteristics shall be reconfirmed by repeating these no-load tests.

The pressure of the fluid for interruption shall be set at its minimum functional value according to 3.7.143. This does not apply to sealed for life generator circuit-breakers.

For electrically or spring-operated generator circuit-breakers, the operations shall be made with the closing solenoid or shunt-closing releases and with the shunt-opening release energised at rated maximum and minimum supply voltages as specified in Table 2.

6.102.7 Alternative operating mechanisms

For a generator circuit-breaker equipped with an alternative operating mechanism, repetition of the type tests under short-circuit, out-of-phase and load current conditions is not necessary.

NOTE 1 In this subclause it is considered that one version of the generator 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 generator circuit-breaker. The other versions, differing only in the operating mechanisms, are referred to as generator circuit-breakers with alternative operating mechanisms.

The tests to be performed are limited to the following:

a) On each of the generator circuit-breakers (the completely tested generator circuit-breaker and the generator circuit-breaker with an alternative operating mechanism) the mechanical characteristics shall be recorded and compared in accordance with 6.101.1.1.

b) On the generator circuit-breaker with an alternative operating mechanism a verification test for breaking and a verification test for making, both under short-circuit conditions, shall be performed. For three-pole operated generator circuit-breakers the verification tests shall be performed three-phase, for single-pole operated generator circuit-breakers the verification tests can be performed single-phase.

   The three-phase verification test for making shall be performed according to 6.102.4.1 a). After this making operation a no-load opening operation shall be performed by normal means and the mechanical characteristics shall be recorded and compared in accordance with 6.101.1.1.

   The single-phase verification test for making consists of a single-phase making test at the rated short-circuit current. The peak current value shall be at least $2,74I_{sc}$. The duration of the current shall be long enough for the generator circuit-breaker to reach its fully closed position. After this making operation a no-load opening operation shall be performed by normal means and the mechanical characteristics shall be recorded and compared in accordance with 6.101.1.1.

   Both the three-phase and the single-phase verification test for breaking consist of a symmetrical breaking test at the rated short-circuit current with the maximum arcing time for the last-pole-to-clear. The breaking operation may be performed at any convenient test voltage.

The course of the contact travel of the completely tested generator circuit-breaker during a breaking test under the same conditions shall be used as a reference curve for the following procedure:

- Two envelope curves shall be drawn from the instant of contact separation to the end of the contact travel of the reference curve. The distance of the two envelopes from the course of the contact travel shall be ±5 % of the total travel or ±2 mm whichever is larger (see Figure 17).
- The course of the contact travel of the generator circuit-breaker with an alternative operating mechanism during its verification test for breaking shall be recorded. If the course of the contact travel during the verification test for breaking is within the envelope curves of the completely tested generator circuit-breaker, the verification test is a valid operation.
- 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 % or 0 mm, +10 % or +4 mm and +0 % or 0 mm, –10 % or –4 mm respectively (see Figure 18 and Figure 19). 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 % or 4 mm.

c) In the particular case where the variation in opening times of the alternative operating mechanism causes the generator circuit-breaker to fall into a different category of earliest possible interruption (see Tables 12, 13, 14 and 15), test-duty 2 of Table 16 or 17 shall be performed on the generator circuit-breaker with an alternative operating mechanism.

If requirements a), b) and c) are met, the reference mechanical characteristics of the completely tested generator circuit-breaker shall apply also for the generator circuit-breakers with alternative operating mechanisms.

NOTE 2 It is understood that the mechanical endurance tests are completely repeated with the alternative operating mechanism.

6.102.8 Behaviour of generator circuit-breaker during tests

During making and breaking tests, the generator 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.

The generator circuit-breaker shall close and latch satisfactorily.

For generator 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 generator 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 generator circuit-breaker and directed away from all live conductors and locations where persons may be present;
- for other types of generator 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 generator circuit-breaker earthed structure, or screens when fitted, during the tests.

NOTE 1 If no other devices are available, the earthed parts, etc. can 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 test-duty repeated. 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 are only reported when seen on an oscillogram.

6.102.9 Condition of generator circuit-breaker after tests

6.102.9.1 General

The generator 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.

After each test-duty the generator circuit-breaker shall be in the following condition:

a) The generator circuit-breaker shall be capable of withstanding a voltage test as a condition check according to 6.2.11.

b) 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 without their temperature rise exceeding the values specified in Table 3 of IEC 62271-1:2007 by more than 10 K.

   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 62271-1:2007).

   For other than sealed for life interrupter units, visual inspection is usually sufficient for verification of the capability of the generator circuit-breaker to carry the rated normal current.

   NOTE Experience shows that an increase of the voltage drop across the generator circuit-breaker cannot alone be considered as reliable evidence of an increase in temperature rise.

   For generator circuit-breakers with sealed for life interrupters either procedure A or B below applies:

   Procedure A

   This procedure is applicable, when a temperature-rise test has been carried out in accordance with 6.5. and the manufacturer has provided the test results to the testing laboratory.

   1) The manufacturer shall make available the results of the appropriate temperature-rise test together with drawings illustrating the circuit-breaker tested. The drawings shall show the configuration and dimensions of the conductors and interrupter together with details and dimensions of the enclosure, if any. The testing laboratory shall ensure that the circuit-breaker submitted for short-circuit tests is identical in all significant details likely to affect the normal current rating of the circuit-breaker on which the temperature-rise test was carried out.

   2) The resistance across the generator circuit-breaker shall be measured before the making and breaking tests. Three measurements of resistance shall be made on each interrupting unit with intervening no-load operations to establish an average value. The

measurements shall be made with d.c. at any convenient value of current between 100 A and the rated normal current.

3) Provided that the average value of the resistance for each interrupting unit is not greater than 120 % of the highest resistance value recorded for the interrupting units submitted to the temperature rise test then the making and breaking tests can proceed. In the event of the resistance measurements exceeding the 120 %, then procedure B shall be applied.

4) After the completion of the making and breaking tests the resistance across each interrupting unit shall be measured again. The measurement procedure shall be identical to that used for the resistance measurements made prior to the making and breaking tests.

5) The condition of the contacts after completion of the making and breaking tests is considered to be satisfactory, if the average value of resistance for each interrupting unit is not greater than 200 % of the maximum value recorded for the interrupting units submitted to the temperature-rise tests.

6) In the event of the average value of resistance for any interrupting unit exceeding 200 % of the maximum value recorded for the original temperature-rise test then the testing laboratory shall request a temperature-rise test to be performed (see assessment for procedure B).

Procedure B

This procedure is applicable either when a manufacturer has not carried out a temperature-rise test on the type of generator circuit-breaker submitted for making and breaking tests, or alternatively, when the testing laboratory is not satisfied that there is a satisfactory relationship between the generator circuit-breaker for test and the generator circuit-breaker on which a temperature-rise test was performed.

1) A temperature-rise test shall be performed after the no-load operations completing the making and breaking tests prior to the replacement of any interrupting units.

2) The condition of the contacts after the making and breaking tests is considered acceptable if the maximum temperature rise recorded at the terminals of any interrupting unit does not exceed by more than 10 K the values specified in Table 3 of IEC 62271-1:2007.

c) The generator circuit-breaker shall be capable of making and breaking load currents according to 6.104, although its short-circuit making and breaking performance may be impaired.

For other than sealed for life interrupter units, visual inspection is usually sufficient for verification of the capability of the generator circuit-breaker to make and break load currents according to 6.104.

For sealed for life generator circuit-breakers verifications according to a) and b) are normally sufficient for verification of the capability of the generator circuit-breaker to make and break load currents according to 6.104.

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 voltage test as a condition check, as requested in 6.2.11 may not be adequate to verify the integrity of the device. In such cases the integrity of the device shall be demonstrated by one of the following:

– appropriate methods as stated by the manufacturer (for example by removing the interrupter and testing it in the interrupter factory with the same procedure as for a new interrupter).
– short-circuit current breaking tests in a circuit which supplies at least 10 % of the rated short-circuit breaking current and at least 50 % of the rated voltage irrespectively of the TRV. One of the three following tests shall be performed:

1) in a three-phase solidly earthed test circuit, one breaking operation.
2) in a three-phase isolated neutral test circuit, three breaking operations. Each pole shall be the first to clear once.
3) in a single-phase test circuit, one breaking operation on each pole.

The requirements mentioned above also apply to synthetic tests.

A successful interruption in each pole demonstrates that the interrupter integrity is maintained.

6.102.9.2 No-load operations after a test-duty

After a test-duty no-load operations shall be repeated under the same condition as the corresponding operations before the test-duty. The no-load operations after a test-duty shall be compared with the corresponding operations made before the test-duty and shall show no significant change. If the test continues on the same test object without maintenance, then the no-load operations are not required at this stage.

6.102.9.3 No-load operations after a series of tests

At the completion of the entire test series of short-circuit or switching tests the mechanical behaviour of the generator circuit-breaker, or sample under test, shall be reconfirmed to that of the reference mechanical characteristics required in 6.102.6.

The no-load operations after a series of tests shall be compared with the corresponding operations made before the series of tests and shall show no significant change.

6.102.10 Demonstration of the most severe switching conditions

6.102.10.1 General

The procedures described in this subclause are relevant for the system-source short-circuit current breaking tests and for the out-of-phase current breaking tests. Each test-duty is demonstrated with a minimum of two tests on one test sample.

The current to be interrupted by a generator circuit-breaker shall be determined at the instant of contact separation in accordance with Figure 10, and shall be stated in terms of the following two values:

– the r.m.s. value of the a.c. component averaged over all phases;
– the degree of asymmetry in each 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 breaking current is measured at the instant corresponding to contact separation, the breaking performance of the generator 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 current is therefore very important, particularly when testing those generator circuit-breakers which arc for several loops of current. To obviate an easement of duty, the decrement of the a.c. component of the 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 generator circuit-breaker are such that it reduces the 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 breaking current in all phases shall be used as the 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 generator circuit-breaker at no-load.

6.102.10.2 Three-phase tests

6.102.10.2.1 General

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-pole-to-clear before starting the sequences. The method of establishing the minimum arcing time is given in 6.102.10.3.

6.102.10.2.2 Three-phase symmetrical breaking operations

The most severe switching condition is considered satisfactory if the following conditions are met:

a) in one of the two opening operations, where in the first-pole-to-clear arc extinction occurs at minimum arcing time;

b) in one of the two opening operations, where in the first-pole-to-clear arc extinction occurs at maximum arcing time.

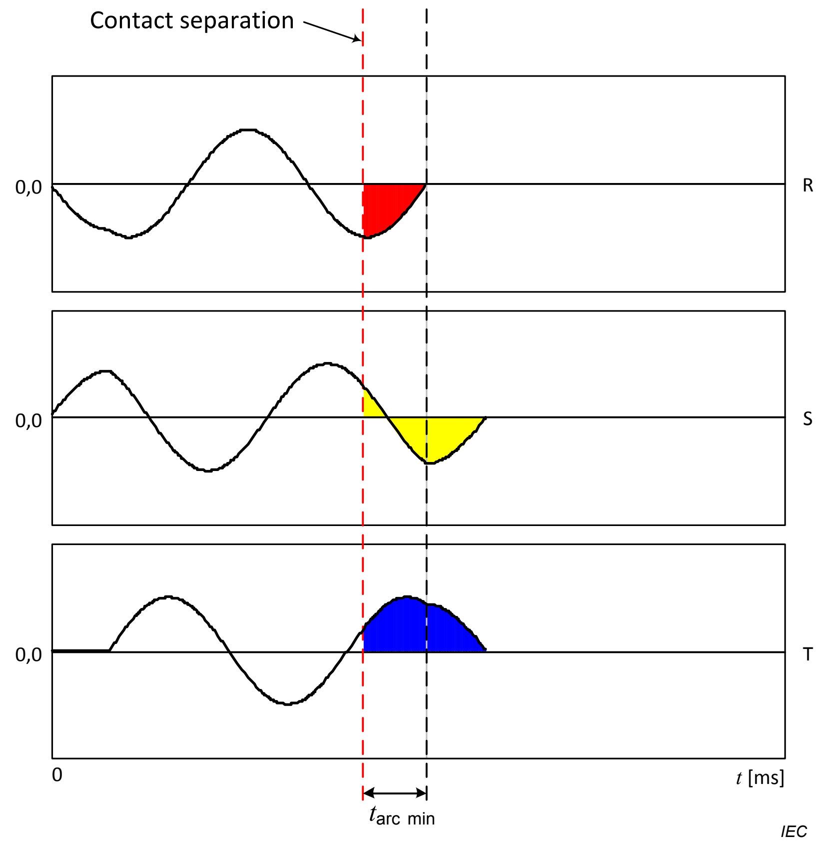
The recommended procedure to achieve these two valid operations is as follows.

First it is necessary to establish the minimum arcing time $t_{\text{arc min}}$. The minimum arcing time may be known from experience. However tests illustrated in Figure 21 are needed to confirm the minimum and the longest arcing times. The minimum arcing time $t_{\text{arc min}}$ is established when any delay in the contact separation with respect to the current waveform results in interruption at the next current zero in another phase, resulting in a valid test with maximum arcing time.

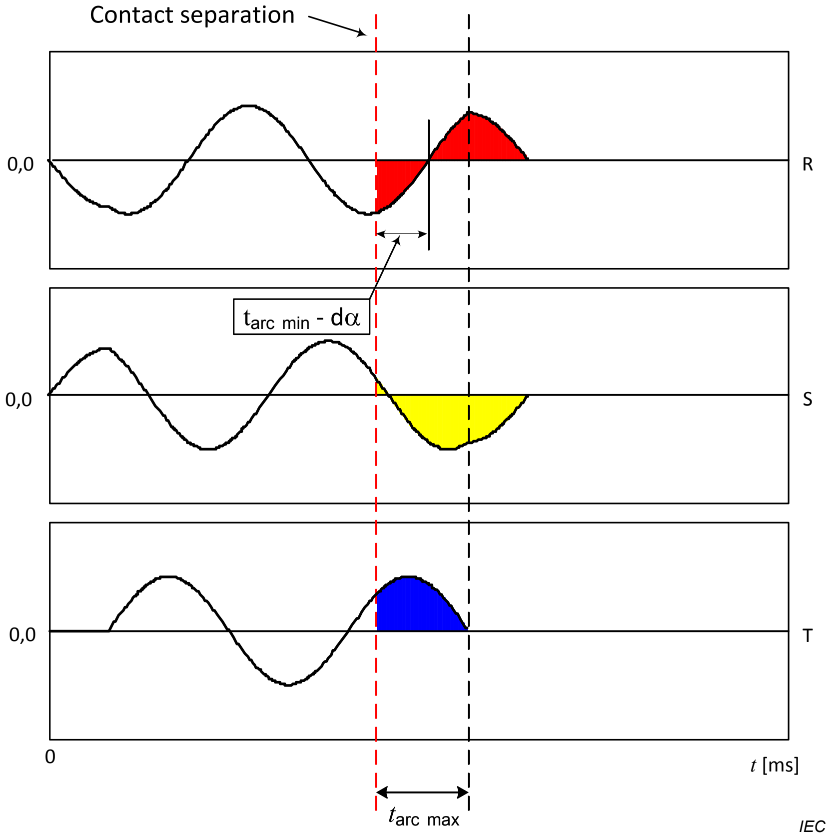
The minimum arcing time is found by changing the setting of the tripping impulse by steps of 18° (dα).

A graphical representation of the two valid breaking operations is given in Figure 21.

As an alternative to the above, three CO-operations could be applied where the tripping impulse shall be advanced or delayed by 40 electrical degrees (40°) between the three opening operations.



(a) Minimum arcing time (in phase R)



(b) Maximum arcing time (in phase T)

Figure 21 – Two valid three-phase symmetrical breaking operations

6.102.10.2.3 Three-phase asymmetrical breaking operations

Since the severity of the tests under asymmetrical breaking conditions can vary widely depending on the moment of contact separation, a procedure has been developed in order to prove the most severe switching conditions.

The following asymmetry criteria shall be fulfilled by the prospective current waveform when performing test-duty 2 and test-duty OP2:

- last current loop peak;
- last current loop duration;
- d.c. component at current zero (parameter controlling the di/dt and the resulting TRV parameters).

The intention is to prove the most severe switching conditions as follows:

a) In one breaking operation arc extinction in the first-pole-to-clear shall occur at the end of a major current loop with the maximum arcing time and with the required maximum asymmetry criteria. This operation shall comply with the TRV requirements for the first-pole-to-clear condition.

b) In one breaking operation arc extinction in one of the last-poles-to-clear shall occur at the end of a major extended current loop with the maximum arcing time and with the required maximum asymmetry criteria. This operation shall comply with the TRV requirements for the last pole-to-clear condition.

NOTE 1 Some generator 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 maximum arcing time was achieved.

NOTE 2 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 NOTE 1.

The sequence is of no consequence as long as the tests fulfil the conditions in a) and b). Between the condition a) and the condition b) tests the initiation of the short-circuit should be changed by 60° in order to transfer the required asymmetry criteria to another phase and to equalize the contact erosion of the poles.

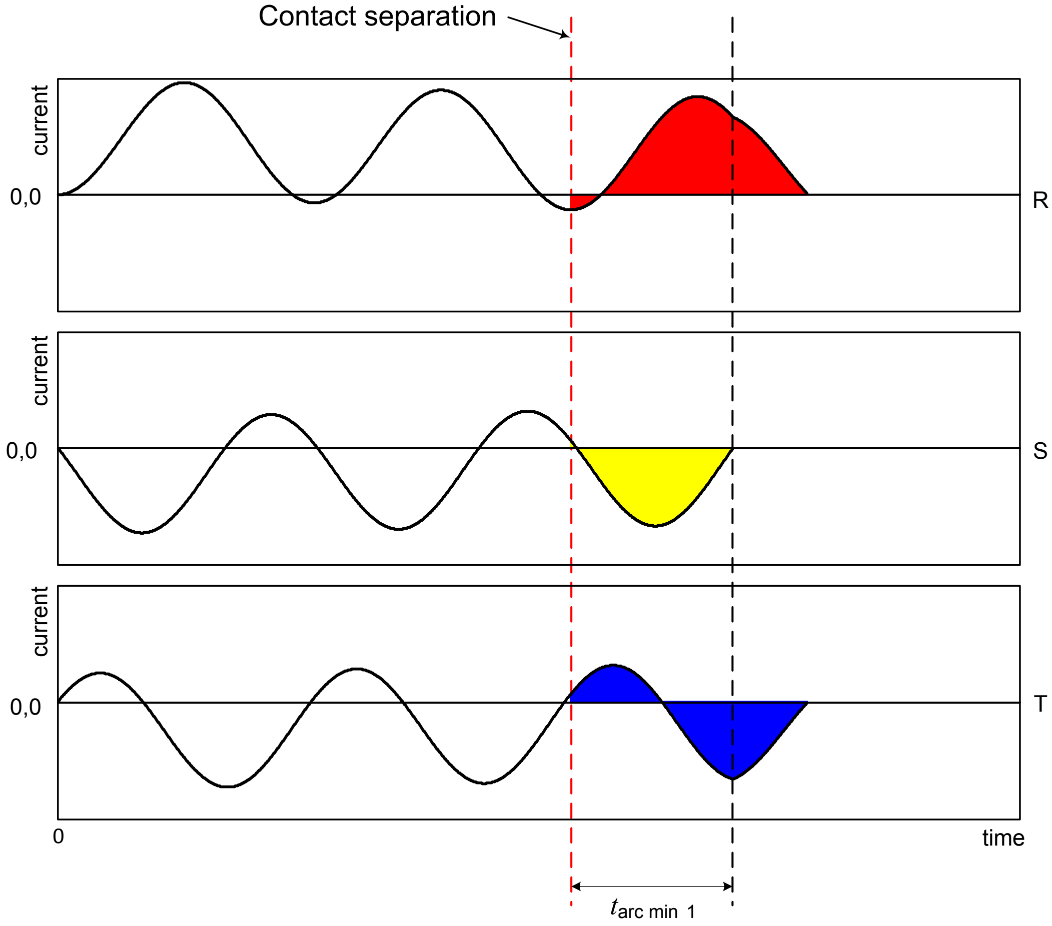
The preferred procedure to demonstrate the conditions a) and b) in four operations on one generator circuit-breaker without reconditioning is as follows:

Demonstration of condition a)

Two breaking operations are required, one according to Figure 22 and one according to Figure 23.

- Figure 22 shows the contact separation to achieve the minimum arcing time $t_{\text{arc min 1}}$ in phase S with intermediate level of asymmetry after a major loop. Parameters for this intermediate asymmetrical major loop are given in Table 12 for 50 Hz and in Table 13 for 60 Hz.
- Figure 23 shows the contact separation delayed by dα (18°) with respect to the current waveform of Figure 22 resulting in a first-pole-to-clear interruption after a major loop in phase R with the required maximum asymmetry criteria and the maximum arcing time $t_{\text{arc max 1}} = t_{\text{arc min 1}} - T \times \text{d}\alpha/360° + \Delta t_1$. Parameters for this maximum asymmetrical major loop and values for the time interval Δt_1 are given in Table 12 for 50 Hz and in Table 13 for 60 Hz.

The minimum arcing time may be known from experience. However tests illustrated in Figure 22 and Figure 23 are needed to confirm the minimum and the maximum arcing times.



Contact separation is set such as to achieve the minimum arcing time in phase S with intermediate level of asymmetry after a major loop

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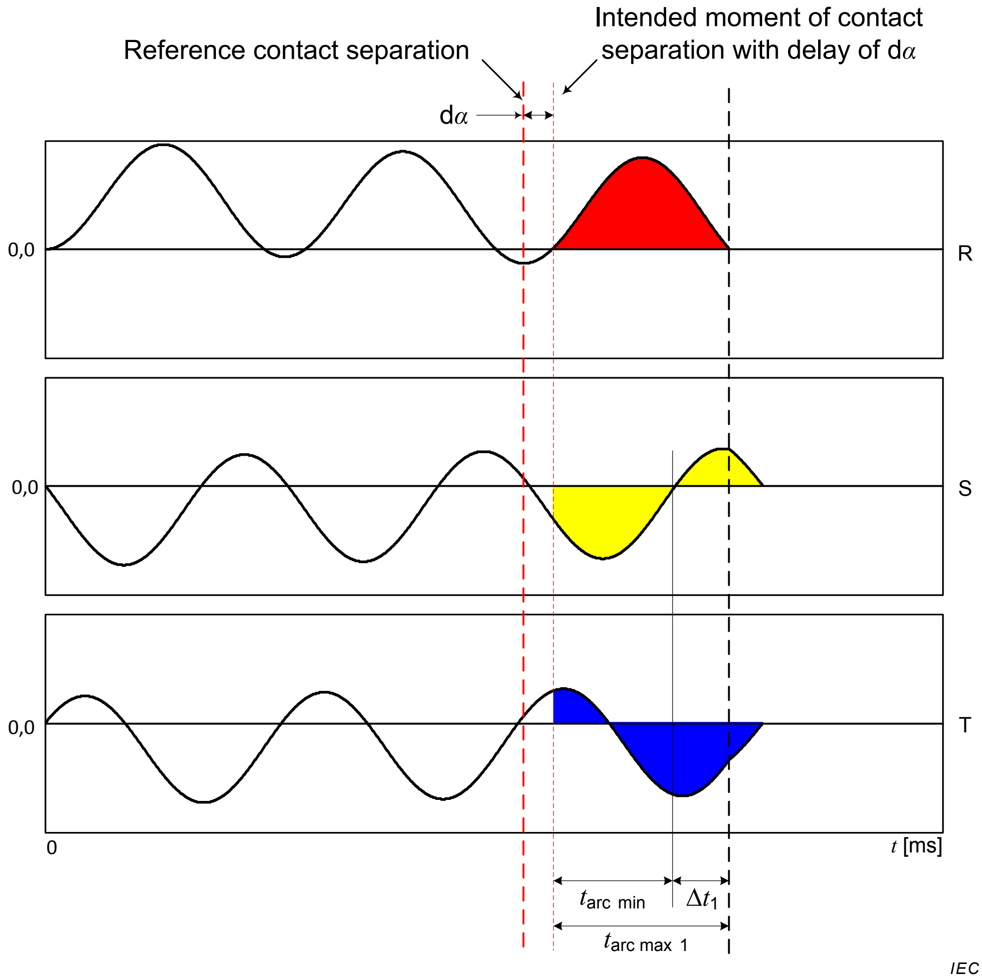
Figure 22 – Three-phase asymmetrical breaking operation – Minimum arcing time with intermediate asymmetry after major loop ($t_{arc\ min\ 1}$)



Contact separation is delayed by dα with respect to Figure 22 in order to achieve the maximum arcing time for a first pole-to-clear (phase R) at maximum asymmetry criteria after a major loop

Key

$t_{\text{arc min 1}}$	minimum arcing time in a phase with intermediate level of asymmetry after a major loop
dα	18°
T	one period of the power frequency
Δt_1	time interval as per Tables 12 and 13
$t_{\text{arc max 1}}$	maximum arcing time for a first-pole-to-clear at maximum asymmetry criteria after a major loop

Figure 23 – Three-phase asymmetrical breaking operation – Maximum arcing time for the first-pole-to-clear after major loop ($t_{\text{arc max 1}}$)

Demonstration of condition b)

Two breaking operations are required, one according to Figure 24 and one according to Figure 25.

- Figure 24 shows the contact separation such as to achieve the minimum arcing time $t_{\text{arc min 2}}$ in phase S with intermediate level of asymmetry after a minor loop. Parameters for this intermediate asymmetrical minor loop are given in Table 14 for 50 Hz and in Table 15 for 60 Hz.
- Figure 25 shows the contact separation delayed by dα (18°) with respect to the current waveform of Figure 24 resulting in a last-pole-to-clear interruption after a major loop in phase T with the required maximum asymmetry criteria and the maximum arcing time $t_{\text{arc max 2}} = t_{\text{arc min 2}} - T \times \text{d}\alpha/360° + \Delta t_2$. Parameters for this maximum asymmetrical major extended loop and values for the time interval Δt_2 are given in Table 14 for 50 Hz and in Table 15 for 60 Hz.

The minimum arcing time may be known from experience. However tests illustrated in Figure 24 and Figure 25 are needed to confirm the minimum and the maximum arcing times.

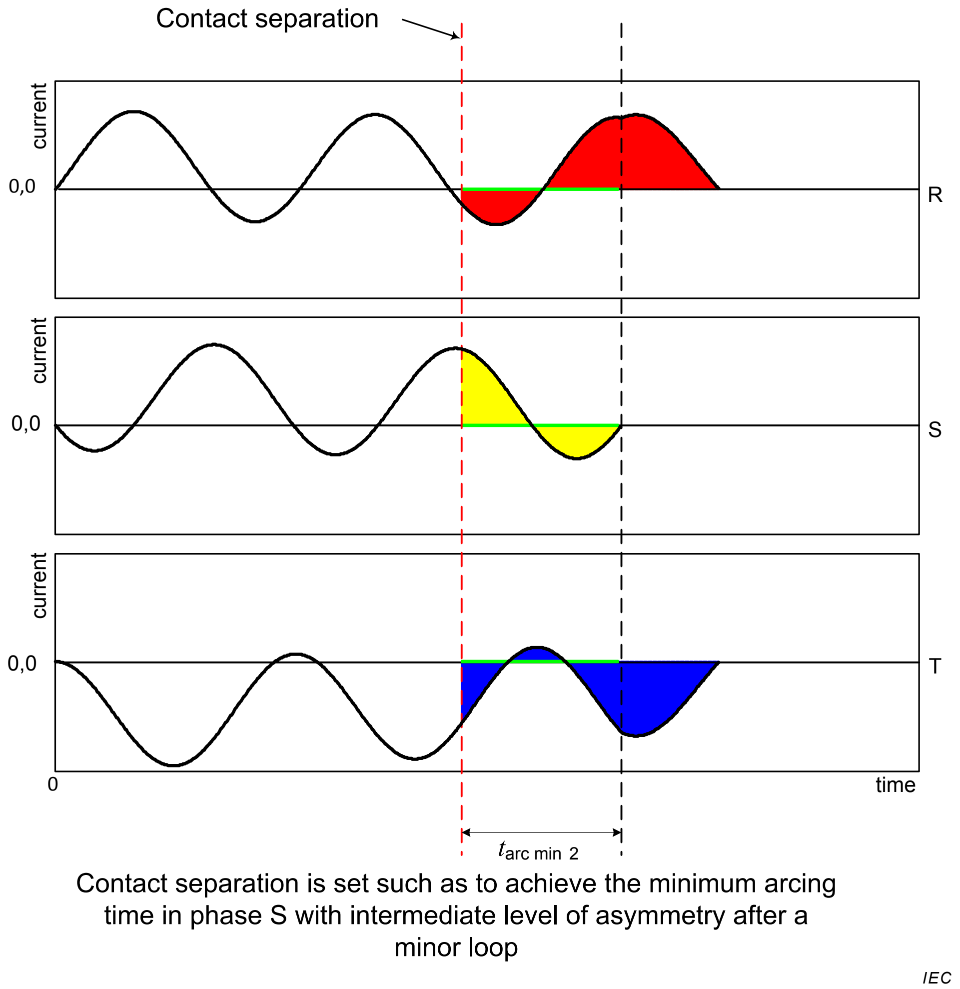
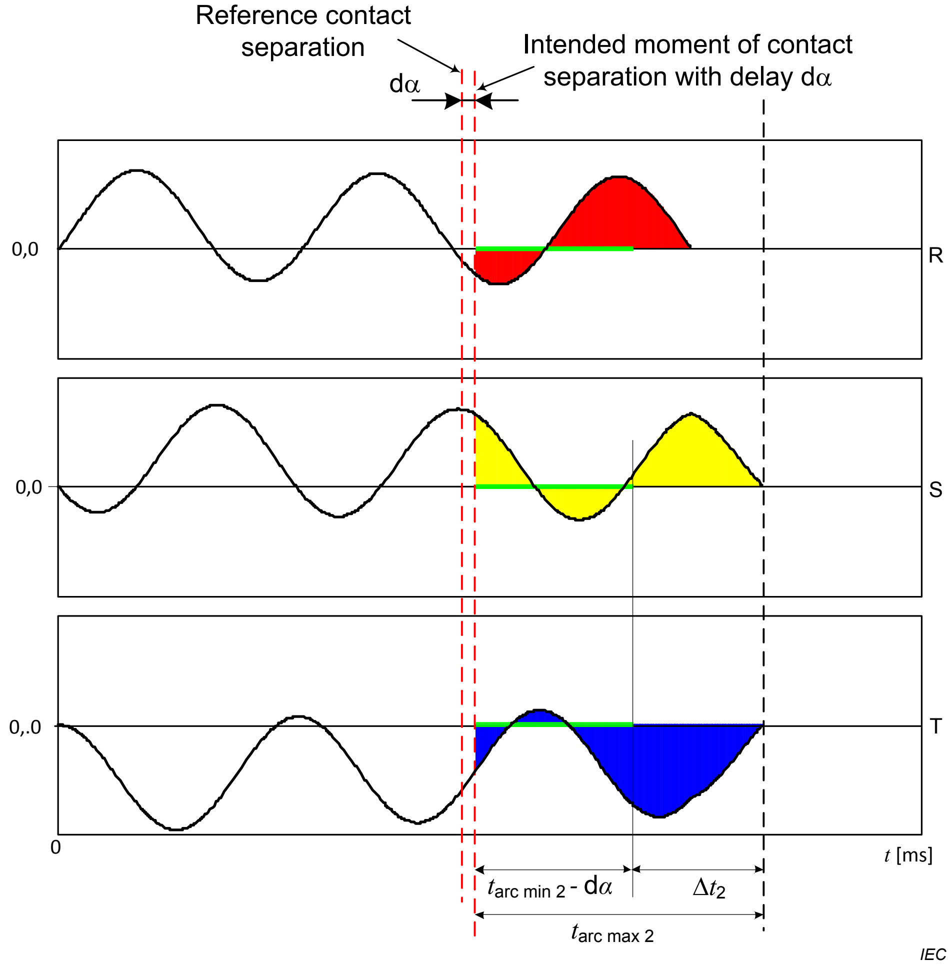


Figure 24 – Three-phase asymmetrical breaking operation – Minimum arcing time with intermediate asymmetry after minor loop ($t_{arc\ min\ 2}$)



Contact separation is delayed by dα with respect to Figure 24 in order to achieve the maximum arcing time for a last pole-to-clear (phase T) at maximum asymmetry criteria after a major extended loop

Key

$t_{arc\ min\ 2}$	minimum arcing time in a phase with intermediate level of asymmetry after a minor loop
dα	18°
T	one period of the power frequency
Δt_2	time interval as per Table 14 and Table 15
$t_{arc\ max\ 2}$	maximum arcing time for a last-pole-to-clear at maximum asymmetry criteria after a major extended loop

Figure 25 – Three-phase asymmetrical breaking operation – Maximum arcing time for the last-pole-to-clear after extended major loop ($t_{arc\ max\ 2}$)

If it is not possible to achieve the requirements a) and b) because of the characteristics of the generator circuit-breaker, the number of breaking operations shall be extended to prove that, in this particular case, the most severe test conditions have been achieved. With the consent of the manufacturer two options to perform additional breaking operations are suggested.

Option 1: Additional breaking operations shall be carried out without reconditioning on the same generator circuit-breaker:

– If during the first 4 breaking operations according to the preferred procedure neither condition a) nor condition b) were achieved, at least two more breaking operations shall be carried out. The test duty is fulfilled, if among all the six breaking operations each of the two conditions a) and b) are met at least once, while taking into account an enlarged tolerance of ±2 ms to the required arcing times.

– If during the first 4 breaking operations according the preferred procedure only one of the conditions a) and b) was achieved, at least one more breaking operation shall be carried out. If during this additional breaking operation the remaining condition is met, the test duty is fulfilled. If a second additional breaking operation is necessary to prove the remaining condition, then, if among all the 6 breaking operations the remaining condition was met at least once, while taking into account an enlarged tolerance of ±2 ms to the required arcing times, the test duty is fulfilled.

Option 2: The preferred procedure as described above shall be repeated with a reconditioned or a new generator circuit-breaker:

During repetition of the preferred procedure the required conditions a) and b) shall be fulfilled taking into account an enlarged tolerance of ±2 ms to the required arcing times.

6.102.10.3 Single-phase tests to substitute for three-phase conditions

6.102.10.3.1 General

This procedure may be used instead of three-phase tests, except where single-phase testing is not permitted according to 6.102.3.2 or 6.102.3.3.

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 Tables 12, 13, 14 and 15.

6.102.10.3.2 Single-phase symmetrical breaking operations

The intention to achieve the most severe switching conditions is considered satisfactory if the following conditions are met:

a) In one of the two opening operations, arc extinction shall occur with the maximum arcing time and with TRV requirements for the first-pole-to-clear condition. The maximum arcing time for the first-pole-to-clear condition is determined as follows:

$t_{\text{arc max 1}} = t_{\text{arc min}} + T \times 42°/360°$

where

$t_{\text{arc min}}$ is the minimum arcing time obtained from one or more additional tests;

T is one period of the power frequency;

42° is the arcing window of the first-pole-to-clear – $d\alpha$ = 60° − 18°

b) In one of the two open operations, arc extinction shall occur with the maximum arcing time and with TRV requirements for the last-pole-to-clear condition. The maximum arcing time for the last-pole-to-clear condition is determined as follows:

$t_{\text{arc max 2}} = t_{\text{arc min}} + T \times 132°/360°$

where

$t_{\text{arc min}}$ is the minimum arcing time obtained from one or more additional tests;

T is one period of the power frequency;

132° is the arcing window of last-pole-to-clear – $d\alpha$ = (60°+90°) − 18°.

It is necessary to establish the minimum arcing time $t_{arc\ min}$ before starting the above sequence. The minimum arcing time may be known from previous testing by using an additional test object clearly identified as the same type or may be found as part of the test. The minimum arcing time 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°. Visual inspection shall show that re-ignition occurred between arcing contacts.

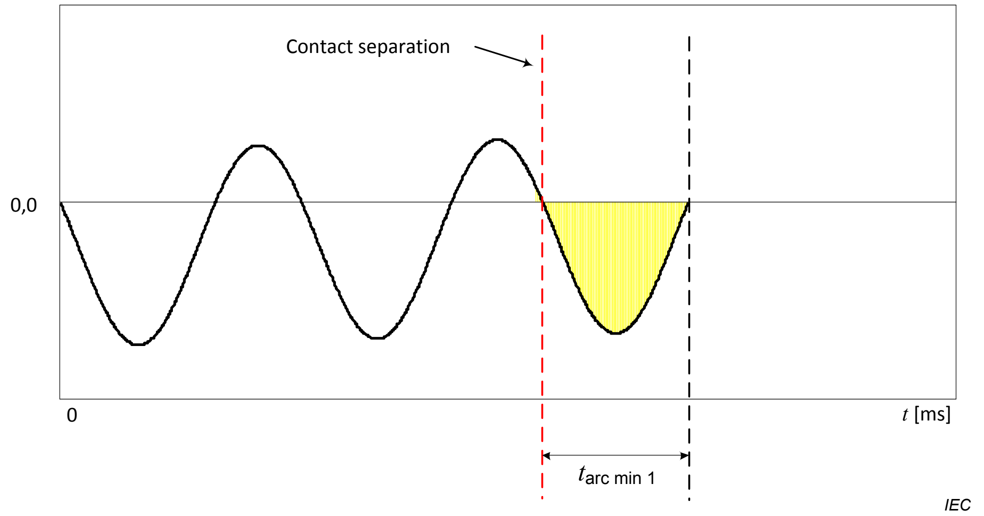
6.102.10.3.3 Single-phase asymmetrical breaking operations

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 as per a) and b) in 6.102.10.2.3. The recommended test procedure for single-phase testing is derived from the three-phase test procedure.

The following asymmetry criteria shall be fulfilled by the prospective current waveform when performing test-duty 2 and test-duty OP2:

- last current loop peak;
- last current loop duration (for the first-pole-to-clear conditions only);
- d.c. component at current zero (parameter controlling the di/dt and the resulting TRV parameters).

Before the first valid opening operation it is necessary to establish the minimum arcing time $t_{arc\ min\ 1}$ derived from a phase with intermediate asymmetry level after a major loop in a three-phase system (Figure 22). Parameters for this intermediate major loop are given in Table 12 for 50 Hz and in Table 13 for 60 Hz. This minimum arcing time may be known from previous testing by using an additional test object clearly identified as the same type or may be found as part of the tests. The minimum arcing time $t_{arc\ min\ 1}$ is established when any 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° ($d\alpha$) (Figure 26). Visual inspection shall show that re-ignition occurred between arcing contacts.



Contact separation is set to achieve the minimum arcing time after a major loop with intermediate asymmetry level

Figure 26 – Single-phase asymmetrical breaking operation – Minimum arcing time with intermediate asymmetry after major loop ($t_{arc\ min\ 1}$)

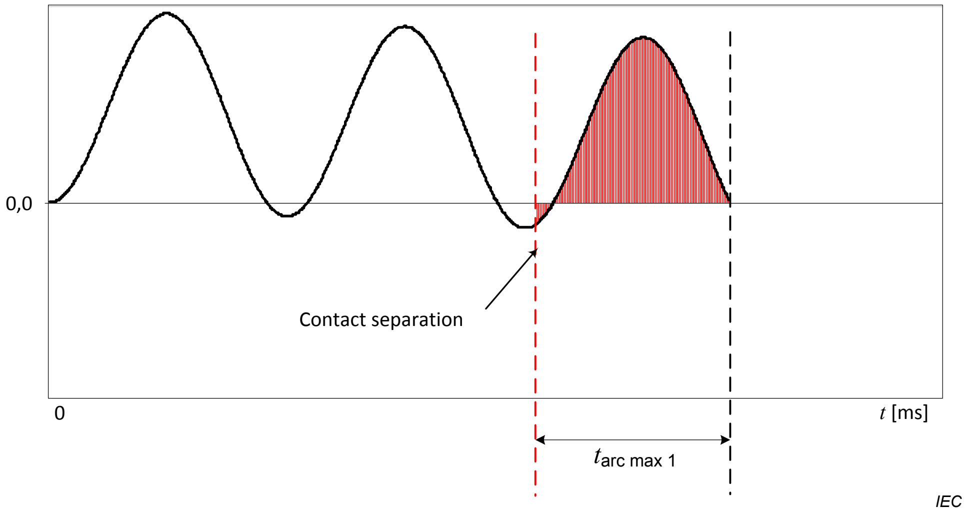
For the first valid opening operation, the initiation of short-circuit and the setting of the control of the tripping impulse shall be such that:

- the required asymmetry criteria for the appropriate major loop are obtained (Figure 27);

– arc extinction occurs with the required asymmetry criteria after a major loop with the maximum arcing time $t_{arc\ max\ 1} = t_{arc\ min\ 1} - T \times d\alpha/360° + \Delta t_1$, with the time interval Δt_1 as given in Table 12 for 50 Hz and in Table 13 for 60 Hz, and with the required maximum asymmetry criteria in order to comply with the TRV requirements for the first-pole-to-clear condition;

– loop parameters of the prospective current as given in Table 12, columns 6, 7 and 9, for 50 Hz and in Table 13, columns 6, 7 and 9, for 60 Hz are fulfilled;

– interruption occurs after a subsequent minor loop if the generator circuit-breaker failed to interrupt after the required major loop.



Contact separation is set to achieve the longest possible arc duration for a first-pole-to-clear at maximum asymmetry criteria after a major loop

Figure 27 – Single-phase asymmetrical breaking operation – Maximum arcing time for the first-pole-to-clear after major loop ($t_{arc\ max\ 1}$)

Before the second valid opening operation it is necessary to establish the minimum arcing time $t_{arc\ min\ 2}$ derived from a phase with intermediate asymmetry level after a minor loop in a three-phase system (Figure 28). Parameters for this intermediate minor loop are given in Table 14 for 50 Hz and in Table 15 for 60 Hz. This minimum arcing time may be known from previous testing by using an additional test object clearly identified as the same type or may be found as part of the tests. The minimum arcing time $t_{arc\ min\ 2}$ is established when any 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) (Figure 28). Visual inspection shall show that re-ignition occurred between arcing contacts.

For the second valid opening operation, the initiation of short-circuit and the setting of the control of the tripping impulse shall be such that:

– the required asymmetry criteria for the appropriate major loop are obtained (Figure 29);

– arc extinction occurs with the required asymmetry criteria after a major loop with the maximum arcing time $t_{arc\ max\ 2} = t_{arc\ min\ 2} - T \times d\alpha/360° + \Delta t_2$, with the time interval Δt_2 as given in Table 14 for 50 Hz and in Table 15 for 60 Hz, and with the required maximum asymmetry criteria in order to comply with the TRV requirements for the last-pole-to-clear condition;

– loop parameters of the prospective current as given in Table 14, columns 6 and 9, for 50 Hz and in Table 15, columns 6 and 9, for 60 Hz are fulfilled;

– interruption occurs after a subsequent minor loop if the generator circuit-breaker failed to interrupt after the required major loop.

NOTE It is recognized that single-phase testing in a direct test circuit to prove the last-poles-to-clear conditions is more severe than in three-phase test circuit because the arcing time of the last-pole-to-clear is used together with the current of the first-pole-to-clear.

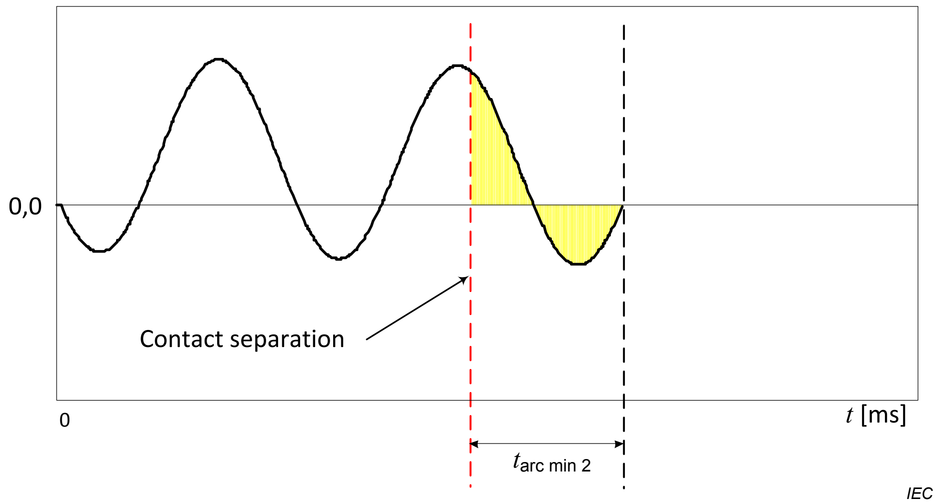
If it is not possible to achieve the requirements a) and b) in 6.102.10.2.3 because of the characteristics of the generator circuit-breaker, the number of breaking operations shall be extended to prove that, in this particular case, the most severe test conditions have been achieved. There are two options to perform additional breaking operations.

Option 1: With the consent of the manufacturer additional breaking operations shall be carried out without reconditioning on the same generator circuit-breaker:

– If during the first two breaking operations according to the preferred procedure neither condition a) nor condition b) were achieved, at least two more breaking operations shall be carried out. The test duty is fulfilled, if among all the four breaking operations each of the two conditions a) and b) are met at least once, while taking into account an enlarged tolerance of ± 2 ms to the required arcing times.
– If during the first two breaking operations according to the preferred procedure only one of the conditions a) and b) was achieved, at least one more breaking operation shall be carried out. If during this additional breaking operation the remaining condition is met, the test duty is fulfilled. If a second additional breaking operation is necessary to prove the remaining condition, then, if among all the four breaking operations the remaining condition was met at least once, while taking into account an enlarged tolerance of ± 2 ms to the required arcing times, the test duty is fulfilled.

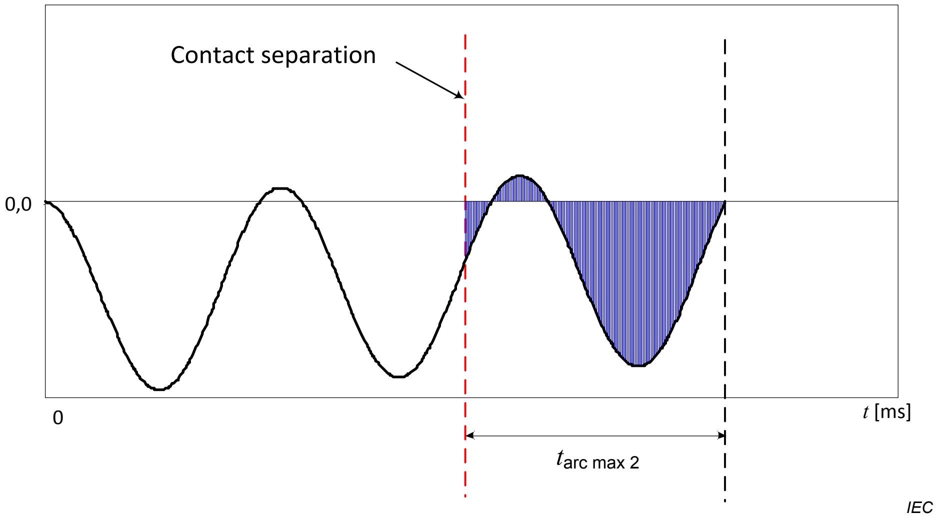
Option 2: The preferred procedure as described above shall be repeated with a reconditioned or a new generator circuit-breaker:

During repetition of the preferred procedure the required conditions a) and b) shall be fulfilled taking into account an enlarged tolerance of ± 2 ms to the required arcing times.



Contact separation is set to achieve the minimum arcing time after a minor loop with intermediate asymmetry level.

Figure 28 – Single-phase asymmetrical breaking operation – Minimum arcing time with intermediate asymmetry after a minor loop ($t_{arc\ min\ 2}$)



Contact separation is set to achieve the maximum arcing time for a last-pole-to-clear at maximum asymmetry criteria after a major loop.

Figure 29 – Single-phase asymmetrical breaking operation – Maximum arcing time for the last-pole-to-clear extended major loop ($t_{arc\ max\ 2}$)

Table 12 – Test parameters for 50 Hz asymmetrical system-source fault test-duties for the first-pole-to-clear

Intermediate major loop					Subsequent major loop in first-pole-to-clear				Time interval
t_1	I_{peak}	Time interval Δt	Degree of asymmetry at current zero	Corresponding di/dt at current zero	I_{peak}	Time interval Δt	Degree of asymmetry at current zero	Corresponding di/dt at current zero	Δt_1
ms	p.u.	ms	%	%	p.u.	ms	%	%	ms
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
32,8	1,39	12,6	37,4	93,6	1,80	15,9	75,3	67,6	4,8
52,6	1,34	12,2	32,3	95,4	1,69	14,9	65,0	77,5	4,5
72,5	1,29	11,9	27,8	96,7	1,59	14,0	56,1	84,1	4,3
92,4	1,25	11,6	23,9	97,7	1,51	13,4	48,4	88,7	4,2
112	1,22	11,4	20,6	98,4	1,44	12,9	41,7	91,9	4,0
132	1,19	11,2	17,7	98,8	1,38	12,5	35,9	94,2	3,9
152	1,16	11,0	15,3	99,2	1,32	12,1	31,0	95,8	3,8
172	1,14	10,9	13,2	99,5	1,28	11,8	26,7	97,0	3,8

Key

t_1 earliest possible interruption in a phase with intermediate level of asymmetry after a major loop (see 3.7.148)

I_{peak} p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt duration of the applicable loop

Δt_1 time interval from current zero in the phase with intermediate degree of asymmetry after a major loop to the subsequent current zero at arc extinction in the appropriate asymmetrical phase resulting in a first-pole-to-clear and major loop

NOTE The test-duties to demonstrate the system-source short-circuit making and breaking current capability are described in Table 16 and Table 17.

Table 13 – Test parameters for 60 Hz asymmetrical system-source fault test-duties for the first-pole-to-clear

Intermediate major loop					Subsequent major loop in first-pole-to-clear				Time interval
t_1	I_{peak}	Time interval	Degree of asymmetry at current zero	Corresponding d*i*/d*t* at current zero	I_{peak}	Time interval	Degree of asymmetry at current zero	Corresponding d*i*/d*t* at current zero	
		Δt				Δt			Δt_1
ms	p.u.	ms	%	%	p.u.	ms	%	%	ms
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
27,4	1,41	10,6	39,3	92,8	1,83	13,6	78,9	63,0	4,1
43,9	1,36	10,3	34,7	94,5	1,73	12,7	69,8	73,0	3,9
60,5	1,32	10,1	30,6	95,8	1,65	12,1	61,7	79,9	3,7
77,1	1,28	9,84	27,0	96,8	1,57	11,6	54,5	84,9	3,6
93,6	1,25	9,66	23,9	97,6	1,50	11,1	48,2	88,6	3,5
110	1,22	9,50	21,1	98,2	1,44	10,8	42,6	91,3	3,4
127	1,19	9,36	18,6	98,6	1,39	10,5	37,6	93,4	3,3
143	1,17	9,24	16,4	99,0	1,35	10,2	33,2	95,0	3,3

Key

t_1 earliest possible interruption in a phase with intermediate level of asymmetry after a major loop (see 3.7.148)

I_{peak} p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt duration of the applicable loop

Δt_1 time interval from current zero in the phase with intermediate degree of asymmetry after a major loop to the subsequent current zero at arc extinction in the appropriate asymmetrical phase resulting in a first-pole-to-clear and major loop

NOTE The test-duties to demonstrate the system-source short-circuit making and breaking current capability are described in Table 16 and Table 17.

Table 14 – Test parameters for 50 Hz asymmetrical system-source fault test-duties for the last-pole-to-clear

Intermediate minor loop					Subsequent major extended loop in last-pole-to-clear				
t_2 ms	I_{peak} p.u.	Time interval Δt ms	Degree of asymmetry at current zero %	Corresponding di/dt at current zero %	I_{peak} p.u.	Time interval Δt ms	Degree of asymmetry at current zero %	Corresponding di/dt at current zero %	Time interval Δt_2 ms
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
26,9	0,56	7,12	42,5	89,5	1,80	17,2	56,8	66,8	12,0
47,1	0,64	7,55	36,5	92,2	1,69	16,2	49,0	72,6	11,4
67,2	0,68	7,90	31,4	94,2	1,59	15,4	42,2	76,6	11,0
87,4	0,72	8,20	27,0	95,6	1,51	14,8	36,4	79,5	10,6
108	0,76	8,46	23,2	96,7	1,44	14,4	31,4	81,5	10,3
128	0,79	8,69	19,9	97,5	1,38	14,0	27,0	82,9	10,0
148	0,82	8,87	17,2	98,1	1,32	13,6	23,3	84,0	9,8
168	0,85	9,03	14,7	98,6	1,28	13,4	20,0	84,7	9,5
188	0,87	9,16	12,7	98,9	1,24	13,1	17,3	85,3	9,3

Key

t_2 earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop (see 3.7.149)

I_{peak} p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt duration of the applicable loop

Δt_2 time interval from current zero in the phase with intermediate degree of asymmetry after a minor loop to the subsequent current zero at arc extinction in the appropriate asymmetrical phase resulting in a last-pole-to-clear and major extended loop

NOTE The test-duties to demonstrate the system-source short-circuit making and breaking current capability are described in Table 16 and Table 17.

Table 15 – Test parameters for 60 Hz asymmetrical system-source fault test-duties for the last-pole-to-clear

	Intermediate minor loop				Subsequent major extended loop in last-pole-to-clear				
t_2 ms	I_{peak} p.u.	Time interval Δt ms	Degree of asymmetry at current zero %	Corresponding di/dt at current zero %	I_{peak} p.u.	Time interval Δt ms	Degree of asymmetry at current zero %	Corresponding di/dt at current zero %	Time interval Δt_2 ms
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
22,4	0,55	5,88	43,7	89,1	1,83	14,6	59,4	64,2	10,2
39,2	0,61	6,18	38,5	91,5	1,73	13,8	52,5	69,9	9,7
56,0	0,65	6,45	34,0	93,4	1,65	13,2	46,4	74,0	9,4
72,8	0,69	6,68	29,9	94,8	1,57	12,7	41,0	77,1	9,1
89,5	0,73	6,88	26,4	95,9	1,50	12,3	36,2	79,4	8,8
106	0,76	7,05	23,3	96,8	1,44	12,0	32,0	81,1	8,5
123	0,79	7,21	20,5	97,5	1,39	11,7	28,2	82,4	8,4
140	0,81	7,34	18,1	98,0	1,35	11,5	24,9	83,4	8,2
157	0,84	7,46	16,0	98,4	1,30	11,3	22,0	84,2	8,0

Key

t_2 earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop (see 3.7.149)

I_{peak} p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt duration of the applicable loop

Δt_2 time interval from current zero in the phase with intermediate degree of asymmetry after a minor loop to the subsequent current zero at arc extinction in the appropriate asymmetrical phase resulting in a last-pole-to-clear and major extended loop

NOTE The test-duties to demonstrate the system-source short-circuit making and breaking current capability are described in Table 16 and Table 17.

6.102.11 Methods of determining prospective transient recovery voltage waves

Assessing the prospective transient recovery voltage characteristics of the circuit shall be done as described in Annex F of IEC 62271-100:2008.

6.103 System-source short-circuit making and breaking tests

6.103.1 Power factor of test circuit

There is no requirement for the power factor of test circuit.

6.103.2 Frequency of test circuit

System-source short-circuit breaking tests shall be performed at rated frequency.

System-source short-circuit making tests performed at 60 Hz are valid for 50 Hz and vice versa.

6.103.3 Earthing of test circuit

The connections to earth of the test circuit for system-source 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.

a) Three-phase tests:

   The generator 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 30a, or vice versa as shown in Figure 30b, if the test can only be made in the latter way.

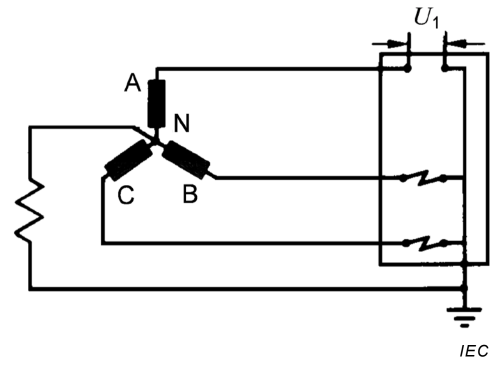
   In accordance with Figure 30a, the neutral of the supply source may be earthed through a resistor, the resistance of which is as high as possible and, expressed in ohms, in no case less than $U/10$, where U is the numerical value in volts of the voltage between lines of the test circuit.

   When a test circuit according to Figure 30b is used, it is recognised that in case of an earth fault at one terminal of the test generator circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through appropriate impedance.

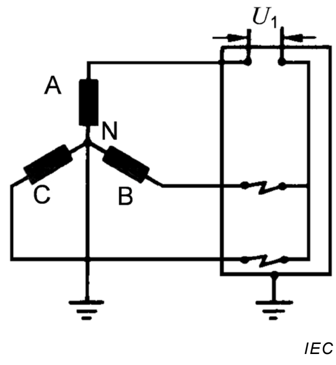
b) Single-phase tests:

   The test circuit and the generator circuit-breaker structure shall be connected as in Figure 31a, 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 generator circuit-breaker if tested in the test circuit shown in Figure 30a.

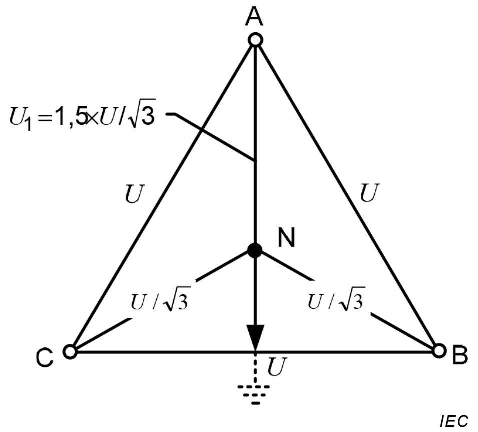
   The preferred test circuit is shown in Figure 31a. Where there are limitations on test station equipment, the circuit shown in Figure 31b may be used if the insulation between phases and/or to earth is not critical. When this insulation is critical, appropriate testing methods are presented in Annex O of IEC 62271-100:2008 and in IEC 62271-101:2012.



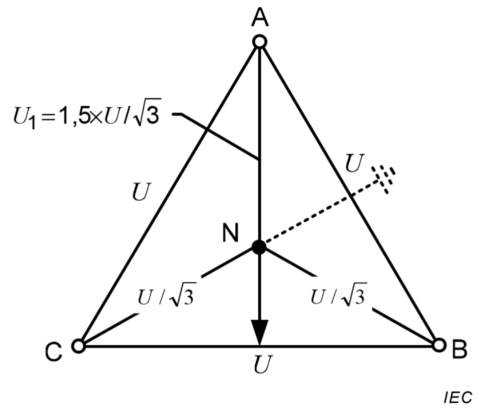
a) Preferred circuit



b) Alternative circuit

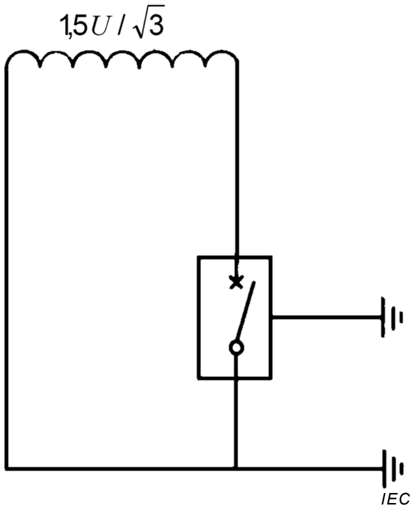


c) Voltage diagram for preferred circuit

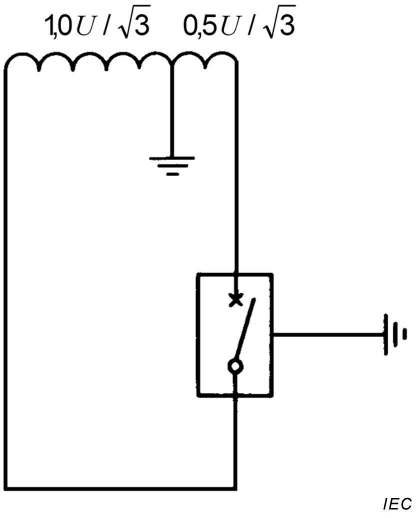


d) Voltage diagram for alternative circuit

Figure 30 – Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1,5



a) Preferred circuit



b) Alternative circuit not applicable for generator circuit-breakers where the insulation between phases and/or to earth is critical

Figure 31 – Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1,5

6.103.4 Connection of test circuit to generator circuit-breaker

Where the physical arrangement of one side of the generator 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 generator circuit-breaker which gives the more severe conditions with respect to voltage to earth, unless the generator circuit-breaker is especially designed for feeding from one side only.

Where it cannot be demonstrated satisfactorily which connection gives the more severe conditions, either of the following is possible:

a) test-duties 1 and 2 according to 6.103.12 shall be made with opposite connections;
b) if a generator-source short-circuit current rating is assigned, the associated test-duties 3, 4, 5, 6A and 6B according to 6.105.12 shall be made with the opposite connection compared to the connection used during test-duties 1 and 2 according to 6.103.12.

6.103.5 Applied voltage for system-source short-circuit making tests

The applied voltage, listed in Tables 16 and 17, shall be as follows:

a) for three-phase tests on a three-pole generator circuit-breaker, the average value of the applied phase-to-phase voltages 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 generator circuit-breaker, the applied voltage shall be not 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, for convenience of testing, a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,5) of the generator circuit-breaker can be applied.

Due to limitations of test facilities it is not always possible to perform the short circuit making tests at rated voltage and rated short-circuit current. Making operations at reduced voltage with a minimum of not less than 50 % of the rated voltage are permissible if the pre-arcing time during making at rated voltage in any phase is not more than 1/10 cycle of the power frequency with a tolerance of 20 %.

The pre-arcing time at rated voltage shall be determined by performing two making tests, one at each polarity, at reduced current. The reduced current shall be low enough to avoid contact erosion.

6.103.6 System-source short-circuit making current

The test quantities are listed in Tables 16 and 17.

6.103.7 System-source short-circuit breaking current

Breaking tests are required with both symmetrical and asymmetrical currents.

The test quantities are listed in Tables 16 and 17 with the following additions:

The short-circuit current to be interrupted by a generator circuit-breaker shall be determined at the instant of contact separation and shall be stated in terms of the following two values:

– the r.m.s. value of the a.c. component averaged over all phases;
– the degree of asymmetry in each phase.

The r.m.s. value of the a.c. component in any phase shall not vary from the average by more than 10 %.

a) Symmetrical breaking current

Any breaking test in which the degree of asymmetry of the current in all phases at contact separation is less than 20 % is considered a symmetrical test.

b) Asymmetrical breaking current

The degree of asymmetry during test duty 2 at contact separation is determined by the following equation:

$$Asy_{\mathrm{cs}} = 100\% \times \mathrm{e}^{\frac{-(t_{\mathrm{opmin}} + t_{\mathrm{r}})}{\tau}}$$

where

Asy_{cs} is the degree of asymmetry at contact separation;

t_{opmin} is the minimum opening time declared by the manufacturer;

t_{r} is the relay time (0,5 cycle; 10 ms for 50 Hz and 8,3 ms for 60 Hz);

τ is the standard d.c. time constant (133 ms, see Figure 11).

The short-circuit current during arcing interval is valid if the following conditions are met:

– the peak of the prospective short-circuit current during the last loop prior to the intended interruption is between 100 % and 110 % of the required value, and
– the duration of the prospective short-circuit current loop prior to the intended interruption is between 90 % and 110 % of the required value.

or if the above tolerances cannot be fulfilled:

– the product of the peak and the duration of the prospective short-circuit current during the last loop prior to the intended interruption is between 100 % and 110 % of the required value.

During synthetic tests the following additional requirements shall be met:

– the peak of the 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.
– the product of the peak and the duration of the short-circuit current during the last loop prior to the interruption is between 90 % and 110 % of the required value.

NOTE 1 These conditions apply only provided that the instant of current initiation is within 10° during both the prospective current calibration and breaking tests.

NOTE 2 For generator circuit-breakers having relatively high arc-voltages, the procedure to obtain the peak and duration of current loop during synthetic tests is explained in Annex A of IEC 62271-101:2010.

6.103.8 Transient recovery voltage (TRV) for system-source short-circuit breaking tests

The prospective circuit TRV (unmodified by the generator circuit-breaker) shall meet the values as listed in Table 3.

For direct testing asymmetrical current-interrupting capabilities shall be demonstrated using test circuits capable of producing the rated TRV envelopes unmodified by the generator circuit-breaker when a symmetrical current is interrupted.

For synthetic testing refer to IEC 62271-101:2012.

6.103.9 Measurement of transient recovery voltage during test

The actual TRV measured during the test may differ from the prospective TRV of the test circuit measured before the test without the generator circuit-breaker present. This is because the generator circuit-breaker itself can influence the TRV due to its resistors and/or capacitors, or other reasons.

The transient recovery voltage during the test shall be recorded.

6.103.10 Power frequency recovery voltage

The test quantities listed in Tables 16 and 17 are the phase-to-earth values.

The power frequency recovery voltage of the test circuit shall not be less than 95 % of the specified value and shall be maintained for at least 0,3 s.

For synthetic test circuits, guidance about details and tolerances is given in IEC 62271-101:2012.

During the single-phase tests, the specified value of $1,5U_r/\sqrt{3}$ shall be maintained for 1 cycle of the power frequency and thereafter may be reduced to $U_r/\sqrt{3}$.

6.103.11 System-source short-circuit test operating sequence

The time intervals between individual operations of a test sequence shall be the time intervals of the standard operating sequence of the generator circuit-breaker, given in 4.106.

Due to test plant limitations, it may not be possible to achieve the 30 min time interval of the rated operating sequence. In such cases the time interval may be extended and the reason for such a delay shall be recorded in the test report. Prolonged time intervals shall not be due to faulty operation of the generator circuit-breaker.

6.103.12 System-source short-circuit test-duties

The basic short-circuit test series shall consist of test-duties 1 and 2 as specified in Tables 16 and 17.

Table 16 – Test duties to demonstrate the system-source short-circuit making and breaking current capability for three-phase tests

Test duty [a,b,c]	Operating sequence	Applied voltage	Making current	System-source short-circuit breaking current at contact separation		Power frequency recovery voltage [i]
				Magnitude	Degree of Asymmetry	
1 [d,e, f, g]	C – 0,25 s – O_{sym} 30 min CO_{sym}	U_r	1st C: $2,74I_{sc}$ 2nd C: -	I_{sc}	< 20 %	$U_r/\sqrt{3}$
1-A [g]	C + 0,25 s	U_r	$2,74I_{sc}$	–	–	–
1-B [f]	$C_{no\text{-}load}O_{sym}$ 30 min CO_{sym}	U_r	–	I_{sc}	< 20 %	$U_r/\sqrt{3}$
2 [h]	$C_{no\text{-}load}O_{asym}$ 30 min $C_{no\text{-}load}O_{asym}$	–	–	I_{sc}	Asy_{cs} [j]	$U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_{sc} r.m.s. value of the a.c. component of the rated system-source short-circuit current of the generator circuit-breaker

Asy_{cs} degree of asymmetry of the short-circuit current at contact separation, see Figure 11.

[a] The test duty sequence is only a suggested sequence. The test duties can be performed in any sequence desired.

[b] No refitting or replacement of parts to the generator circuit-breaker is permitted during each test duty.

[c] If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

[d] The operating sequence can also be reversed to CO_{sym} – 30 min – C – 0,25 s – $O_{sym.}$

[e] Test duty 1 can be replaced by test duties 1-A and 1-B.

[f] The making operation shall occur within ±20° of the peak value of the applied voltage in one of the three phases.

[g] Higher values can be tested if agreed by the manufacturer.

[h] To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

[i] This value applies after current interruption in the last pole.

[j] The degree of asymmetry at contact separation is for reference only. The parameters to be met are I_{peak}, Δt and di/dt. The required values for these parameters are given in Tables 12 through 15.

Table 17 – Test duties to demonstrate the system-source short-circuit making and breaking current capability for single-phase tests

Test duty [a,b,c]	Operating sequence	Applied voltage	Making current	System-source short-circuit breaking current at contact separation		Power frequency recovery voltage [i]
				Magnitude	Degree of Asymmetry	
1 [d,e, f, g]	C_{asym} – 0,25 s – O_{sym} 30 min $C_{sym}O_{sym}$	$U_r/\sqrt{3}$	1st C: $2{,}74I_{sc}$ 2nd C: -	I_{sc}	< 20 %	$(1{,}5)U_r/\sqrt{3}$
1-A [g]	C_{asym} + 0,25 s	$U_r/\sqrt{3}$	$2{,}74I_{sc}$	–	–	–
1-B [f]	$C_{no\text{-}load}O_{sym}$ 30 min $C_{sym}O_{sym}$	$U_r/\sqrt{3}$	–	I_{sc}	< 20 %	$(1{,}5)U_r/\sqrt{3}$
2 [h]	$C_{no\text{-}load}O_{asym}$ 30 min $C_{no\text{-}load}O_{asym}$	–	–	I_{sc}	Asy_{cs} [j]	$(1{,}5)U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_{sc} r.m.s. value of the a.c. component of the rated system-source short-circuit current of the generator circuit-breaker

Asy_{cs} degree of asymmetry of the short-circuit current at contact separation, see Figure 11.

[a] The test duty sequence is only a suggested sequence. The test duties can be performed in any sequence desired.

[b] No refitting or replacement of parts to the generator circuit-breaker is permitted during each test duty.

[c] If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

[d] The operating sequence can also be reversed to $C_{sym}O_{sym}$ – 30 min – C_{asym} – 0,25 s – $O_{sym.}$

[e] Test duty 1 can be replaced by test duties 1-A and 1-B.

[f] The making operation shall occur within ±20° of the peak value of the applied voltage.

[g] Higher values can be tested if agreed by the manufacturer.

[h] To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

[i] For first-pole-to-clear conditions the recovery voltage is $1{,}5U_r/\sqrt{3}$. For last-pole-to-clear conditions the recovery voltage is $U_r/\sqrt{3}$.

[j] The degree of asymmetry at contact separation is for reference only. The parameters to be met are I_{peak}, Δt and di/dt. The required values for these parameters are given in Tables 12 through 15.

6.104 Load current breaking tests

6.104.1 General

Tests are made to determine the ability of the generator circuit-breaker to switch load currents up to the rated continuous current of the generator, such as load currents that may be encountered in normal service.

When switching the generator from the system, both generator circuit-breaker terminals remain energized. The power frequency recovery voltage appearing across the generator circuit-breaker is equal to the sum of voltage drops on the reactances of the generator and transformer and the corresponding short-circuit reactance of the high-voltage system. Since the voltage drops are caused by the load current, the recovery voltage will always have a phase displacement of 90° to the load current and will be independent of the load phase angle of the generator. When switching the rated load current, the voltage drops of a generator-transformer bank generally do not reach 50 % of rated voltage. Therefore, the load switching capability of a generator circuit-breaker could be tested using an inductive short-circuit test circuit as recommended. The test results are valid for any lagging or leading power factors.

6.104.2 Conditions of test severity

Load current switching tests shall be made under the following conditions:

a) The test current shall be the rated continuous current I_r.

b) The test circuit shall be similar to the usual short-circuit test arrangement.

c) Power frequency and transient recovery test voltages shall be based on the rated voltage, U_r.
   - If three-phase tests are made, they shall be made with phase-to-phase voltage equal to $0{,}5U_r$.
   - If single-phase tests are made, the test voltage shall be equal to $0{,}5 \times 1{,}5 \times U_r / \sqrt{3} = 0{,}44U_r$.

d) The TRV rate of the first-pole-to-clear in three-phase tests and for the case of single-phase test circuits shall be as specified in Table 5.

e) The normally earthed parts of the generator circuit-breaker shall be earthed.

f) Either three-phase or single-phase tests can be made.

   If three-phase tests are made, either the neutral of the supply or the short-circuit point shall be earthed, but not both. If single-phase tests are made, the test circuit shall be earthed.

g) The degree of asymmetry at contact separation shall be $<$ 20 %.

h) Tests made at 60 Hz are also valid for 50 Hz and vice versa.

i) Tests shall be made at the minimum interrupting and operating medium pressure and minimum control voltage specified by the manufacturer.

6.104.3 Number of tests

If three-phase tests are made, the test duty shall comprise 3 breaking tests with random uncontrolled times. For single-phase tests, the test duty shall comprise 6 breaking tests where the tripping times are controlled and distributed in steps of approximately 30° with respect to the current wave.

The time interval between two tests shall take into account thermal limitations of parts such as resistors.

6.105 Generator-source short-circuit current making and breaking tests

6.105.1 Power factor of test circuit

There is no requirement for the power factor of test circuit.

6.105.2 Frequency of test circuit

Generator-source short-circuit breaking tests shall be performed at rated frequency. However for test-duties 5, 6A and 6B, tests made at 50 Hz are also valid for 60 Hz but not vice versa.

Generator-source short-circuit making tests performed at 60 Hz are valid for 50 Hz and vice versa.

6.105.3 Earthing of test circuit

The connections to earth of the test circuit for generator-source 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.

a) Three-phase tests:

   The generator 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 30a, or vice versa as shown in Figure 30b, if the test can only be made in the latter way.

   In accordance with Figure 30a, 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 30b is used, it is recognised that in case of an earth fault at one terminal of the test generator circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through appropriate impedance.

b) Single-phase tests:

   The test circuit and the generator circuit-breaker structure shall be connected as in Figure 31a, 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 generator circuit-breaker if tested in the test circuit shown in Figure 30a.

The preferred test circuit is shown in Figure 31a. Where there are limitations on test station equipment, the circuit shown in Figure 31b may be used if the insulation between phases and/or to earth is not critical. When this insulation is critical, appropriate testing methods are presented in Annex O of IEC 62271-100:2008 and in IEC 62271-101:2012.

6.105.4 Connection of the test circuit to the generator circuit-breaker

Where the physical arrangement of one side of the generator 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 generator circuit-breaker which gives the more severe conditions with respect to voltage to earth, unless the generator circuit-breaker is especially designed for feeding from one side only.

Where it cannot be demonstrated satisfactorily which connection gives the more severe conditions, either of the following possibilities shall be performed:

a) in case test-duties 1 and 2 according to 6.103.12 have been made with opposite connections, any side can be connected to perform the test-duties 3, 4, 5, 6A and 6B according to 6.105.12;
b) in case test-duties 1 and 2 according to 6.103.12 have been made with the same connection, the test duties 3, 4, 5, 6A and 6B according to 6.105.12 shall be made with the opposite connection compared to the connection made during test-duties 1 and 2 according to 6.103.12.

6.105.5 Applied voltage for generator-source short-circuit making tests

The applied voltage listed in Tables 18 and 19 shall be as follows:

a) For three-phase tests on a three-pole generator circuit-breaker, the average value of the applied phase-to-phase voltages 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 generator circuit-breaker, the applied voltage shall be not 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, for convenience of testing, a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,5) of the generator circuit-breaker can be applied.

Due to limitations of test facilities it is not always possible to perform the short circuit making tests at rated voltage and rated short-circuit current. Making operations at reduced voltage with a minimum of not less than 50 % of the rated voltage are permissible if the pre-arcing time during making at rated voltage in any phase is not more than 1/10 cycle of the power frequency with a tolerance of 20 %.

The pre-arcing time at rated voltage shall be determined by performing two making tests, one at each polarity, at reduced current. The reduced current shall be low enough to avoid contact erosion.

6.105.6 Generator-source short-circuit making current

The test quantities are listed in Tables 18 and 19.

It is recognized that the peak value of the generator-source short-circuit making current is usually considerably lower than the peak value of the system-source short-circuit making current.

If the peak value of the generator-source short-circuit making current is higher than the peak value of the system-source short-circuit making current then test-duty 3 is required.

6.105.7 Generator-source short-circuit breaking current

6.105.7.1 General

The test quantities are listed in Tables 18 and 19.

The generator-source short-circuit current to be interrupted by a generator circuit-breaker shall be determined at the instant of contact separation and shall be stated in terms of the following two values:

– the r.m.s. value of the a.c. component averaged over all phases;

– the percentage value of the maximum degree of asymmetry in any phase.

6.105.7.2 AC component of generator-source short-circuit breaking current

The r.m.s. value of the a.c. component in any phase shall not vary from the average by more than 10 %.

6.105.7.3 Degree of asymmetry of generator-source short-circuit breaking current

Breaking tests are required with both symmetrical and asymmetrical currents. Any breaking test in which the degree of asymmetry of the current in all phases at contact separation is less than 20 % is considered a symmetrical test.

It is generally accepted that the generator circuit-breaker will be required, during its life, to interrupt short-circuit currents from the generator-source with delayed current zeros. The capability of the generator circuit-breaker to interrupt the current with delayed zero crossings shall be verified by computations that consider the effect of the arc-voltage on the prospective short-circuit current. The arc-voltage model is derived from these tests with comparable magnitudes of current (see 8.103.6.3.6.3).

6.105.8 Transient recovery voltage (TRV) for generator-source short-circuit breaking tests

The prospective circuit TRV (unmodified by the generator circuit-breaker) shall meet the values as listed in Table 4.

6.105.9 Measurement of transient recovery voltage during test

The actual TRV measured during the test may differ from the prospective TRV of the test circuit measured before the test without the generator circuit-breaker present. This is because the generator circuit-breaker itself can influence the TRV due to its resistors and/or capacitors, or other reasons.

The transient recovery voltage during the test shall be recorded.

6.105.10 Power frequency recovery voltage

The test quantities are listed in Tables 18 and 19.

The power frequency recovery voltage of the test circuit shall not be less than 95 % of the specified value and shall be maintained for at least 0,3 s.

For synthetic test circuits, guidance about details and tolerances is given in IEC 62271-101:2012.

During the single-phase tests, the specified values shall be maintained for 1 cycle of the power frequency and thereafter may be reduced to the equivalent single-phase-to-earth voltage.

6.105.11 Generator-source short-circuit test operating sequence

The time intervals between individual operations of a test sequence shall be the time intervals of the standard operating sequence of the generator circuit-breaker, given in 4.106.

Due to test plant limitations, it may not be possible to achieve the 30 min time interval of the rated operating sequence. In such cases the time interval may be extended and the reason for such a delay shall be recorded in the test report. Prolonged time intervals shall not be due to faulty operation of the generator circuit-breaker.

6.105.12 Generator-source short-circuit breaking test-duties

6.105.12.1 General

The test series shall include test-duties as specified in Tables 18 and 19.

6.105.12.2 Making test-duty

The making test shall be performed according to test duty 3. Tests made at 60 Hz are also valid for 50 Hz and vice versa.

6.105.12.3 Symmetrical current breaking test-duty

The symmetrical current breaking tests shall be performed according to test-duty 4.

6.105.12.4 Asymmetrical current breaking test-duties

The asymmetrical current breaking tests shall be performed according to test-duties 5 and 6A for class G1 generator circuit-breakers or according to test-duty 6B for G2 class generator circuit-breakers.

For test-duty 5 the test procedure shall include a prospective test current waveform where the r.m.s. value of the a.c. component of this current is I_{scg} and current peaks and relative minimums until the first current zero crossing shall be recorded. The prospective test current waveform shall have a minimum of three full cycles before the first current zero occurs in order to show two relative minimums without zero crossing (see Figure 32).

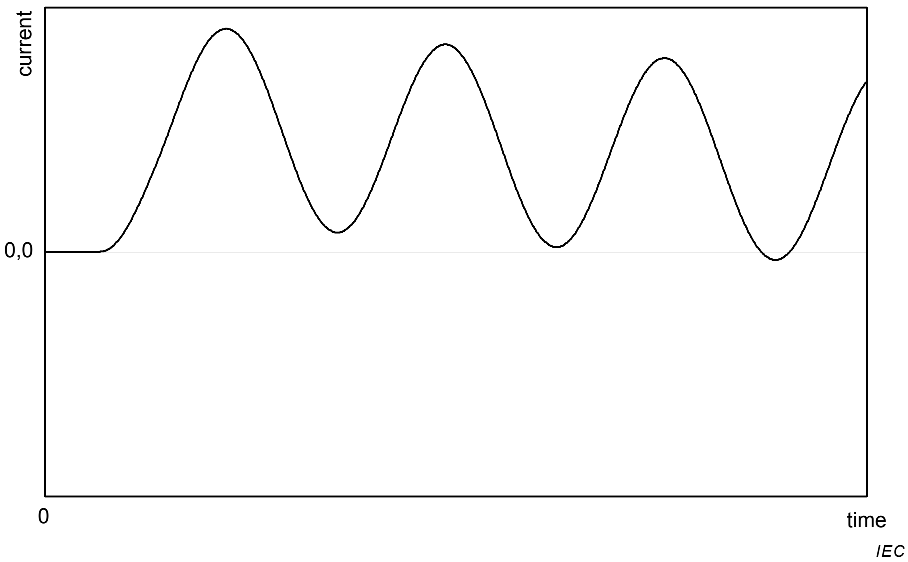


Figure 32 – Example of a valid prospective test current for test-duty 5

The contact separation shall occur not later than 1,5 cycles before the first current zero of the prospective current. This setting shall result in the required degree of asymmetry at contact separation and in an arcing time of at least one full cycle. Figure 33 shows an example of a valid test and Figure 34 shows an example of an invalid test.

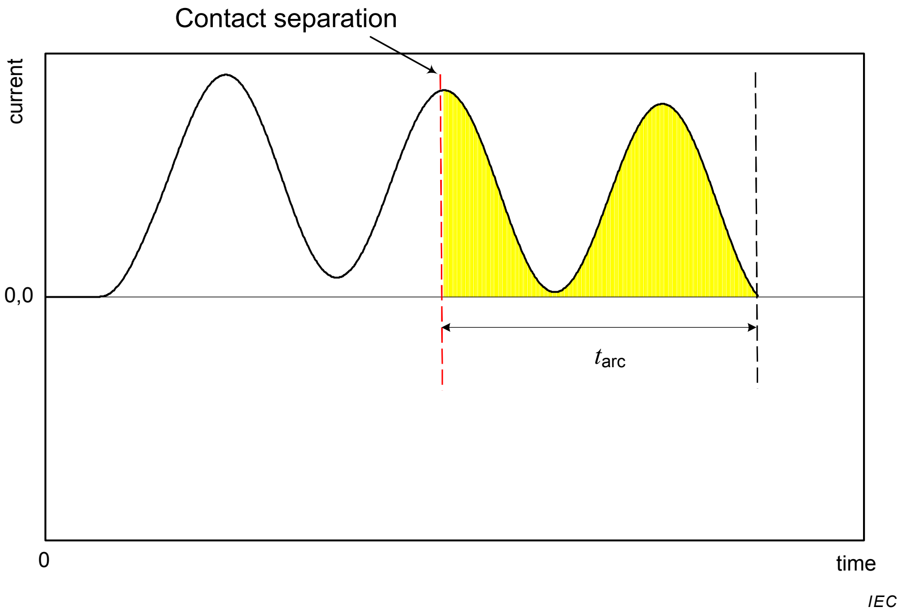


Figure 33 – Example of a valid test for test-duty 5

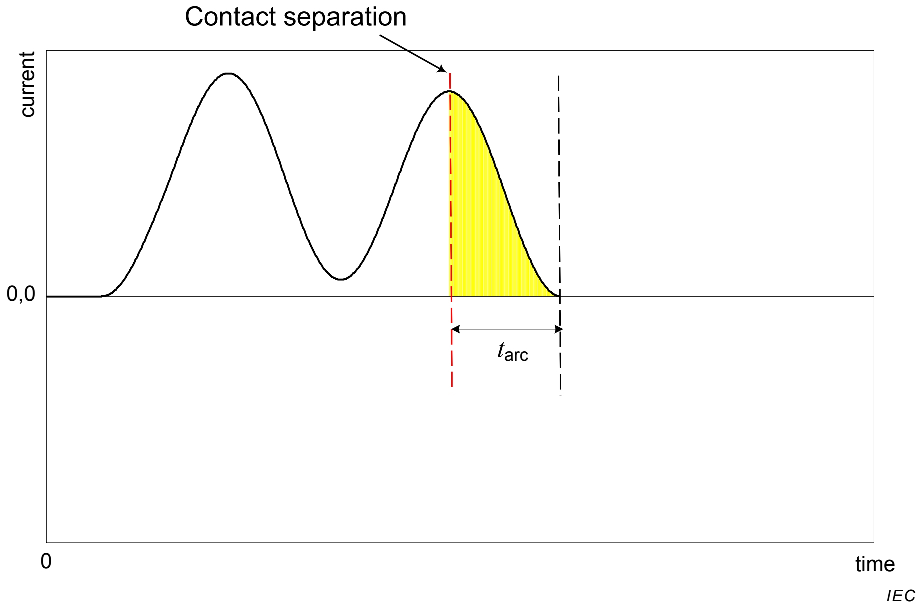


Figure 34 – Example of an invalid test for test-duty 5

In the case of an invalid test as per Figure 34, contact separation shall be advanced by 180 electrical degrees. The resulting arcing time shall be at least one full cycle. Figure 35 shows an example of a valid test in this case.

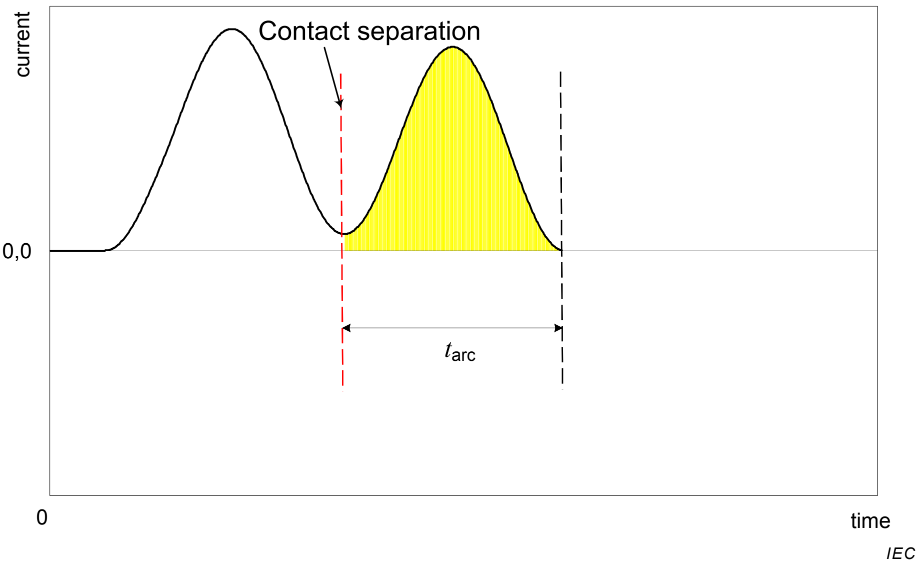


Figure 35 – Second example of a valid test for test-duty 5

For test-duties 6A and 6B the test procedure shall include a prospective test current waveform where the r.m.s. value of the a.c. component of this current is 0,74 I_{scg} for test-duty 6 A and I_{scg} for test-duty 6B respectively and current peaks and relative minimums until the first current zero crossing shall be recorded. The prospective test current waveform shall have three full cycles before the first current zero occurs in order to show two relative minimums without zero crossing (see Figure 36).

NOTE With the manufacturer's consent the number of full cycles before the first current zero occurs can be increased.

The contact separation shall occur not later than 2,6 cycles before the first current zero of the prospective current. This setting shall result in the required degree of asymmetry at contact separation and in an arcing time of at least 1,5 cycles. Figure 37 and Figure 38 show examples of valid tests.

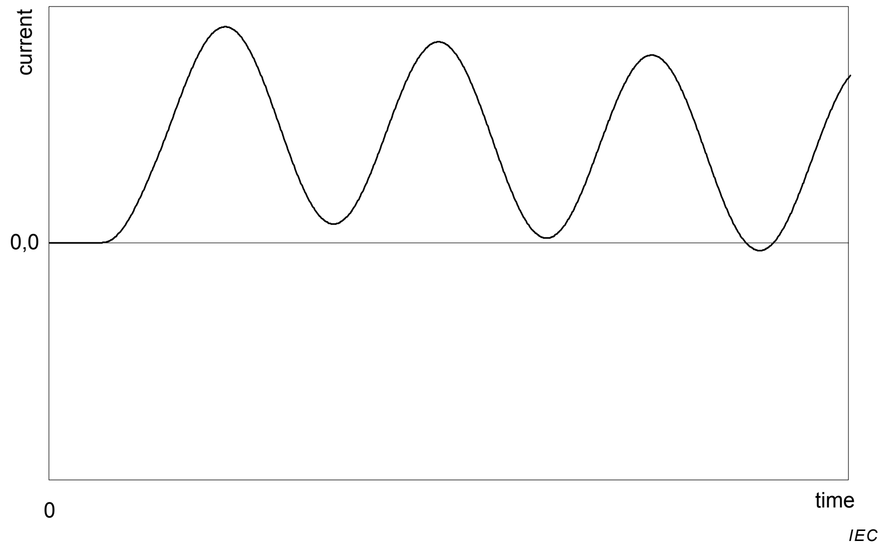


Figure 36 – Example of a valid prospective test current for test-duties 6A and 6B

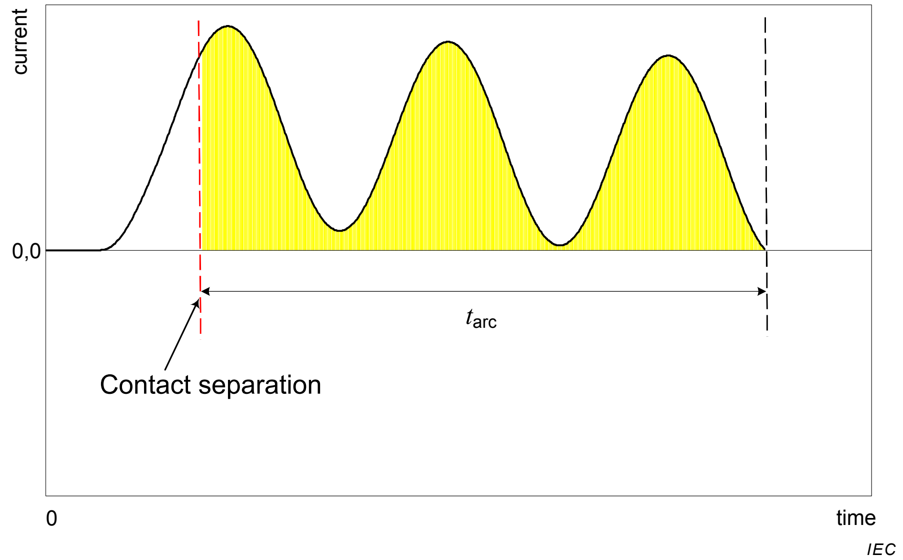


Figure 37 – Example of a valid test for test-duties 6A and 6B

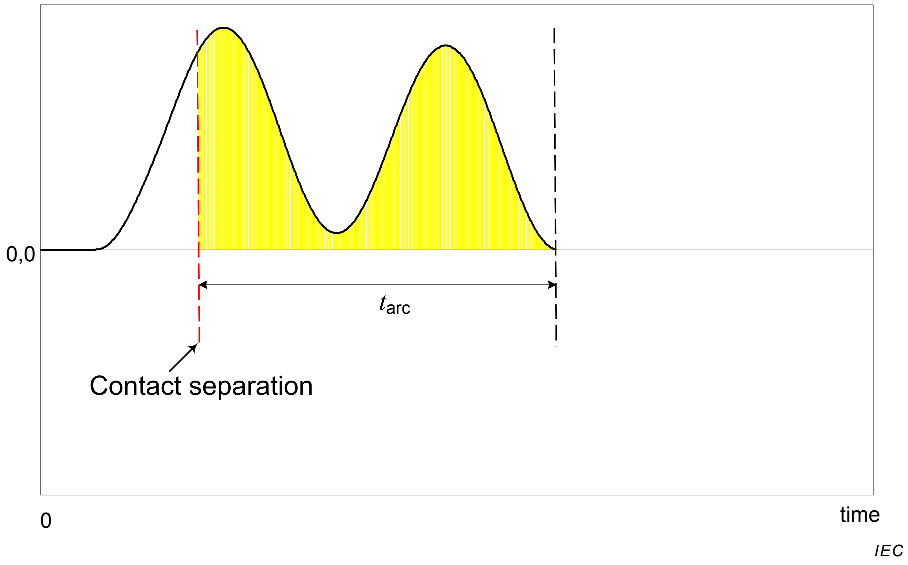


Figure 38 – Example of a valid test for test-duties 6A and 6B

The degree of asymmetry at contact separation shall be recorded.

Table 18 – Test duties to demonstrate the generator-source short-circuit making and breaking current capability for three-phase tests

Test duty [a,b,c]	Operating sequence	Applied voltage	Making current	Generator-source short-circuit breaking current at contact separation		Power frequency recovery voltage [n]
				Magnitude	Degree of asymmetry	
3 [d]	C + 0,25 s	U_r	I_{MC}	–	–	–
4	$C_{no\text{-}load}O_{sym}$ and $C_{no\text{-}load}O_{sym}$	–	–	I_{scg}	< 20 %	$U_r/\sqrt{3}$
5 [f, h, j, m]	$C_{no\text{-}load}O_{asym}$	–	–	I_{scg}	≥ 110 % [g]	$U_r/\sqrt{3}$ [e]
6A [f, i, k, m]	$C_{no\text{-}load}O_{asym}$	–	–	$0{,}74I_{scg}$	≥ 130 % [g]	$U_r/\sqrt{3}$ [e]
6B [f, h, l, m]	$C_{no\text{-}load}O_{asym}$	–	–	I_{scg}	≥ 130 % [g]	$U_r/\sqrt{3}$ [e]

Key

U_r rated voltage of the generator circuit-breaker

I_{scg} r.m.s. value of the a.c. component of the rated generator-source short-circuit breaking current of the generator circuit-breaker

[a] The test duty sequence is only a suggested sequence. The test duties can be performed in any sequence desired.

[b] No refitting or replacement of parts to the generator circuit-breaker is permitted during each test duty.

[c] If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

[d] Test duty 3 is not required if I_{MC} has already been proven in test-duty 1 or 1-A.

[e] Due to limitations of test facilities it is not always possible to perform the breaking operations at rated voltage and rated short-circuit current. Breaking operation at reduced recovery voltage with a minimum of not less than 50 % of the rated voltage is permissible.

[f] For practical reasons this test is normally performed as a single-phase test.

[g] This value is determined from the prospective current.

[h] A prospective test is required at 100 % of I_{scg}.

[i] A prospective test is required at 74 % of I_{scg}.

[j] Test-duty 5 is mandatory for class G1 generator circuit-breakers but not mandatory for class G2 generator circuit-breakers as it is covered by test-duty 6B.

[k] Test-duty 6A is mandatory only for class G1 generator circuit-breakers.

[l] Test-duty 6B is mandatory only for class G2 generator circuit-breakers.

[m] To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

[n] This value applies after current interruption in the last pole.

Table 19 – Test duties to demonstrate the generator-source short-circuit making and breaking current capability for single-phase tests

Test duty [a,b,c]	Operating duty	Applied voltage	Making current	Generator-source short-circuit breaking current at contact separation		Power frequency recovery voltage
				Magnitude	Degree of asymmetry	
3 [d]	C + 0,25 s	$U_r/\sqrt{3}$	I_{MC}	–	–	–
4	$C_{no-load}O_{sym}$ and $C_{no-load}O_{sym}$	$U_r/\sqrt{3}$	–	I_{scg}	< 20 %	$(1,5)U_r/\sqrt{3}$ [m]
5 [g, i, l]	$C_{no-load}O_{asym}$	–	–	I_{scg}	≥ 110 % [f]	$U_r/\sqrt{3}$ [e]
6A [h, j, l]	$C_{no-load}O_{asym}$	–	–	$0,74I_{scg}$	≥ 130 % [f]	$U_r/\sqrt{3}$ [e]
6B [g, k, l]	$C_{no-load}O_{asym}$	–	–	I_{scg}	≥ 130 % [f]	$U_r/\sqrt{3}$ [e]

Key

U_r rated voltage of the generator circuit-breaker

I_{scg} r.m.s. value of the a.c. component of the rated generator-source short-circuit current of the generator circuit-breaker

a The test duty sequence is only a suggested sequence. The test duties can be performed in any sequence desired.

b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test duty.

c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

d Test duty 3 is not required if I_{MC} has already been proven in test-duty 1 or 1-A.

e Due to limitations of test facilities it is not always possible to perform the breaking operations at rated voltage and rated short-circuit current. Breaking operation at reduced recovery voltage with a minimum of not less than 50 % of the rated voltage is permissible.

f This value is determined from the prospective current.

g A prospective test is required at 100 % of I_{scg}.

h A prospective test is required at 74 % of I_{scg}.

i Test-duty 5 is mandatory for class G1 generator circuit-breakers but not mandatory for class G2 generator circuit-breakers as it is covered by test-duty 6B.

j Test-duty 6A is mandatory only for class G1 generator circuit-breakers.

k Test-duty 6B is mandatory only for class G2 generator circuit-breakers.

l To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

m For first-pole-to-clear conditions the recovery voltage is $1,5U_r/\sqrt{3}$. For last-pole-to-clear conditions the recovery voltage $U_r/\sqrt{3}$.

6.106 Out-of-phase making and breaking tests

6.106.1 General

The out-of-phase conditions are abnormal circuit conditions due to loss or lack of synchronism between generator and power system at the instant of operation of the generator circuit-breaker. The phase angle difference between rotating phasors representing the generated voltages on each side of the generator circuit-breaker may exceed the normal value and may be as much as 180°. The out-of-phase current resulting from this condition is dependent on this phase angle and attains its maximum value at 180° (phase opposition). If the sum of the short-circuit reactances of transformer and network on the transformer side of the circuit-breaker is less than the generator short-circuit reactance, the out-of-phase current at full phase opposition would exceed the generator substransient short-circuit current I''_d resulting from a terminal short-circuit. The resulting electrodynamic overstress for the generator windings shall be prevented from occurring by adequate measures such as preventing incorrect synchronization.

The majority of generator circuit-breakers are expected to close but not to interrupt under full phase opposition conditions. Only generator circuit-breakers having full interrupting capability (to clear short-circuit currents on either side of the circuit-breaker) could have an assigned out-of-phase current switching rating. The rating is limited as outlined in Tables 20 and 21 and as described in 6.106.2 and 6.106.3.

When out-of-phase current switching is a matter of special importance and the user specifies the generator circuit-breaker for full-phase opposition capability, a special generator circuit-breaker may be required with an interrupting rating often exceeding rated short-circuit current interrupting capability, especially with the following:

a) power frequency recovery voltage of U_r and with transient recovery voltage to be computed for the first-pole-to-clear;
b) phase opposition current having a magnitude between the system-source short-circuit current and generator-source short-circuit current. The value shall be computed for each individual installation.

6.106.2 Out-of-phase current switching capability

Out-of-phase current switching capability is specified in terms of the following:

a) The maximum value of the out-of-phase recovery voltage for the first-pole-to-clear. This value implicitly defines the maximum out-of-phase angle at which the generator circuit-breaker shall be capable of switching under certain prescribed conditions. If a generator circuit-breaker has an assigned out-of-phase current switching rating, it is based on an out-of-phase angle of 90° at rated voltage.
b) The maximum out-of-phase current that the generator circuit-breaker shall be capable of switching at the maximum out-of-phase recovery voltage specified. The value of the assigned out-of-phase current switching rating shall be 50 % of the symmetrical system-source short-circuit current.

6.106.3 Conditions of test severity

The out-of-phase current switching tests shall be carried out under the following conditions of severity:

a) opening and closing operations carried out in conformity with the instructions given by the manufacturer for the operation and proper use of the generator circuit-breaker and its auxiliary equipment;
b) earthing condition of generator neutral: not effectively earthed, thus, the recovery voltage for the first-pole-to-clear will be $\sqrt{2} \times 1{,}5 \times U_r/\sqrt{3} = 1{,}22\ U_r$ corresponding to an out-of-phase angle of 90°;
c) absence of a fault on either side of the generator circuit-breaker;
d) tests performed at 60 Hz are acceptable for 50 Hz, provided the arcing window for 50 Hz is covered.
e) synthetic tests performed at 50 Hz, but where the injection current of the synthetic circuit represents 60 Hz, are acceptable for 50 Hz and for 60 Hz applications;
f) tests and further conditions of severity are outlined in Tables 20 and 21.

Table 20 – Test duties to demonstrate the out-of-phase current switching capability for three-phase tests

Test duty [a,b,c]	Operating duty	Applied voltage	Out-of-phase breaking current at contact separation		Power frequency recovery voltage [h]
			Magnitude	Degree of Asymmetry	
OP1 [d, f]	CO_{sym} – 30 min – CO_{sym}	$\sqrt{2}U_r$	I_d	< 20 %	$\sqrt{2}U_r/\sqrt{3}$
OP2 [e, g]	$C_{no\text{-}load}O_{asym}$ – 30 min – $C_{no\text{-}load}O_{asym}$	-	I_d	75 % [i]	$\sqrt{2}U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_d r.m.s. value of the a.c. component of the rated out-of-phase breaking current of the generator circuit-breaker

[a] The test duty sequence is only a suggested sequence. The test duties can be performed in any sequence desired.

[b] No refitting or replacement of parts to the generator circuit-breaker is permitted during each test duty. Refitting or replacement of parts to the generator circuit-breaker is permitted between test duties 1 and 2.

[c] If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

[d] procedure is given in 6.102.10.2.2

[e] procedure is given in 6.102.10.2.3

[f] In one of the two operations making shall occur within ±20° of the peak value of the applied voltage in one phase of the three-phase tests.

[g] To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

[h] This value applies after current interruption in the last pole.

[I] 75 % is for reference only. The parameters to be met are I_{peak}, Δt and di/dt. The required values for these parameters are given in the second rows of Tables 12 through 15.

Table 21 – Test duties to demonstrate the out-of-phase current switching capability for single-phase tests

Test duty [a,b,c]	Operating duty	Applied voltage	Out-of-phase breaking current at contact separation		Power frequency recovery voltage [d]
			Magnitude	Degree of Asymmetry	
OP1 [e, g]	CO_{sym} – 30 min – CO_{sym}	$\sqrt{2}U_r/\sqrt{3}$	I_d	< 20 %	$(1,5)\sqrt{2}U_r/\sqrt{3}$
OP2 [f, h]	$C_{no\text{-}load}O_{asym}$ – 30 min – $C_{no\text{-}load}O_{asym}$	–	I_d	75 % [i]	$(1,5)\sqrt{2}U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_d r.m.s. value of the a.c. component of the rated out-of-phase breaking current of the generator circuit-breaker

[a] The test duty sequence is only a suggested sequence. The test duties can be performed in any sequence desired.

[b] No refitting or replacement of parts to the generator circuit-breaker is permitted during each test duty. Refitting or replacement of parts to the generator circuit-breaker is permitted between test duties 1 and 2.

[c] If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

[d] For first-pole-to-clear conditions the recovery voltage is $1,5\sqrt{2}U_r/\sqrt{3}$. For last-pole-to-clear conditions the recovery voltage $\sqrt{2}U_r/\sqrt{3}$.

[e] procedure is given in 6.102.10.3.2

[f] procedure is given in 6.102.10.3.3

[g] In one of the two operations making shall occur within ±20° of the peak value of the applied voltage.

[h] To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

[i] 75 % is for reference only. The parameters to be met are I_{peak}, Δt and di/dt. The required values for these parameters are given in the second rows of Tables 12 through 15.

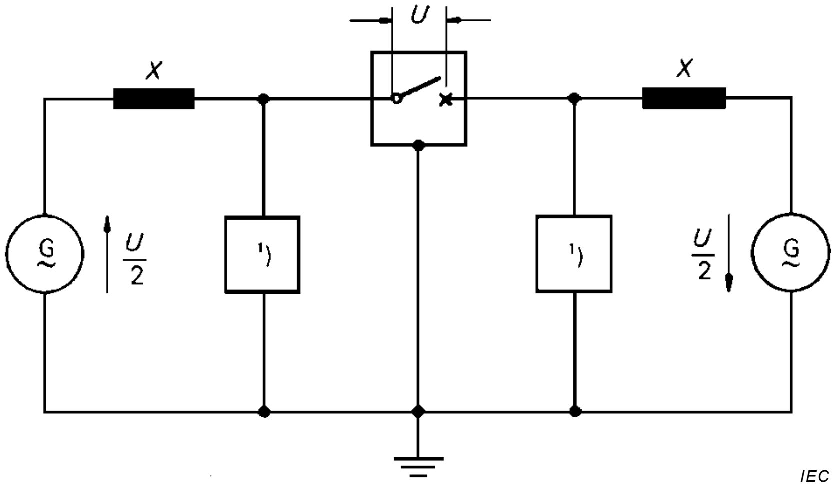
6.106.4 Test circuit

The following condition shall be satisfied:

For single-phase tests, the test circuit shall be arranged so that approximately one-half of the applied voltage and the recovery voltage is on each side of the generator circuit-breaker (see Figure 39).

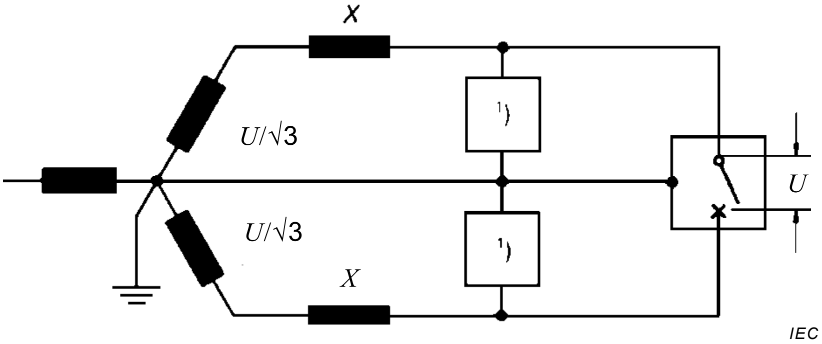
If it is not feasible to use this circuit in the testing station, it is permissible to use either of the following circuits shown in Figure 40 and Figure 41 at the option of the manufacturer:

1) Two identical voltages separated in phase by 120° instead of 180° may be used provided that the total voltage across the generator circuit-breaker is as stated in Table 21 (see Figure 40).
2) Tests with one terminal of the generator circuit-breaker earthed may be used (see Figure 41).



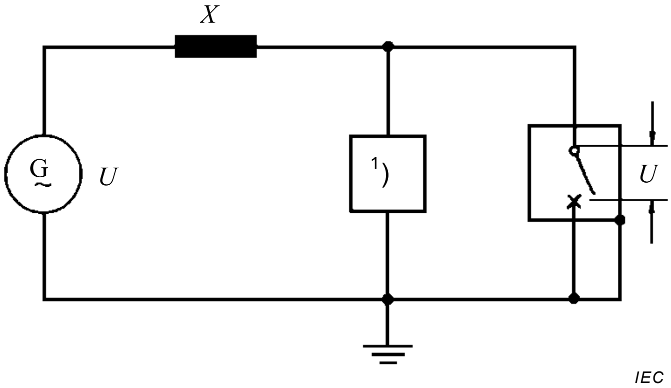
1) The squares represent combinations of capacitances and resistances.

Figure 39 – Test circuit for single-phase out-of-phase tests



1) The squares represent combinations of capacitances and resistances.

Figure 40 – 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 41 – Test circuit for out-of-phase tests with one terminal of the generator circuit-breaker earthed (subject to agreement of the manufacturer)

6.106.5 Applied voltage before out-of-phase making tests

The test quantities are listed in Tables 20 and 21 where the applied voltage shall be as follows:

a) For three-phase tests on a three-pole generator circuit-breaker, the average value of the applied voltages phase-to-phase shall not be less than $\sqrt{2}\ U_r$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

b) For single-phase tests on a three-pole generator circuit-breaker, the applied voltage shall not be less than the phase-to-earth value $\sqrt{2}\ U_r/\sqrt{3}$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

NOTE For convenience of testing the applied voltage can be increased with the agreement of the manufacturer to 1,5 $U_r\sqrt{2}/\sqrt{3}$.

Due to limitations of test facilities it is not always possible to perform the making operations at appropriate voltage and rated out-of-phase current. Making operations at reduced applied voltage with a minimum of not less than 50 % of the appropriate voltage are permissible if the pre-arcing time during making at appropriate voltage in any phase is not more than 1/10 cycle of power frequency with a tolerance of 20 %. The pre-arcing time at appropriate voltage shall be determined by performing two making tests, one at each polarity, at reduced current. The reduced current shall be low enough to avoid contact erosion.

6.106.6 Transient recovery voltage (TRV) for out-of-phase breaking tests

The prospective circuit TRV (unmodified by the generator circuit-breaker) shall meet the values as listed in Table 6.

6.106.7 Demonstration of the most severe switching conditions during test-duty OP1

The procedure given in 6.102.10.2.2 (three-phase tests) and in 6.102.10.3.2 (single-phase tests) is applicable.

6.106.8 Demonstration of the most severe switching conditions during test-duty OP2

For testing purpose asymmetrical current switching capability test-duty OP2 is based on a time constant of 133 ms.

The procedure given in 6.102.10.2.3 (three-phase tests) and in 6.102.10.3.3 (single-phase tests) is applicable with the following addition:

– the earliest possible interruption is independent from the relay time and the opening time;
– the degree of asymmetry at contact separation is independent from the relay time and the opening time;
– for testing purpose the earliest possible interruption in a phase with intermediate level of asymmetry after a major loop is considered as 52,6 ms for 50 Hz and as 43,9 ms for 60 Hz. The applicable loop parameters are specified in the second row of Table 12 for 50 Hz and in the second row of Table 13 for 60 Hz;
– for testing purpose the earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop is considered as 47,1 ms for 50 Hz and as 39,2 ms for 60 Hz. The applicable loop parameters are specified in the second row of Table 14 for 50 Hz and in the second row of Table 15 for 60 Hz.

7 Routine tests

Clause 7 of IEC 62271-1:2007 is applicable with the following modification:

Routine tests shall be made on the complete generator circuit-breaker. However, when generator circuit-breakers are assembled and shipped as separate units, the routine tests shall be performed on site.

7.1 Dielectric test on the main circuit

Subclause 7.1 of IEC 62271-1:2007 is applicable with the following modifications:

The test voltage shall be the one specified in column (2) of Table 1 of this document.

For generator circuit-breakers having interrupters with one interrupting medium, enclosed in a different insulating fluid, the power frequency withstand voltage test alone may be insufficient to show whether or not either interrupting medium or the insulating medium, has been compromised by a leak that may have developed in the enclosure of the interrupter.

For example, suppose a generator circuit-breaker has vacuum interrupters that are enclosed in an SF_6 filled enclosure. If a leak were to develop allowing SF_6 gas to enter the vacuum interrupter chamber, it could be possible for the interrupters to withstand a power frequency withstand voltage test, but still be unable to clear the rated short-circuit current. In this case, the manufacturer shall advise the user what would be an appropriate way to verify that integrity of the vacuum chamber has not been compromised.

If the generator circuit-breaker is equipped with additional components (e.g. surge arresters, surge capacitors, voltage transformers, etc.), then those components can be disconnected or removed prior to the dielectric test.

7.2 Tests on auxiliary and control circuits

7.2.1 Inspection of auxiliary and control circuits, and verification of conformity to the circuit diagrams and wiring diagrams

Subclause 7.2.1 of IEC 62271-1:2007 is applicable with the following addition.

All resistors and heaters shall be checked either by operation or resistance measurements. All closing, tripping, control valve, and relay coils shall be checked either by resistance measurement or turn counters and shall be within prescribed manufacturing limits.

7.2.2 Functional tests

Subclause 7.2.2 of IEC 62271-1:2007 is applicable with the following addition.

The tests shall be performed with the maximum, minimum and rated values of the supply voltage defined in Table 2.

7.2.3 Verification of protection against electrical shock

Subclause 7.2.3 of IEC 62271-1:2007 is applicable.

7.2.4 Dielectric tests

Subclause 7.2.4 of IEC 62271-1:2007 is not applicable and is replaced with the following:

All control wiring associated with current transformer secondaries and voltage device secondaries shall receive a power frequency withstand voltage test of 2 500 V for 1 min. All other control wiring shall receive a power frequency withstand voltage test of 1 500 V for 1 min.

If the generator circuit-breaker control circuit includes a motor, the motor may be disconnected during dielectric tests on the control circuit and subsequently tested, in place, at its specified dielectric withstand voltage, but at not less than 900 V.

7.3 Measurement of the resistance of the main circuit

Subclause 7.3 of IEC 62271-1:2007 is not applicable.

The d.c. resistance of the current-carrying circuit from terminal to terminal of each pole unit in the closed position shall be measured with at least 100 A flowing in the circuit and shall not exceed the limit set for the rating of the generator circuit-breaker by the manufacturer.

7.4 Tightness test

Subclause 7.4 of IEC 62271-1:2007 is not applicable and is replaced with the following:

Routine tightness tests shall be performed at normal ambient temperature with the assembly filled at the pressure (or density) corresponding to the manufacturer's test practice.

7.4.1 Controlled pressure systems for gas

Subclause 7.4.1 of IEC 62271-1:2007 is applicable.

7.4.2 Closed pressure systems for gas

Subclause 7.4.2 of IEC 62271-1:2007 is not applicable and is replaced with the following:

The purpose of tightness tests is to demonstrate that the absolute leakage rate F does not exceed the specified value of the permissible leakage rate F_p.

Tightness test shall be performed with the same fluid or with helium and under the same conditions as used in service. Where possible, the tests should be performed on a complete system at the rated pressure (or rated density). If this is not practical, the tests may be performed on parts, components or subassemblies. In such cases, the leakage rate of the total system shall be determined by summation of the component leakage rates using the tightness coordination chart TC (refer to Annex E of IEC 62271-1:2007). The possible leakages between subassemblies of different pressures shall also be taken into account.

Only cumulative leakage measurements allow calculation of leakage rates. For this reason, sniffing is not acceptable because it is not cumulative.

The routine test report should include such information as:

– an indication of the calibration of the meters used to detect leakage rates;
– the results of the measurements;
– the test gas.

In general, for the application of an adequate test method, reference is made to IEC 60068-2-17 [30].

7.4.3 Sealed pressure systems

Subclause 7.4.3 of IEC 62271-1:2007 is applicable.

7.4.4 Liquid tightness tests

Subclause 7.4.4 of IEC 62271-1:2007 is applicable.

7.5 Design and visual checks

Subclause 7.5 of IEC 62271-1:2007 is not applicable and is replaced with the following:

The generator circuit-breaker shall be checked to verify its compliance with the order specification.

For example the following items shall be checked if applicable:

– the language and data on the nameplates;
– the values of the resistors and capacitors connected to the main circuit;
– identification of any auxiliary equipment;
– the colour and quality of paint and corrosion protection of metallic surfaces.

7.101 Mechanical operating tests

Mechanical operating tests shall be performed at rated pressure for interruption and insulation and shall include the following:

a) at maximum supply voltage of operating devices and of auxiliary and control circuits and maximum functional pressure for operation of the mechanism (if applicable):
   – five closing operations;
   – five opening operations.
b) at minimum supply voltage of operating devices and of auxiliary and control circuits and minimum functional pressure for operation of the mechanism (if applicable):
   – five closing operations;
   – five opening operations.
c) at rated supply voltage of operating devices and of auxiliary and control circuits and rated filling pressure for operation of the mechanism (if applicable):
   – five close-open operating cycles with the opening mechanism energised by the closing of the main contacts; during these tests, the close control switch shall be held to maintain the close signal to demonstrate that both the anti-pumping and the (electrically) trip-free functions of the control circuit of the generator circuit-breaker are working properly.

Mechanical operating tests shall be made on the complete generator circuit-breaker. However, when generator 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 routine mechanical operating tests shall be performed on site to confirm the compatibility of such separate units and components when assembled as a complete generator circuit-breaker.

For all required operating sequences the following shall be performed and records made:

– measurement of opening and closing times;
– where applicable, measurement of fluid consumption during opening and closing 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 characteristic, as defined in 6.101.1.1, from the instant of contact separation to the end of the contact travel.

The mechanical characteristics can be recorded directly, using a travel transducer or similar device on the generator 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 16. 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 generator 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;

  NOTE A valve is not a rupture disc, but is resettable, so this is not a destructive test.

– operation of electrical, mechanical, pneumatic or hydraulic interlocks and signalling devices;
– where applicable, on rising pressure for insulation and interruption: disappearance of the low-pressure or low-density alarm;
– where applicable, on dropping pressure for insulation and interruption: appearance of low-pressure or low-density alarm;
– operation of anti-pumping device;
– general performance of equipment within the required tolerance of the supply voltage;
– inspection of earthing terminals of the generator circuit-breaker.

If adjustments are required during the mechanical operating tests, the complete test sequence shall be repeated following the adjustments.

8 Guide to the selection of generator circuit-breakers

Clause 8 of IEC 62271-1:2007 is not applicable.

8.101 General

This clause is intended for general use as a guide in the application of a.c. high-voltage generator circuit-breakers. Familiarity with other standards applying to generator circuit-breakers is assumed, and provisions of those standards are indicated herein only when necessary for clarity in describing application requirements. A typical application example is presented in Annex E.

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	8.103.2
Rated insulation level	8.103.3
Rated frequency	8.103.4
Rated normal current	8.103.5
Short-circuit current rating	8.103.6
TRV rating for system-source and generator-source short-circuits	8.103.7
Rated load making and breaking current	8.103.8
Rated out-of-phase making and breaking current	8.103.9
Excitation switching current	8.103.10
Capacitive switching current	8.103.11

For rated characteristics not dealt with in Clause 8, reference should, if applicable, be made to Clause 4.

When selecting a generator circuit-breaker, due allowance should be made for the likely future development of the system as a whole, so that the generator circuit-breaker may be suitable not merely for immediate needs but also for the requirements of the future.

8.102 General application conditions

8.102.1 Normal service conditions

8.102.1.1 General

Normal service conditions for generator circuit-breakers are defined in 2.1.

8.102.1.2 Provisions for system growth

Power system facilities can be increased from time to time to serve larger loads. Although the generator is unlikely to be replaced with a larger generator, system growth usually results in higher values of short-circuit current. Therefore, liberal allowance in the generator circuit-breaker rating for possible future increases in system-source short-circuit current is advisable.

8.102.1.3 System design

Methods for limiting the magnitude of short-circuit currents or reducing the probability of high-current short-circuits by system design are outside the scope of this standard. Such methods should be considered where short-circuit currents approach the maximum capability of the generator circuit-breaker.

8.102.2 Special service conditions

8.102.2.1 General

Special service conditions are listed in 2.2. Special specification, installation, operation, and maintenance provisions should be considered where these conditions are encountered, and should be called to the attention of the manufacturer as necessary.

8.102.2.2 Application at abnormal temperatures

The use of apparatus in ambient temperatures outside the limits of those specified in 2.1 is considered special. In most applications, the generator circuit-breaker is installed as an integral part of the isolated phase bus. Under these conditions, the isolated phase bus cooling directly affects the temperature inside of the enclosed generator circuit-breaker. The ambient temperature and generator circuit-breaker thermal time-constant govern the normal current application described in 4.4.1.

8.102.2.3 Application at altitudes above 1 000 m

The normal service conditions specified in Clause 2 of IEC 62271-1:2007 provide for generator 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 62271-1:2007 is applicable.

The rated short-circuit breaking current at rated voltage, related required capabilities and the rated break-time are not affected by altitude. The rated normal current may have to be corrected and the manufacturer should be consulted.

8.102.2.4 Exposure to damaging fumes or vapors, steam, salt spray, oil spray, excessive moisture, dripping water, and other similar conditions

Equipment subject to such conditions may require the following special construction or protective features:

a) provisions to avoid condensation on all electrical insulation and current-carrying parts;
b) bushings with extra creepage distance;
c) special maintenance, including insulator cleaning in cases where particulate exposure represents a hazard to insulation integrity;
d) the use of materials resistant to fungus growth.

8.102.2.5 Exposure to excessive or abrasive, magnetic, or metallic dust

Equipment subject to such conditions may require the following special construction or protective features:

a) totally enclosed equipment or compartments and provision for conditioned ventilating air;
b) derating where current-carrying equipment designed for ventilated operation is enclosed in a non-ventilated compartment.

8.102.2.6 Exposure to explosive mixtures of dust or gases

Generator circuit-breakers are not designed for use in explosive atmospheres. For this type of service, special consideration should be given so that acceptable equipment is selected.

8.102.2.7 Exposure to abnormal vibration, shock, or tilting

Generator circuit-breakers are designed for mounting on substantially level structures free from excessive vibration, shock or tilting. Where any of these abnormal conditions exist, recommendations for the particular application should be obtained from the manufacturer.

8.102.2.8 Seasonal or infrequent use

Equipment stored or de-energized for long periods, such as during generator maintenance, should be protected against accelerated deterioration. Before energizing for service, operating performance and insulation integrity should be checked.

8.102.2.9 Application of unusual forces

During normal operation, the generator circuit-breaker may be subjected to abnormal thermal and seismic forces, in addition to normal short-circuit current and thermal forces.

Abnormal thermal forces are due to the thermal cycling of connections to the generator circuit-breaker. The application of a generator circuit-breaker, as part of a long rigid bus system, may produce severe compression and tensile forces on generator circuit-breaker connections. Consult the manufacturer for this application.

Applications where seismic forces exceed 0,5 g should be checked with the manufacturer.

8.102.2.10 Application effects of magnetic fields

Occasionally, the busbars in power plants are not enclosed and in general, effects of magnetic fields for generator normal (continuous) current below 6 300 A is usually of no concern. However, the magnetic field in the vicinity of the bus between generator and transformer may have adverse effects on equipment and building steel if the bus current exceeds 6 300 A. For such a case, the manufacturer should be consulted for values of magnetic fields outside of the generator circuit-breaker housing because induced voltages and currents could produce undesired heating effects. For this reason, and to avoid electromagnetic forces between the current-carrying busbars, isolated-phase bus is usually used.

Precautions need to be observed for the following conditions:

a) The difference in the return current through the generator circuit-breaker enclosure and the current flow in the busbar is above 6 300 A.
b) The generator circuit-breaker enclosure external magnetic field plus the magnetic field caused by the difference in current flowing through the enclosure and active part of the generator circuit-breaker is higher than the magnetic field of a 6 300 A current.

These precautions include avoidance of metal connections and/or the placement of metal support structures adjacent to and between generator circuit-breaker poles and bus phases.

8.103 Application consideration

8.103.1 General

In usual applications, the principal function of the generator circuit-breaker is to carry generator rated load current and provide a means for interruption of short-circuit current from the generator as well as from the power system. However, the generator circuit-breaker can be used for load, transformer excitation, or out-of-phase current switching. In some cases, these switching requirements may be the determining factor in the selection of a generator circuit-breaker rather than short-circuit current interruption requirements.

8.103.2 Rated voltage

The maximum operating voltage of the generator cannot exceed the rated voltage of the generator circuit-breaker since this is the generator circuit-breaker’s upper limit for operation.

NOTE The operating voltages of generators with ratings of 200 MVA to 1 500 MVA vary widely, from approximately 10 kV to 27 kV. Consequently, when defining short-circuit duties, the rated voltage is the maximum operating voltage of the generator to which the generator circuit-breaker is connected.

8.103.3 Rated insulation level

The preferred withstand voltage levels are specified for generator circuit-breakers in Table 1. The dielectric performance is required down to the minimum functional pressure for insulation.

In the event of pressure loss of the insulating medium, the loss of dielectric withstand is progressive. If the insulating medium is a gas other than compressed air, the inner parts of the generator circuit-breaker may remain filled with the gas at atmospheric pressure that has higher dielectric properties than the ambient atmospheric air. For a certain time under this circumstance, the generator circuit-breaker is able to withstand more than the operating voltage, even in phase opposition conditions. This time should be used to remove the generator circuit-breaker from service by complete electrical isolation, preferably by automatic means, before any ingress of humidity, dust, or both, has taken place. This electrical isolation should be completed within 1 h of the loss of insulation medium pressure.

Unusual circumstances may exist where, due to operational conditions, a time longer than 1 h is desirable before the generator circuit-breaker is isolated from the source. If such a situation exists, the generator circuit-breaker should be prevented from operating. To provide for this unusual circumstance, the following data should be requested from the manufacturer:

a) withstand voltage-to-earth and across contacts with the insulating medium at atmospheric pressure;
b) the current-carrying capability of the generator circuit-breaker with the insulating medium at atmospheric pressure.

8.103.4 Rated frequency

The rated frequency for generator circuit-breakers is 50 Hz or 60 Hz, depending on the system power frequency in which the generator circuit-breaker is installed.

8.103.5 Rated normal current

8.103.5.1 Application considerations for normal operation

Generator circuit-breakers are usually designed as an integral part of the bus between the generator and transformer. The generator circuit-breaker shall be able to carry the rated normal current of the generator. The metal enclosed bus is usually phase-isolated. In many cases, the generator circuit-breaker is equipped with a cooling system using air or water.

Current-carrying capabilities of generator circuit-breakers under various conditions of ambient temperature and load vary from other high-voltage circuit-breakers. Generator circuit-breakers have two current-carrying parts that have to be considered, i.e. the active part with the interrupting device, and the metal enclosure.

Various parts of the generator circuit-breaker and the connected bus have different temperature limits that are detailed in 4.4.2.

8.103.5.2 Continuous load current-carrying capability based on actual ambient and connected bus temperature

For determining the value of continuous current-carrying capability based on the actual ambient and the connected bus temperature, consult the manufacturer.

If the bus connected to the generator circuit-breaker has a temperature limit at the connection equal to the maximum authorized by IEEE Std C37.23™-2003, it will heat up the generator circuit-breaker in the majority of cases. As a consequence, the generator circuit-breaker continuous current-carrying capability would have to be reduced. An economical compromise shall be found to adapt the current-carrying capability of the bus and the generator circuit-breaker.

8.103.5.3 Emergency conditions

Following the loss of normally required auxiliary forced-cooling systems, the temperature of the generator circuit-breaker parts will increase. For generator circuit-breakers, 4.4.101 establishes the parameters involved. In 6.5.101, the tests for such emergency conditions are explained.

8.103.6 Short-circuit current rating

8.103.6.1 Background of short-circuit current rating

The short-circuit current, which a generator circuit-breaker can experience, is explained by Figure 42, a general diagram of a power station, with a short-circuit shown in the following different locations:

a) the system-source short-circuit current (location a, Figure 42);

b) the generator-source short-circuit current (locations b and c, Figure 42);

(Location b has a higher short-circuit current than location c; therefore location c can be disregarded for the following considerations.)

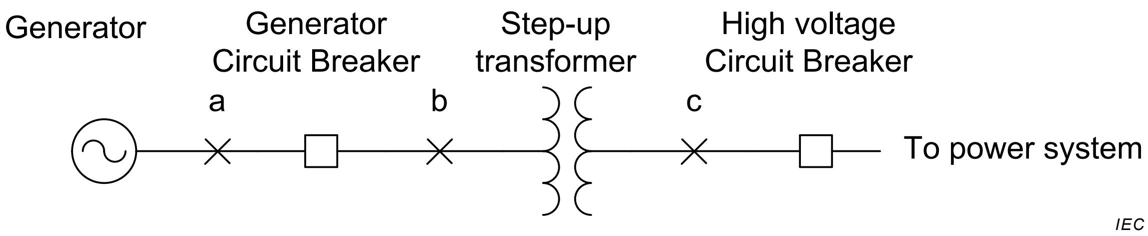


Figure 42 – General circuit diagram of a power station

In most applications, the a.c. component of the system-source short-circuit current is higher than that of the generator-source case because the sum of the short-circuit reactance of the transformer and the system is lower than the subtransient and transient reactances of the generator.

8.103.6.2 Short-circuit current rating

The definition for short-circuit current rating given in 4.101.1 states that it is the r.m.s. value of the a.c. component of the three-phase short-circuit current to which all required short-circuit capabilities are related.

It is to be noted that, if the short-circuit performance capability of a generator circuit-breaker design has been demonstrated for a certain generator-source fault rating, or for a certain system-source fault rating, then that proven short-circuit performance capability also serves to demonstrate the capability for less severe generator-source faults, or for less severe system-source faults. However, it is important to remember that parameters for generator circuit faults include short-time current withstand, transient recovery voltage (TRV), making current, degree of asymmetry and most severe switching conditions, as well as the symmetrical current, for both system-source faults and generator-source faults. Proven capabilities for all of these parameters shall be demonstrated to meet or exceed the respective requirements for the intended application.

8.103.6.3 Related capabilities

8.103.6.3.1 General

The following are related capabilities concerned with the short-circuit current:

a) System-source short-circuit currents:
   – symmetrical interrupting capability;
   – asymmetrical interrupting capability;
   – short-time current-carrying capability.
b) Generator-source short-circuit currents:
   – symmetrical interrupting capability;
   – asymmetrical interrupting capability;
   – asymmetrical interrupting capability for maximum degree of asymmetry.
c) Generator-source or system-source: making capability.

8.103.6.3.2 Symmetrical interrupting capability for three-phase system-source faults

This capability is based on the r.m.s. value of the a.c. component of the rated system-source short-circuit breaking current.

8.103.6.3.3 Asymmetrical interrupting capability for three-phase system-source faults

This capability is based on the rated system-source short-circuit breaking current. Its d.c. component decays with a time constant of 133 ms and depends on the instant contact separation occurs, which is the sum of 1/2 cycle tripping delay plus the minimum opening time of the generator circuit-breaker. It is calculated with the equation below and illustrated by Figure 10. The numerical values are shown in Figure 11.

The degree of asymmetry Asy_{cs} at the time t_{cs} is determined by the following equation:

$$Asy_{\text{cs}} = 100\ \% \times \frac{I_{\text{dccs}}}{I_{\text{accs}}} = \text{degree of asymmetry at contact separation}$$

where

I_{accs} is the peak value of the a.c. component of the rated system-source short-circuit breaking current at contact separation;

I_{dccs} is the d.c. component of the system-source short-circuit breaking current at contact separation and can be calculated as follows:

$$I_{\text{dccs}} = I_{\text{accs}}\, e^{-t_{\text{cs}}/\tau}$$

where

τ is 133 ms.

The asymmetrical interrupting capability is calculated as follows:

$$I_{\text{asymcs}} = \sqrt{I_{\text{sc}}^2 + I_{\text{dccs}}^2} = \sqrt{I_{\text{sc}}^2 + \left(I_{\text{accs}} \times e^{-t_{\text{cs}}/\tau}\right)^2} = \sqrt{I_{\text{sc}}^2 + \left(I_{\text{sc}} \times Asy_{\text{cs}} \times \sqrt{2}\right)^2} = I_{\text{sc}}\sqrt{1 + 2Asy_{\text{cs}}{}^2}$$

In order to assess the capability of the generator circuit-breaker to interrupt a given short-circuit current, provided that the making current does not exceed the rated making current capability, any combination of a.c. and d.c. components is permissible provided that the following conditions are met at the instant of contact separation:

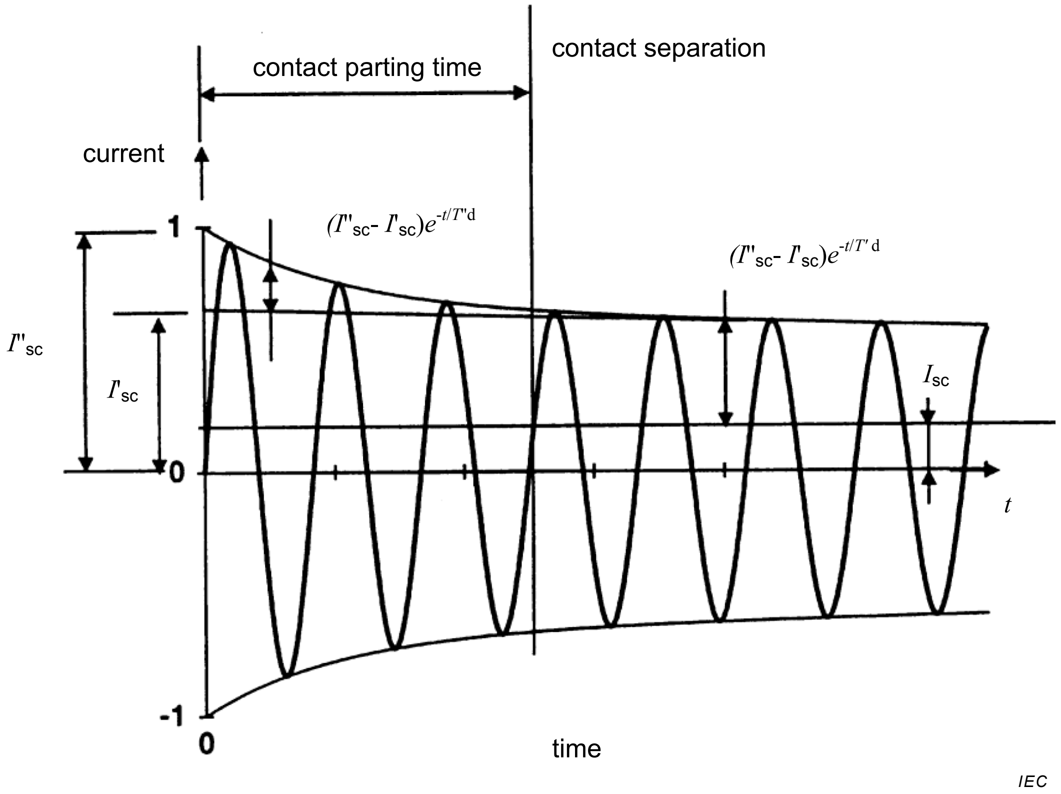
a) the a.c. component does not exceed the a.c. component of the rated system-source short-circuit breaking current;

b) the asymmetrical short-circuit current does not exceed the asymmetrical interrupting capability;

c) the degree of asymmetry does not exceed 100 %.

8.103.6.3.4 Symmetrical interrupting capability for three-phase generator-source faults

The a.c. component of the generator-source short-circuit breaking current can be significantly lower than the system-source short-circuit breaking current. Its value is measured from the envelope of the current excursion at the moment of contact separation when the source of the current is entirely from a generator without transformation. This envelope has to be calculated from a full-load rated power factor condition taking the generator constants into account. It shall be recognized that the a.c. component of this short-circuit current decays with the subtransient and transient time constants of the generator and is illustrated by Figure 43.



Key

I''_{sc} Subtransient component of the generator-source short-circuit

I'_{sc} Transient component of the generator-source short-circuit

I_{sc} Steady state component of the generator-source short-circuit

T''_d Subtransient time constant of the generator

T'_d Transient time constant of the generator

Figure 43 – Generator-source short-circuit current

8.103.6.3.5 Asymmetrical interrupting capability for three-phase generator-source faults

The a.c. component of the short-circuit current, when the source is from a generator without transformation, may decay faster than the d.c. component. The decay of the a.c. component is governed by the subtransient and transient time constants τ'_d, τ''_d, τ'_q, τ''_q of the generator and the decay of the d.c. component by the short-circuit time constant, $\tau_a = X''_d/\omega R_a$, where X''_d is the direct axis subtransient reactance and R_a represents the armature d.c. resistance. As a consequence, the d.c. component at contact separation can be higher than the peak value of the a.c. component. A survey of many generators with different ratings revealed that at full load and with the generator operating in the overexcited mode with a lagging power factor the degree of asymmetry could be even higher than 110 %. This value varies very little within a practical range of contact separation times.

In order to assess the capability of the generator circuit-breaker to interrupt a given short-circuit current, provided that the making current does not exceed the rated making current capability, any combination of a.c. and d.c. components is permissible provided that the following conditions are met at the instant of contact separation:

a) the a.c. component does not exceed the a.c. component of the rated generator-source short-circuit breaking current;

b) the asymmetrical short-circuit current does not exceed the asymmetrical interrupting capability;

c) the degree of asymmetry from the generator-source might exceed 100 % provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time.

The capability of the generator circuit-breaker to force current to zero shall be ascertained by calculations in accordance with 8.103.6.3.6.3.

8.103.6.3.6 Generator-source asymmetrical interrupting capability for maximum degree of asymmetry

8.103.6.3.6.1 General

The highest value of asymmetry occurs when, prior to the fault, the generator is operating in the underexcited mode with a leading power factor. Under this condition, the d.c. component may be higher than the peak value of the a.c. component of the short-circuit current and may lead to delayed current zeros. This principle is illustrated in Figure 44 and explained in 8.103.6.3.6.2 to 8.103.6.3.6.4.

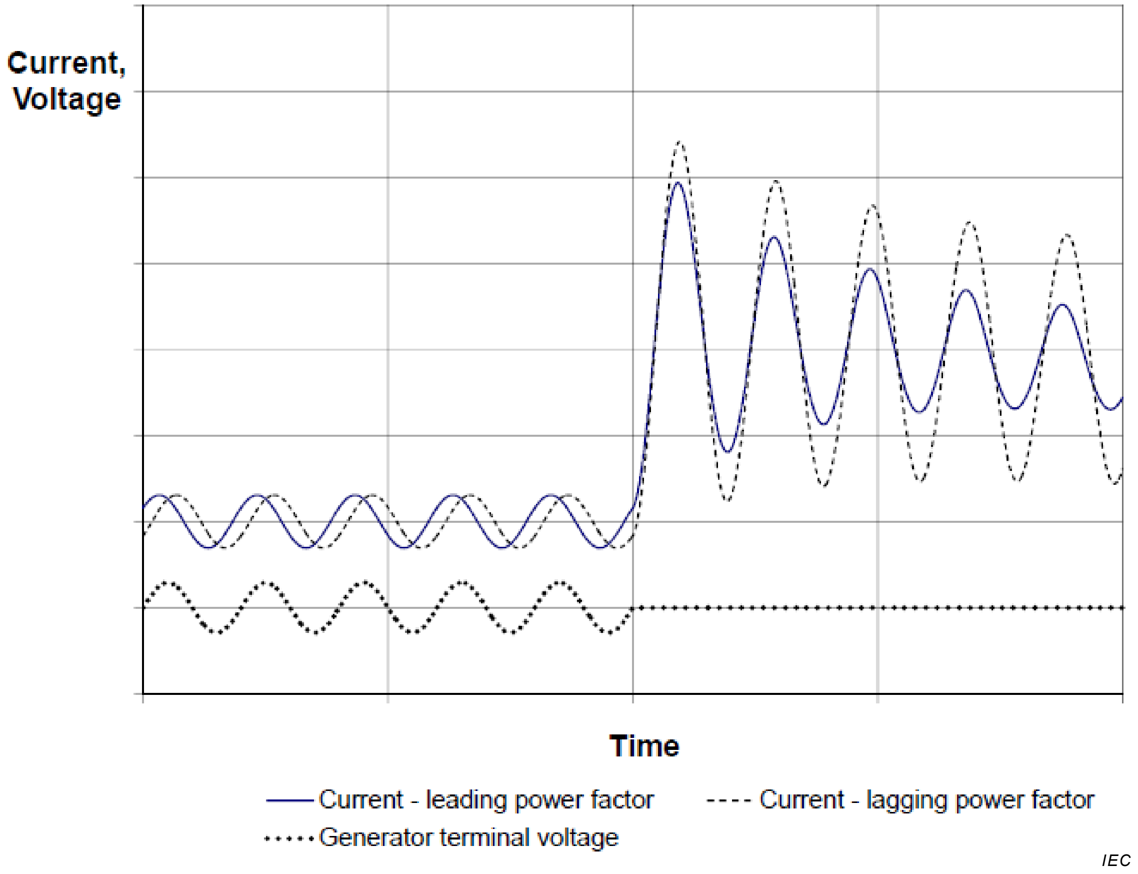


Figure 44 – Generator-source short-circuit current in case of generator delivering power with lagging or leading power factor prior to fault initiation

When a short-circuit occurs, but prior to the fault the generator is carrying load with lagging power factor, the short-circuit current excursion is similar to the dashed curve, whereas for a leading power factor its excursion follows the solid curve in Figure 44.

The analysis of a large number of generators resulted in a degree of asymmetry in the order of 130 %. The a.c. component of the short-circuit current for this case is only 74 % of the assigned a.c. component of the rated generator-source short-circuit breaking current. It is recognized that the degree of asymmetry in some cases can reach very high values and exceed 130 %.

8.103.6.3.6.2 Origin of high asymmetries with delayed current zeros

A short-circuit current will flow if the generator circuit-breaker is closed into a short-circuit or as a consequence of a flashover in at least two phases to earth or between phases. If a short-circuit is initiated at voltage zero in one phase, this implies that the current in the corresponding phase exhibits the maximum degree of asymmetry.

The a.c. component of the short-circuit current will decrease exponentially in time with the short-circuit subtransient and transient time constants τ'_d, τ''_d, τ'_q, τ''_q of the generator, depending on the specific case (often only the open circuit time constants τ'_{d0}, τ''_{d0}, τ'_{q0}, τ''_{q0} are known. For computation of the short-circuit currents, the short-circuit time constants τ'_d, τ''_d, τ'_q, τ''_q can be calculated using relatively simple equations). The d.c. component of the short-circuit current decays exponentially in time, with the short-circuit time constant $\tau_a = X''_d/(2\pi f \times R_a)$. Depending on the value of these time constants, which may vary in a relatively wide range for different sizes and designs of generators, the a.c. component of the short-circuit current may decrease faster than the d.c. component, leading to delayed current zeros for a certain period of time.

Typical values for time constants mentioned in the preceeding paragraph are τ''_d and τ''_q = 25 ms to 45 ms, τ'_d = 0,8 s to 1,5 s, τ'_q = 250 ms to 400 ms, τ_a = 150 ms to 400 ms.

Figure 45 shows an example of a calculation of short-circuit current for a generator-source fault.

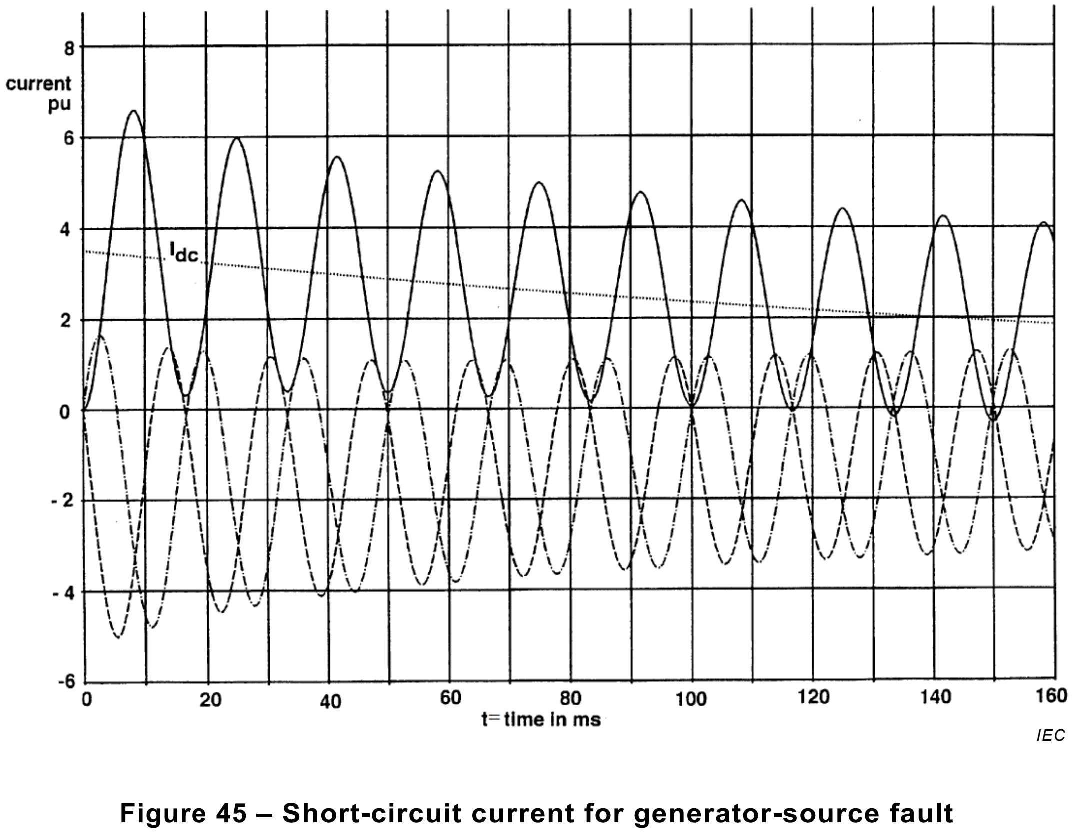


Figure 45 – Short-circuit current for generator-source fault

As described in 8.103.6.3.6, the highest value of asymmetry occurs when, prior to the fault, the generator is operating in the underexcited mode with a leading power factor. Under such a condition, the a.c. component of short-circuit current is lower than the assigned a.c. component of the rated generator-source short-circuit breaking current. In the case where the generator is carrying load with a lagging power factor prior to the fault, the asymmetry will be lower but the a.c. component will be higher.

8.103.6.3.6.3 Interruption of short-circuit currents with delayed current zeros

Additional resistance in series with the armature resistance, $R_a = X"_d/(2\pi f\ \tau_a)$, forces the d.c. component of the short-circuit current to decay faster. If R_{add} is the additional resistance, the d.c. component decreases more quickly with the time constant $\tau_a = X"_d/[2\pi f \times (R_a+R_{add})]$. Such additional resistance may be the connection from the generator to the fault location, but especially the arc resistance of the fault and the circuit-breaker arc resistance after contact separation. If there is an arc at the fault location, this arc resistance further reduces the time constant of the d.c. component from the beginning of the fault and the generator circuit-breaker arc resistance after contact separation. The values of these additional series resistances are normally high enough to force a fast decay of the d.c. component of the short-circuit current so that current zeros are produced.

Figure 46 shows the effect of the arc-voltage on the current from the example shown in Figure 40, in the phase with the highest asymmetry. At the moment of contact separation, the decay of the d.c. component changes suddenly due to the influence of the arc voltage of the generator circuit-breaker. The d.c. component of the current does not decrease exponentially because arc resistance due to arc voltage is not constant. Arc resistance at the fault location was not taken into account in this example. However, within one cycle after contact separation, current zeros occur.

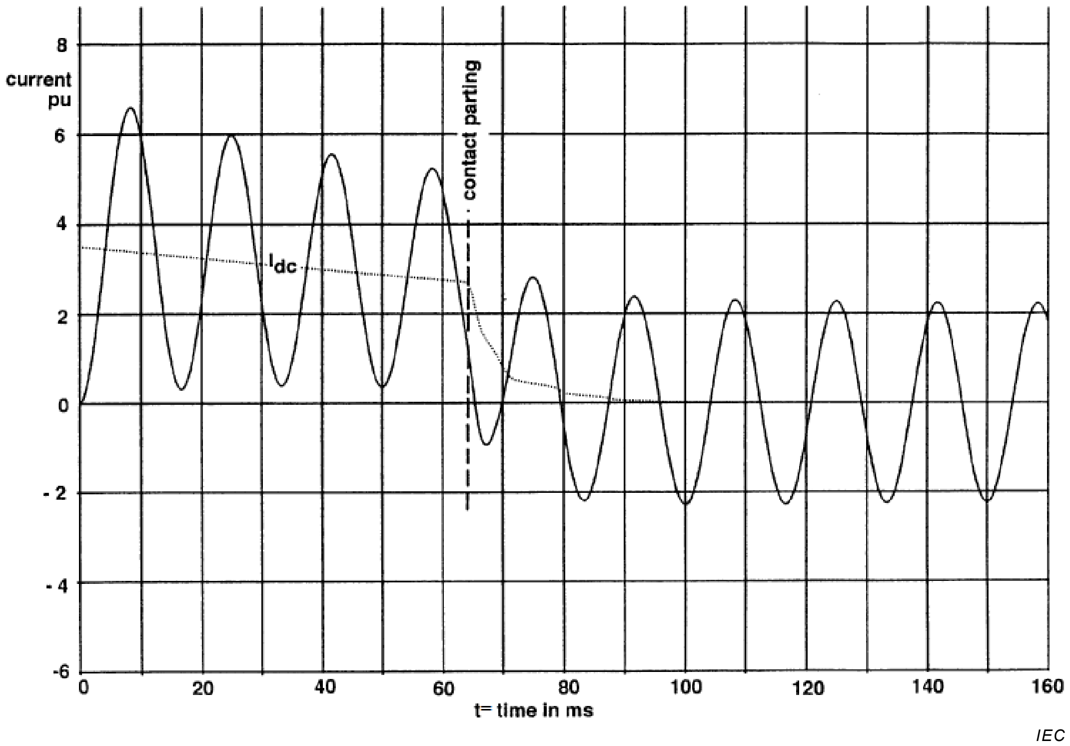


Figure 46 – Short-circuit current with circuit-breaker arc voltage after contact separation

8.103.6.3.6.4 Proof of the capability of the generator circuit-breaker

The capability of a generator circuit-breaker to interrupt short-circuit currents with delayed current zero crossings occurring in actual service conditions, may be difficult to demonstrate in high power testing stations.

If, in some cases, three-phase tests in power testing stations are possible, the conditions described in 6.105 shall be observed.

When the current exhibits delayed current zeros (i.e. degree of asymmetry > 100 %) the capability of the generator circuit-breaker to force current zeros shall be demonstrated by means of a calculation considering the effect of the arc voltage of the generator circuit-breaker on the prospective current. The arc voltage versus current characteristic of one break of the generator circuit-breaker can be derived from short-circuit current interrupting tests. The arc voltage versus current characteristic can be used as described in [4] to model the generator circuit-breaker. To be able to investigate the behaviour of the circuit-breaker during the interruption of currents with delayed current zeros the arc voltage characteristic has to be transferred into a mathematical model. From the arc voltage $u_{\text{arc}}(i,t)$ and the current $i(t)$ the arc resistance $R_{\text{arc}}(i,t)$ can be obtained. In order to model the behaviour of the generator circuit-breaker a non-linear time-varying resistance of the value $R_{\text{arc}}(i,t)$ has to be inserted into the simulation at the time of the separation of the contacts of the generator circuit-breaker.

The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

1) Fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry.
2) Fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

For each of the situations 1 and 2 the following two cases shall be investigated:

a) Generator at no-load with the generator circuit-breaker closing into a three-phase fault. In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account.
b) Generator in service with leading power factor. An arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

8.103.6.3.7 Guide for the selection of the class of the generator circuit-breaker

8.103.6.3.7.1 General

In order to select the class of the generator circuit-breaker which is required for a specific application the following steps shall be followed and the requirements laid down in 8.103.6.3.7.2, 8.103.6.3.7.3 and 8.103.6.3.7.4 shall be met simultaneously.

8.103.6.3.7.2 Case of generator delivering power with lagging power factor prior to fault

Calculate the r.m.s. value of the a.c. component of the prospective generator-source short-circuit current $I_{\text{scg\_lagg}}$ and the asymmetrical current in case of three-phase fault occurring between the generator-circuit-breaker and the associated step-up transformer with the generator delivering power with lagging power factor prior to fault. Fault initiation shall be assumed at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry. These two values shall be calculated at the instant of intended contact separation in the phase exhibiting the maximum degree of asymmetry.

One of the following conditions shall be met:

a) Select a generator circuit-breaker class G1 with the r.m.s. value of the a.c. component of the rated generator-source short-circuit breaking current I_{scg} not less than I_{scg_lagg} provided that the asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker;

b) Select a generator circuit-breaker class G2 with the r.m.s. value of the a.c. component of the rated generator-source short-circuit breaking current I_{scg} not less than I_{scg_lagg} provided that the asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker.

The asymmetrical interrupting capability is equal to $I_{scg}\sqrt{1+2\cdot(1,1)^2}$ and $I_{scg}\sqrt{1+2\cdot(1,3)^2}$ for generator circuit-breakers class G1 and class G2 respectively.

8.103.6.3.7.3 Case of generator unloaded prior to fault

Calculate the r.m.s. value of the a.c. component I_{scg_unl} and the degree of asymmetry of the prospective generator-source short-circuit current in case of three-phase fault occurring between the generator-circuit-breaker and the associated step-up transformer with the generator unloaded prior to fault. No fault arc voltage shall be taken into consideration for the calculations. Fault initiation shall be assumed at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry. The r.m.s. value of the a.c. component and the degree of asymmetry of this prospective generator-source short-circuit current shall be calculated at the instant of intended contact separation in the phase exhibiting the maximum degree of asymmetry.

- If the calculated degree of asymmetry does not exceed 110 % a generator circuit-breaker having I_{scg} not less than I_{scg_unl} with either class G1 or class G2 is adequate for the application provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:
  - fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
  - fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

  In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

  The technical data of the actual generator shall be used for these computations.

  The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

- If the calculated degree of asymmetry is between 110 % and 130 % one of the following conditions shall be met:
  1) select a generator circuit-breaker class G1 with the r.m.s. value of the a.c. component of the rated generator-source short-circuit breaking current I_{scg} not less than I_{scg_unl} provided that the following conditions are met:
     i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker.
     ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

– fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

– fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

2) select a generator circuit-breaker class G1 with 0,74 I_{scg} not less than I_{scg_unl} provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

– fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

– fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

3) select a generator circuit-breaker with class G2 and I_{scg} not less than I_{scg_unl} provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

– fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

– fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

- If the calculated degree of asymmetry exceeds 130 % one of the following conditions shall be met:

1) select a generator circuit-breaker class G1 with the r.m.s. value of the a.c. component of the rated generator-source short-circuit breaking current I_{scg} higher than I_{scg_unl} provided that the following conditions are met:

i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker.

ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

– fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

– fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

2) select a generator circuit-breaker class G1 with 0,74 I_{scg} higher than I_{scg_unl} provided that the following conditions are met:

i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed $0{,}74 \times I_{scg}\sqrt{1+2(1{,}3)^2}$.

ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

– fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

– fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

3) select a generator circuit-breaker with class G2 and I_{scg} higher than I_{scg_unl} so that the following conditions are met:

i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker.

ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

– fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

– fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

8.103.6.3.7.4 Case of generator delivering power with leading power factor prior to fault

Calculate the r.m.s. value of the a.c. component $I_{\text{scg\_lead}}$ and the degree of asymmetry of the prospective generator-source short-circuit current in case of a three-phase fault occurring between the generator-circuit-breaker and the associated step-up transformer with the generator loaded with leading power factor prior to fault. Fault initiation shall be assumed at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry. The r.m.s. value of the a.c. component and the degree of asymmetry of this prospective generator-source short-circuit current shall be calculated at the instant of intended contact separation in the phase exhibiting the maximum degree of asymmetry.

- If the calculated degree of asymmetry does not exceed 110 % a generator circuit-breaker having I_{scg} not less than $I_{\text{scg\_lead}}$ with either class G1 or class G2 is adequate for the application provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:
  - fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
  - fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

  In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

  The technical data of the actual generator shall be used for these computations.

  The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

- If the calculated degree of asymmetry is between 110 % and 130 % one of the following conditions shall be met:
  1) select a generator circuit-breaker class G1 with the r.m.s. value of the a.c. component of the rated generator-source short-circuit breaking current I_{scg} not less than $I_{\text{scg\_lead}}$ provided that the following conditions are met:
     i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker.
     ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

– fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

– fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

2) select a generator circuit-breaker class G1 with 0,74 I_{scg} not less than $I_{\text{scg\_lead}}$ provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

   – fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

   – fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

   In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

   The technical data of the actual generator shall be used for these computations.

   The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

3) select a generator circuit-breaker with class G2 and I_{scg} not less than $I_{\text{scg\_lead}}$ provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

   – fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

   – fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

   In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

   The technical data of the actual generator shall be used for these computations.

   The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

- If the calculated degree of asymmetry exceeds 130 % one of the following conditions shall be met:

1) select a generator circuit-breaker class G1 with the r.m.s. value of the a.c. component of the rated generator-source short-circuit breaking current I_{scg} higher than I_{scg_lead} provided that the following conditions are met:

   i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker.

   ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

   – fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

   – fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

   In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

   The technical data of the actual generator shall be used for these computations.

   The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

2) select a generator circuit-breaker class G1 with 0,74 I_{scg} higher than I_{scg_lead} provided that the following conditions are met:

   i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed $0{,}74 \times I_{scg}\sqrt{1+2(1{,}3)^2}$.

   ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

   – fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry.

   – fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

   In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

   The technical data of the actual generator shall be used for these computations.

   The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

3) select a generator circuit-breaker with class G2 and I_{scg} higher than I_{scg_lead} so that the following conditions are met:

   i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker.

   ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum permissible arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

  In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

  The technical data of the actual generator shall be used for these computations.

  The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

8.103.6.3.8 Making current capability

The short-circuit current into which the generator circuit-breaker shall close is determined by the higher value of either the system-source short-circuit current or the generator-source short-circuit current. In the majority of applications the system-source short-circuit current is higher than the generator-source short-circuit current.

The ratio of the peak value of the short-circuit current to the r.m.s. value of the a.c. component of the rated system-source short-circuit breaking current of the generator circuit-breaker is determined by the following equation:

$$\frac{I_{\text{mc}}}{I_{\text{sc}}} = \sqrt{2}\left(e^{-\frac{t}{133}} + 1\right) = 2{,}74$$

with t approximately 1/2 cycle in ms.

In cases where the generator-source short-circuit current might be higher than the system-source short-circuit current special considerations are necessary. The required generator-source symmetrical interrupting capability at contact separation depends on the decay of the a.c. current with the generator time constants τ'_{d}, τ''_{d}, τ'_{q}, and τ''_{q} varies from one application to another. The required making current has to be established by calculation. The equation in E.4.2 could be used for an estimation.

8.103.6.3.9 Faults in case of three-winding step-up transformers

When two generators are connected to the high-voltage system by means of a three-winding step-up transformer, special attention should be paid to the system-source short-circuit current. In case of three-phase earthed fault occurring at location F in Figure 47, both the a.c. component and the degree of asymmetry of the system-source short-circuit current which should be interrupted by the Generator circuit-breaker #1 can attain very high values because of the additional contribution to the current of the Generator #2.

Because the a.c. component of the fault current fed by the Generator #2 is not constant, the ratio of the peak value of the short-circuit current seen by Generator circuit-breaker #1 to the r.m.s. value of the a.c. component of the short-circuit breaking current (at contact separation of Generator circuit-breaker #1) could exceed the standard value of 2,74 (refer to Annex I).

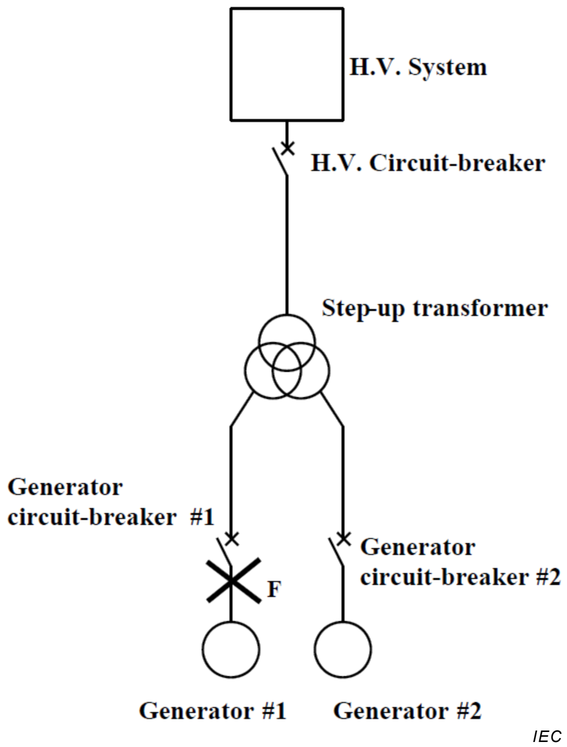


Figure 47 – Single-line diagram of a power station with two generators connected to the high-voltage system by means of a three-winding step-up transformer

In addition the fault current fed by Generator #2 in case of fault occurring at location F generally features a relatively small magnitude and a very high degree of asymmetry and it often exhibits several cycles without natural zero crossing (refer to Annex I). These delayed current zeros have totally different causes and are extremely dissimilar in comparison with the currents associated with generator terminal faults and out-of-phase synchronising. The waveform of this current is obtained as the superposition of two contributions, i.e. one oscillating at power frequency and a transient one whose course is dictated by the time constants of the circuit. The transient component consists of two decaying exponential functions: this waveform is over-damped as the damping contribution prevails over the oscillating one. If the Generator circuit-breaker #2 has to interrupt this current the capability of the generator circuit-breaker to force current zeros shall be demonstrated by means of calculations considering the effect of the arc voltage of the generator circuit-breaker on the prospective short-circuit current.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

8.103.7 TRV rating for system-source and generator-source short-circuits

8.103.7.1 Background

The principles in IEEE Std C37.011™-2011 are applicable when TRV problems are considered during the interruption process of short-circuit currents by a generator circuit-breaker. An exception is that the short-line fault rating does not apply.

The generator circuit-breaker is a special application because it is installed between a generator and step-up transformer, the characteristics of which largely dictate the waveshape of the prospective TRV for various duties. Therefore, the TRV ratings are defined for the generator-source and the system-source faults, depending on the generator or transformer ratings (see Tables 3 and 4). These ratings are determined for the first-pole-to-clear and for symmetrical current interruption in case of three-phase earthed faults. Rated TRVs are prospective values assuming an ideal generator circuit-breaker. These values may be modified by the generator circuit-breaker characteristics or by the asymmetry of the current.

A system with a TRV that exceeds the rated values shall be modified in such a way as to mitigate the TRV. This is achieved by placing a low ohmic resistor in parallel with the main interrupting device of the generator circuit-breaker or by connecting capacitors to its terminals. Capacitors can be installed between the step-up transformer and the generator circuit-breaker, or between the generator and the generator circuit-breaker, or at both sides, or capacitors can be part of the generator circuit-breaker assembly. The interrupting capability demonstrated by relevant type tests is valid only if capacitors of the same capacitance value as taken into account during the tests are installed according to the tested configuration. An interrupting capability different than that tested cannot be confirmed for the generator circuit-breaker with a different capacitance value of the capacitors used to mitigate the TRV.

8.103.7.2 Basis of standardized TRV parameters for the interrupting of short-circuit currents

8.103.7.2.1 General

Several cases should be considered based on the following:

a) system-source faults where the short-circuit is located on the generator side of the generator circuit-breaker;
b) generator-source faults where the short-circuit is located on the transformer side of the generator circuit-breaker.

The neutral of the generator is not-effectively earthed, thus the single-phase to earth fault current is not significant. A three-phase fault is the most severe case and gives the maximum short-circuit current and the maximum TRV rate.

8.103.7.2.2 Influence of the station configuration

8.103.7.2.2.1 General

The most commonly used station one-line configuration is shown in Figure 48, where the generator and the step-up transformer have essentially the same rating. Other arrangements having the same total rating as in Figure 48 are shown in Figure 49 and Figure 50. In each case, the auxiliary transformer is a minor source of short-circuit current and can be neglected.

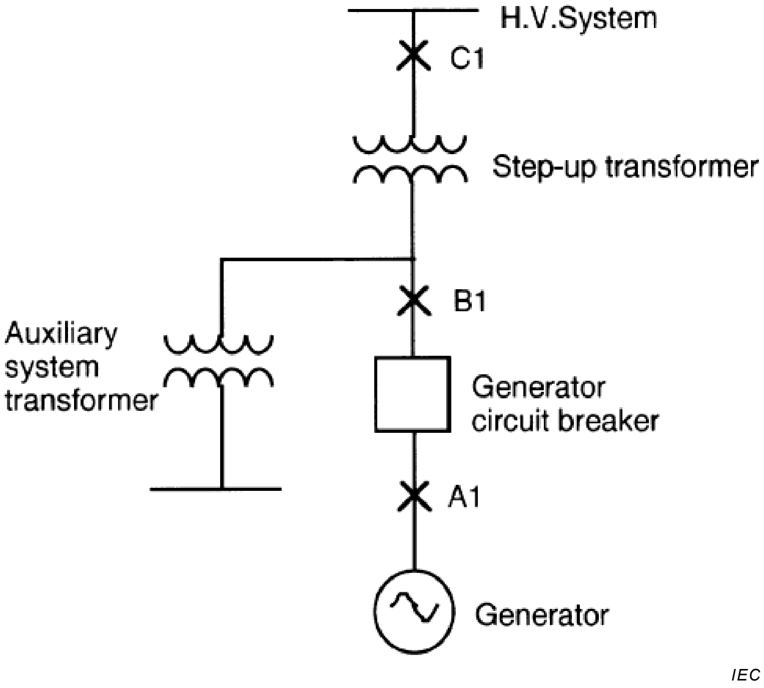


Figure 48 – Single-line diagram of unit generator system

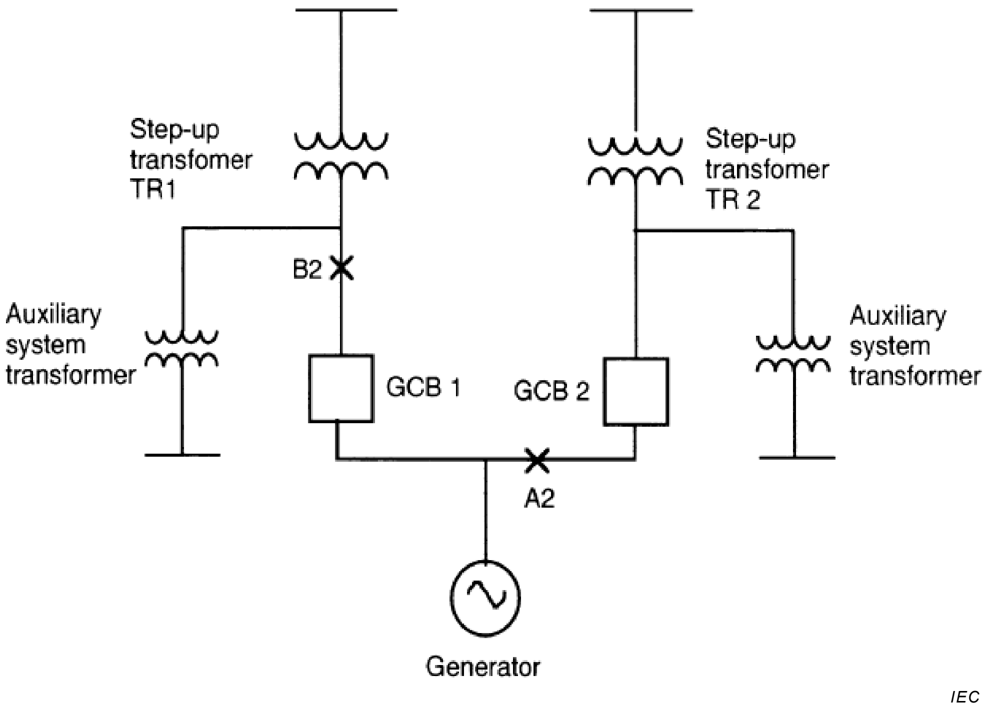


Figure 49 – Single-line diagram of half-sized transformer unit system

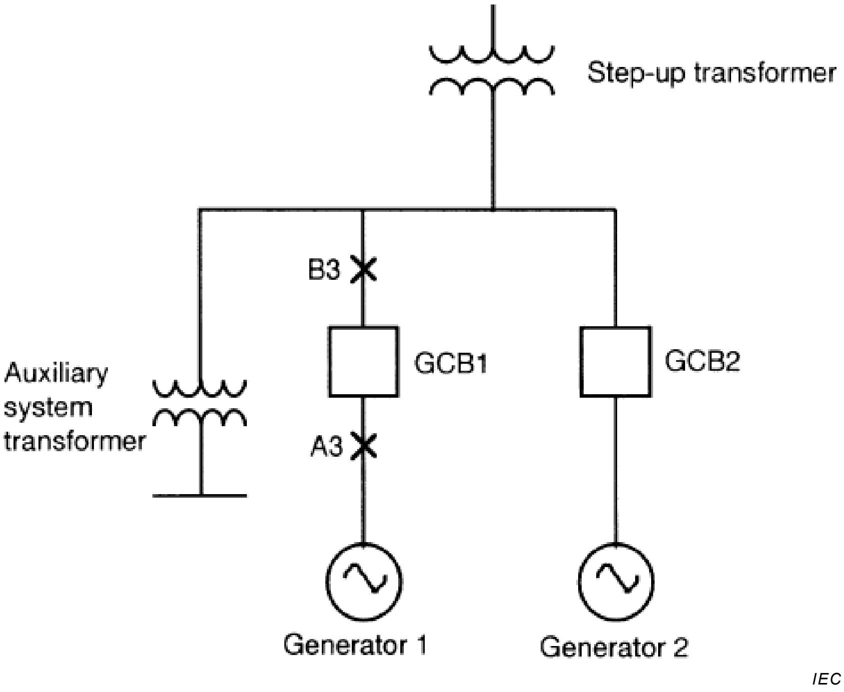


Figure 50 – Single-line diagram of system with half-sized generators

8.103.7.2.2.2 System-source faults

For a system-source fault at A1 in Figure 48, the short-circuit current is determined by the sum of the transformer short-circuit reactance, X_T and the high-voltage (HV) system reactance, X_S. The maximum value of short-circuit current is obtained for a given transformer when X_S is minimum or assumed to be zero.

The natural frequency of the transformer is much higher than the natural frequency of the HV system. Therefore, the TRV first oscillates at the value of voltage drop in the transformer, $I_{sc} \times X_T\sqrt{2}$ to the prospective value of 1,5 $I_{sc} \times X_T\sqrt{2}$, where I_{sc} is the r.m.s. value of the available symmetrical short-circuit current.

The voltage drop in the transformer is equal to the total normal frequency recovery voltage for $X_S = 0$. Therefore, the TRV rate is maximum when the short-circuit current is maximum. This is contrary to what is observed in HV systems, where the TRV rate increases when the short-circuit current decreases.

Practically, the maximum observed TRV rate is 75 % to 90 % of the theoretical value determined from the natural frequency of the step-up transformer, taking into account the capacitance of the low-voltage side, including the auxiliary transformer.

A larger reduction in TRV rate is observed if capacitors are installed on the low voltage side of the step-up transformer. The TRV rate is reduced from 6 kV/μs to a value of 4 kV/μs with the addition of 0,1 μF to 0,2 μF of capacitance per phase. The standardized values of TRV rate do not take into account this capacitance.

For a system-source fault at A2 in Figure 49, the situation is the same as for a fault at A1 in Figure 48, except that the short-circuit current and the TRV parameters seen by the individual circuit-breakers are related to a step-up transformer of lower rating.

For a system-source fault at A3 in Figure 50, the short-circuit current is higher because the fault is also fed by the generator, G2. However, the TRV rate is lower because of the capacitance of the G2 generator windings. If the generator G2 is out of service, the situation is the same as for a fault at A1 in Figure 48, except that the generator G1 is approximately half the rating.

In the special case where generator circuit-breaker is connected to the step-up transformer by shielded cables, the additional capacitance of the cables modifies the prospective TRV, as illustrated in Annex F.

8.103.7.2.2.3 Generator-source faults

For a generator-source fault at B1 in Figure 48, the short-circuit current is usually lower than for the system-source fault at A1 in Figure 48, because of the higher reactance of the generator windings.

Although the short-circuit current and TRV rate are lower for generator-source faults than for system-source faults, generator-source faults cannot be ignored because of the high degree of asymmetry of the short-circuit current (see 8.103.6.3.5), thus the corresponding TRV parameters shall be specified.

For a generator-source fault at C1 in Figure 48, on the HV side of the transformer, the short-circuit current is lower when compared to a fault at B1 in Figure 42. This fault location can usually be ignored because the resulting stresses on the generator circuit-breaker are much lower than for faults at A1 and B1 in Figure 48.

The TRV results from transformer and generator voltage oscillations. The magnitude of each oscillation is approximately proportional to the transformer and generator reactances, respectively.

For a generator-source fault at B2 in Figure 49, if the transformer TR2 is out of service, the oscillation is the same as for a fault at B1 in Figure 48 with the short-circuit current and TRV parameters determined by the rating of the generator. If the transformer TR2 is in service and the generator circuit-breaker GCB1 is the first to open, the short-circuit current is higher than for a fault at B1 in Figure 48, and TRV parameters are intermediate in value, between TRV parameters for the full-sized generator and TRV parameters for the half-sized transformer. This case needs special consideration to determine the required TRV parameters.

8.103.7.2.2.4 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 generator 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 generator circuit-breaker) or clearing a fault behind the reactor (reactor at load side of generator circuit-breaker). The resulting TRV frequency can exceed 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 generator 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, depending on the generator circuit-breaker ratings.

Based on the preceding considerations, no rated values of TRV and no special test duty are specified for this fault case.

8.103.7.3 Rated prospective transient recovery voltage

The rated voltages of generators and associated step-up transformers are not standardized. The short-circuit currents therefore will vary widely.

After reviewing available equipment data, TRV parameters were standardized based on the power rating of the step-up transformer and generator, respectively.

Table 3 gives the parameters of the rated TRV applicable when the fault is located on the generator side of the generator circuit-breaker and the source of the short-circuit current is the power system through a step-up transformer. The values are applicable to the interrupting operation of the a.c. component of rated system-source short-circuit breaking current according to 4.101.2 and symmetrical interrupting capability for three-phase faults according to 8.103.6.3.2. For the asymmetrical interrupting capability for three-phase faults according to 8.103.6.3.3, the same prospective TRV parameters are to be used but the actual TRV will be less severe due to the asymmetry. At the instant of current interruption at current zero, the normal frequency recovery voltage is shifted in phase due to the d.c. component of the current and the TRV oscillates around a lower instantaneous normal frequency recovery voltage value than for the symmetrical case.

Table 4 gives the parameters of the rated TRV applicable when the fault is located on the transformer side of the generator circuit-breaker and the source of the short-circuit current is the generator. The values are applicable to the interrupting operation of the a.c. component of rated generator-source short-circuit breaking current according to 4.101.3 and generator-source symmetrical interrupting capability for three-phase faults according to 8.103.6.3.4. For the generator-source asymmetrical interrupting capability for three-phase faults according to 8.103.6.3.5, and the generator-source asymmetrical interrupting capability for maximum degree of asymmetry according to 8.103.6.3.6, the same prospective TRV parameters are to be used but the actual TRV will be less severe due to the asymmetry for the same reason stated above. At the interruption of the short-circuit current with maximum asymmetry, the transient oscillation of the recovery voltage will be very small or even non-existent since at the moment of short-circuit current interruption, the normal frequency voltage value may be very small or zero.

TRV parameters listed in Tables 3 and 4 apply to the first-pole-to-clear for a three-phase earthed fault, with a first-pole-to-clear factor equal to 1,5. The TRV oscillates as shown in Figure 13.

If the generator circuit-breaker requires that the prospective TRV be modified by the addition of capacitors, then the amount of equivalent capacitance required shall be given in the test report and on the nameplate. It is recognized that connecting a shielded cable or a cable bus between the generator and the circuit-breaker may provide this capacitance.

The curve rises to the crest value, u_c equal to $1,84U_r$ where U_r is the r.m.s. value of the rated voltage in kV and the value 1,84 is equal to

$$\sqrt{\frac{2}{3}} \times 1{,}5 \text{ (= first-pole-to-clear factor)} \times 1{,}5 \text{ (= amplitude factor)}$$

The rising part of the TRV curve is bounded by two lines. One line goes through the origin and tangent to the TRV curve with a slope equal to the rate-of-rise of the TRV (RRRV). The other line has the same slope and goes through the point t_d, time delay.

Near the crest, the TRV curve has approximately a 1–cos wave-shape with a time-to-crest, T2, equal to

$$T2 = \frac{t_3}{0{,}85} = \frac{u_\mathrm{c}}{0{,}85 \times \mathrm{RRRV}}$$

The reference lines for the prospective transient recovery voltage wave of the test circuit shall at no time be below the specified reference lines required for the application.

The manufacturer shall approve the extent by which the TRV envelope of the test circuit exceeds the specified reference line.

8.103.7.4 First-pole-to-clear factor

The first-pole-to-clear factor is 1,5 and corresponds to the worst condition of a three-phase earthed fault on a non-effectively earthed system.

8.103.7.5 Amplitude factor

Analysis of the available data gives 1,5 as a realistic value, with no capacitance connected to the terminals of the generator circuit-breaker.

8.103.8 Rated load making and breaking current

8.103.8.1 General

During normal service of the generator, the load current is reduced to zero before an opening operation of the generator circuit-breaker is initiated. However, the interruption of full load current may be required occasionally for emergency circumstances. Prospective transient recovery voltages are shown in Table 5 for this situation.

8.103.8.2 Power frequency recovery voltage

The single-line diagram, Figure 51, and the equivalent circuit, Figure 52, show a generator supplying a load having an impedance Z_L through a transformer T with a reactance, X_t and a transmission line with a reactance X_L. The generator is synchronized with the rest of the system symbolized by a single generator $E"_\mathrm{Gn}$, a single transformer X_tn, and a single load, Z_n.

In comparison with the sum of reactances from the generator G1 to the load Z_L, the short-circuit reactance of the HV network is small and can be neglected. Thus, when I_L is interrupted and the network only serves the load Z_L, there is no voltage drop in the HV network.

The magnitude of the load current I_L determines voltage drops through the reactances of generator G1 and transformer T.

These voltage drops have a phase shift of 90° leading, to the current I_L, irrespective of the load phase angle ϕ, as shown on vectorial diagrams Figure 53 and Figure 54, the latter corresponding to an almost pure resistive load.

After the interruption of I_L, these voltage drops are zero. The voltage on the transformer side of the generator circuit-breaker decreases from V_p to V_np, with the natural frequency of the transformer side circuit. The voltage on the generator side of the generator circuit-breaker increases from V_p to $E"_\mathrm{G1}$ with the natural frequency of the generator side circuit. The amplitude of the voltage across the transformer, which was $\sqrt{2}I_\mathrm{L}X_\mathrm{t}$ before interruption of I_L, drops to zero.

For rapid changes in load conditions of the generator, the subtransient reactance $X"_\mathrm{d}$ has to be taken into account and the amplitude of the voltage drop V_s is equal to $\sqrt{2}I_\mathrm{L}X"_\mathrm{d}$.

The power frequency recovery voltage appearing across the generator circuit-breaker terminals (see Figure 55) consists of the sum of the voltage variations on each side of the generator circuit-breaker, following load interruption, i.e., $I_L(X''_d + X_t)$, in kV r.m.s., and for the first-pole-to-clear in a three-phase system the voltage is equal to $1{,}5 I_L(X''_d + X_t)$. The power frequency recovery voltage across the generator circuit-breaker terminals expressed in p.u. (per unit) of the rated voltage is equal to

$$1{,}5\frac{u_r}{\sqrt{3}}\times\left(x''_d + x_t\right)$$

where

u_r is the rated voltage in p.u.;

x''_d is the per unit reactance value of the generator;

x_t is the per unit reactance value of the transformer.

In practice, even for the larger units, the sum of $x''_d + x_t$ does not exceed 0,5 p.u., therefore the recovery voltage across the generator circuit-breaker during a full load interruption will not exceed 50 % of the recovery voltage value which appears after a short-circuit interruption and consequently is standardized at

$$1{,}5\frac{u_r}{\sqrt{3}}\times 0{,}5 = 0{,}43\ u_r$$

for interruption of the rated normal current of the generator.

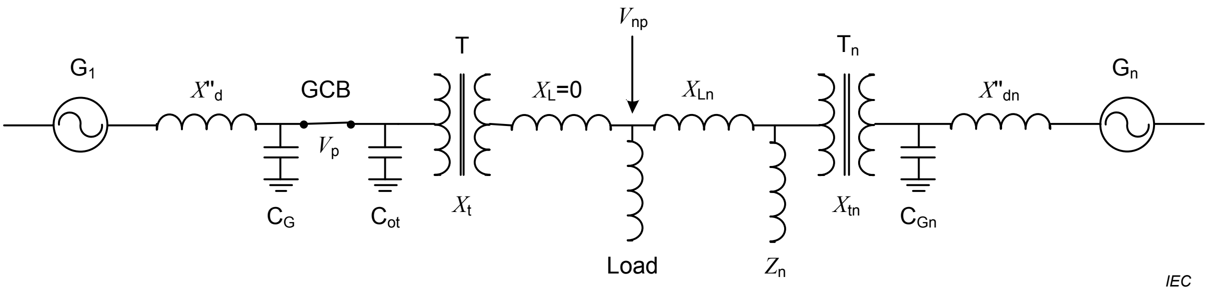


Figure 51 – Single-line diagram of power system

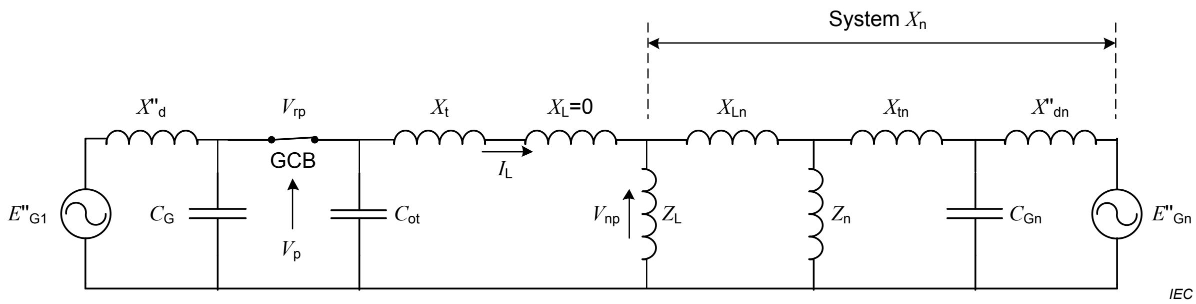


Figure 52 – Equivalent circuit of power system

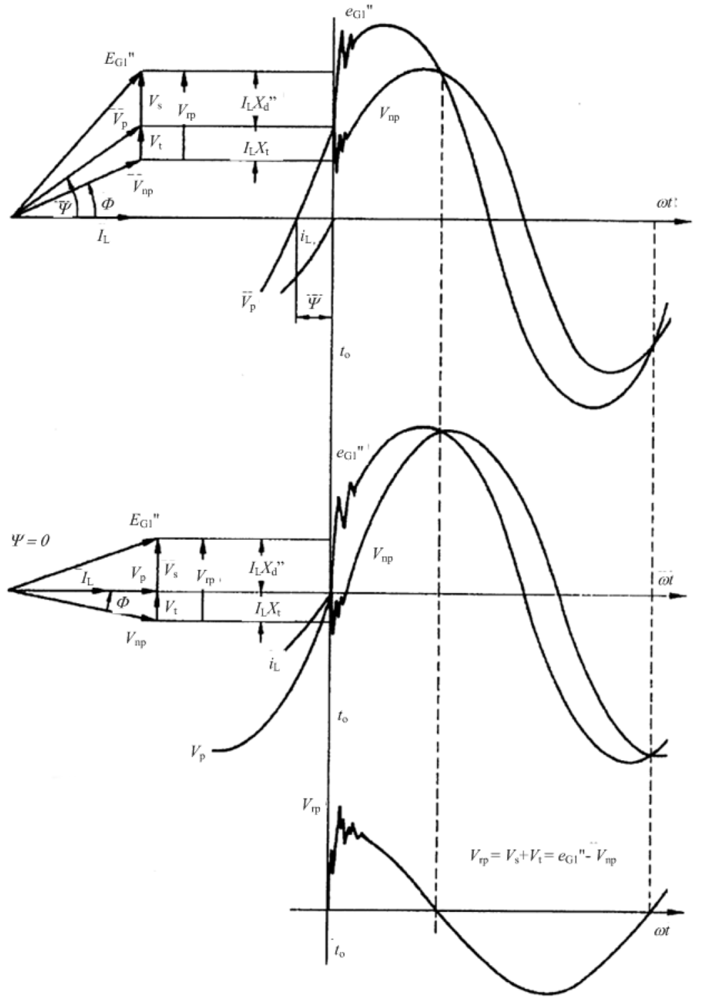


Figure 53 – Voltage diagram for lagging power factor load

Figure 54 – Voltage diagram for unity power factor load

Figure 55 – Recovery voltage across the generator circuit-breaker

IEC

Key to Figures 51, 52, 53, 54 and 55

C_G	Capacitance on generator side	X_n	HV system short-circuit reactance = $X"_{dn}$ + X_{tn} + X_{Ln}
C_{ot}	Capacitance on transformer side	X_t	Transformer reactance
$E"_{G1}$ ($e"_{G1}$)	Generator voltage at the generator circuit-breaker terminals after time t_o	Z_L	Load impedance
I_L (i_L)	Load current	G1	Generator (load current I_L)
V_{np}	System voltage (at the load terminals)	GCB	Generator circuit-breaker
V_p (v_p)	Operating voltage at the circuit-breaker terminals before time t_o	T	Transformer
V_{rp} (v_{rp})	Recovery voltage across the switch	ψ	Phase angle at the generator circuit-breaker location
$X"_d$	Subtransient generator reactance	ϕ	Load phase angle
X_L	Line reactance (from transformer to load)	ω	Angular system frequency

8.103.8.3 Prospective transient recovery voltage

The TRV across the first-pole-to-clear for load current switching is normally a dual frequency oscillatory curve, as shown in Figure 56; the natural frequency of the transformer being higher than the natural frequency of the generator. Also, the first peak of the transformer side voltage is smaller than the first peak of the generator side voltage because X_t is always smaller than $X"_d$.

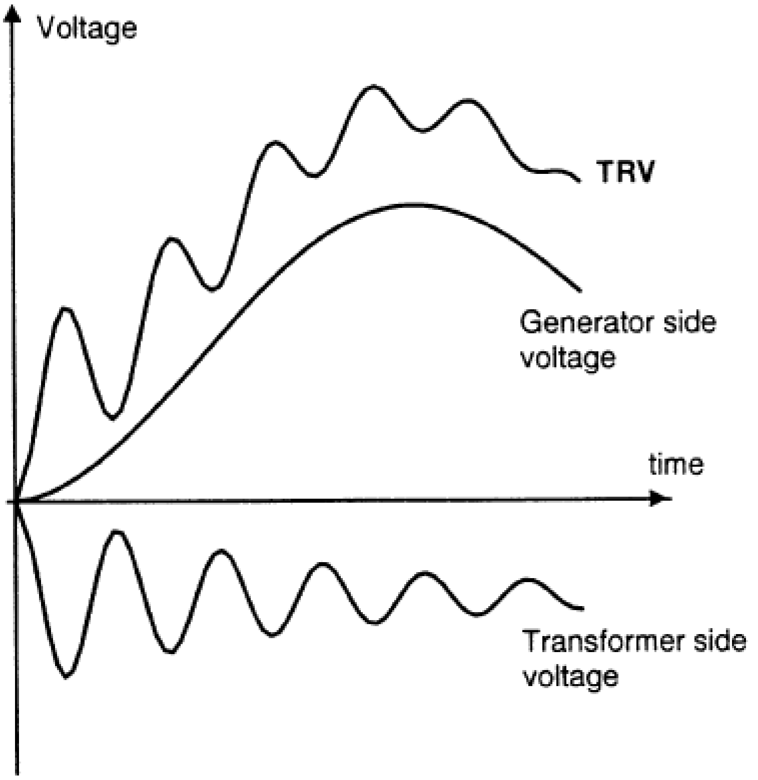


Figure 56 – TRV curve for the first-pole-to-clear

Theoretical calculations prove to be difficult and yield pessimistic results. Measurements at the site by injecting current at low voltage with the high-voltage side of the transformer short-circuited (representing a fault on the high-voltage side by neglecting the HV system reactances) are preferable.

Standardized TRV rate values have been selected by reviewing available results of measurements. Standardized values do not consider the use of capacitors, which would reduce the TRV rate.

The interrupting capability of the generator circuit-breaker demonstrated by relevant type tests is valid only if capacitors of the same capacitance value as used during the tests are installed according to the tested configuration. An interrupting capability different than that tested cannot be confirmed for the generator circuit-breaker equipped with a different capacitance value of the capacitors used to mitigate the TRV.

8.103.8.4 Endurance capability

The endurance capability gives the user some guidance for the servicing and maintenance of generator circuit-breakers. Several subclauses in this standard deal with service and endurance capability (see 4.108, 6.101.2.3 and 6.101.2.4).

The endurance capability consists of the following two types of requirements:

a) Electrical endurance that essentially is a measure of contact wear and gives guidance as to when to replace arcing contacts or other parts of the generator circuit-breaker, which are exposed to the arc or stressed electrically during switching.
b) Mechanical endurance, to ensure that the minimum number of operations can be performed without the need for servicing or overhaul. The number of operations is

specified in 4.108. If a greater number is desired, it is subject to agreement between the user and the manufacturer.

8.103.9 Rated out-of-phase making and breaking current

8.103.9.1 Out-of-phase current

During out-of-phase conditions, the current through the generator, the generator circuit-breaker, the transformer, and the HV system at $t = 0$, i.e., at the moment of initiation of the out-of-phase condition, can be calculated using the following equation, provided that the generator, transformer, and system reactances are in per unit on the generator rated MVA basis and the single-line diagram of the station is as shown in Figure 48 and Figure 49.

$$I_{oph} = \frac{\delta \times I_n}{x''_d + x_t + x_s}$$

where

I_{oph} is the maximum out-of-phase current;

δ is $\frac{\text{out-of-phase voltage}}{\text{rated voltage}}$;

δ is $\sqrt{2}$ for a 90° out-of-phase angle, and 2 for a 180° out-of-phase angle;

I_n is the generator rated current;

x''_d is the p.u. generator subtransient reactance;

x_t is the p.u. transformer reactance based on generator rating;

x_s is the p.u. system reactance based on generator rating.

The ultimate out-of-phase current is lower than the initial out-of-phase current at $t = 0$ because it decreases based on the time constants of the generator, the transformer and the system. The calculation of the current excursion shall be performed by computer programs that simulate the generator behaviour correctly. The current resulting from out-of-phase synchronizing might show delayed current zeros whose causes are totally different compared to generator terminal faults [10]. The rapid movement of the rotor from initial out-of-phase angle φ_0 to $\varphi = 0$ results in a very small a.c. component of the fault current and a dominant d.c. component when the condition of $\varphi = 0$ is reached. The current resulting from out-of-phase synchronizing has to be assessed by the aid of computer simulations which allow modelling power station equipment with a high level of accuracy, especially the synchronous machine. The moment of inertia of the turbine, the rotor and excitation equipment of the generator is of special importance. This is because the instant when the $\varphi = 0$ condition is reached is determined by the angular velocity of the rotor.

In case the fault current shows delayed current zeros the capability of the generator circuit-breaker to force current zeros shall be demonstrated by means of a calculation considering the effect of arc voltage. The procedure described in 8.103.6.3.6.3 applies.

The following two typical situations shall be considered for a particular out-of-phase current for a three-phase fault:

a) initiation of the out-of-phase condition at voltage zero across the open contacts of the generator circuit-breaker in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

b) initiation of the out-of-phase condition at voltage maximum across the open contacts of the generator circuit-breaker in one phase which implies that the current in the corresponding phase is symmetrical.

For each of the above situations a) and b) the following two cases shall be investigated:

1) Generator at no-load with the generator circuit-breaker closing with the phase angle difference between phasors representing the voltages on each side of the generator circuit-breaker. The case of generator voltage leading the system voltage referred to the LV-side of the step-up transformer shall be investigated. In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. Contact separation occurs at the minimum opening time of the generator circuit-breaker after initiation of the out-of-phase condition plus tripping delay of the protection system. The tripping delay is generally equal to 0,5 cycles at power frequency.
2) Generator at no-load with the generator circuit-breaker closing with the phase angle difference between phasors representing the voltages on each side of the generator circuit-breaker. The case of generator voltage lagging the system voltage referred to the LV-side of the step-up transformer shall be investigated. In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. Contact separation occurs at the minimum opening time of the generator circuit-breaker after initiation of the out-of-phase condition plus tripping delay of the protection system. The tripping delay is generally equal to 0,5 cycles at power frequency.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

If the generator is connected to the system in full phase opposition, $\delta = 2$, I_{oph} will in general exceed the generator terminal short-circuit current, which is not acceptable for the safety of the generator. Therefore, precautions should be taken to avoid this situation (automatic synchronization).

A generator circuit-breaker is not required to interrupt the full phase opposition current with a recovery voltage twice the maximum operating voltage, thus the assigned out-of-phase current switching rating will not exceed 50 % of the rated short-circuit current of the generator circuit-breaker, which corresponds to a maximum out-of-phase angle of 90°.

8.103.9.2 TRV parameters

Circuits involved in out-of-phase current switching have the same configuration as for load current switching. Therefore, the TRV is standardized in the same manner according to 8.103.8.2 taking into account a normal frequency recovery voltage equal to √2 times the maximum operating voltage of the generator. The TRV parameters are given in Table 6.

The interrupting capability of the generator circuit-breaker demonstrated by relevant type tests is valid only if capacitors of the same capacitance value as used during the tests are installed according to the tested configuration. An interrupting capability different than that tested cannot be confirmed for the generator circuit-breaker equipped with a different capacitance value of the capacitors used to mitigate the TRV.

8.103.10 Excitation switching current

During routine operation, a generator step-up transformer is seldom switched in an unloaded condition. However, consideration should be given to switching of transformer excitation current. The excitation current is 10 A to 50 A, depending on the rating and no-load characteristics of the transformer. Excitation current switching is not so much a matter of the generator circuit-breaker capability, but a question of whether overvoltages are produced due to current chopping.

The value of chopped current, and consequently the overvoltages produced, are dependent on the generator circuit-breaker, system configuration, and also the various system parameters. Modern transformers have a low no-load current value compared to older designs, and their magnetic characteristics are such that a relatively low amount of energy is released when current chopping occurs during switching, leading to moderate chopping overvoltages. Furthermore, the transformer LV side is usually protected by additional capacitance and by surge arresters.

Chopping overvoltages are produced only on the transformer side of the generator circuit-breaker. No overvoltages occur on the generator side because the inductance of the generator is much lower than the magnetizing impedance of the transformer, and the energy content is low and not of sufficient magnitude to produce overvoltages.

Air-blast generator circuit-breakers are usually shunted by low-ohmic damping resistors in series with an auxiliary interrupter. This auxiliary interrupter interrupts these small inductive currents, thus, current chopping levels are in the order of those of air-blast distribution circuit-breakers. Some air-blast generator circuit-breakers may be equipped with voltage-dependent resistors connected across the magnetizing current interrupter.

Experience indicates that the current chopping level of SF_6 self-blast generator circuit-breakers is low and should not produce overvoltages of concern.

In general, no difficulties should be expected due to switching of excitation currents. If tests and/or calculations are to be carried out for a specific application, they should be performed based on agreement between the user and the manufacturer.

Therefore a detailed test procedure for switching unloaded transformers, i.e. breaking transformer excitation currents, is not considered in this standard. The reasons for this are as follows:

a) due to the non-linearity of the transformer core, it is not possible to correctly model the switching of the transformer excitation current by using linear components in a test laboratory. Tests conducted using an available transformer, such as a test transformer, will only be valid for the transformer tested and cannot be representative for other transformers;
b) as detailed in IEC 62271-306, the characteristics of this duty are usually less severe than any other inductive current switching duty. It should be noted that such a duty may produce severe overvoltages within the transformer winding(s) depending on the circuit-breaker re-ignition behaviour and transformer winding resonance frequencies.

8.103.11 Capacitive switching current

The generator circuit-breaker normally is not called on to switch capacitive currents. Therefore capacitive switching is considered a special application and is not addressed in this standard. And if the generator circuit-breaker is required to have a capacitive current switching capability, the manufacturer should be consulted.

NOTE In case a surge capacitor is connected to the circuit, its capacitance value is usually in the order of 200 nF. The resulting current is less than 4 A and generator circuit-breakers are capable of switching such capacitive currents.

9 Information to be given with enquiries, tenders and orders

Clause 9 of IEC 62271-1:2007 is not applicable.

When enquiring for or ordering a generator circuit-breaker, the following particulars should be supplied by the enquirer and responded to by the manufacturer:

a) Particulars of systems:
    1) single-line diagram of the power station;
    2) rated, minimum and maximum operating voltages;

3) rated frequency;

4) generator data (ratings, decrement curve, reactances, time constants, armature resistance, moment of inertia and operating capability curve showing MW and MVAr limits);

5) earthing method of the generator;

6) power transformers' data (ratings, reactances, resistances or time constant);

7) power transformers' tap changer steps, if any, and change of impedance with tap-changer operation;

8) maximum system short-circuit current on high-voltage side of main transformer (including future requirements);

9) high-voltage system time constant;

10) value of surge capacitors, if any.

b) Application:

1) type of power station (e.g. fossil, hydro, nuclear, base-load, or peaking power station);

2) 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 8.102.2);

3) indoor or outdoor installation of the generator circuit-breaker;

4) limiting dimensions at generator circuit-breaker location;

5) minimum and maximum phase spacings;

6) interlocks and key coordination system;

7) type of bus between generator and generator step-up transformer (e.g. isolated phase bus, segregated phase bus, cable bus, cables, etc). Note that if cables are used, the type of cable construction should be given.

8) bus conductor and enclosure temperatures at generator circuit-breaker terminals;

9) cooling of bus (if forced air cooling, air flow rate and inlet air temperature at each pole of the generator circuit-breaker);

10) overpressure of air for enclosed buses;

11) expected frequency of operations.

c) Required characteristics of generator circuit-breaker:

1) operating voltage;

2) insulation level;

3) power frequency;

4) normal current;

5) short-time withstand current;

6) peak withstand current;

7) duration of short-circuit;

8) short-circuit making current;

9) system-source short-circuit breaking current (r.m.s. value of the a.c. component and time constant);

10) if applicable, generator-source short-circuit breaking current (r.m.s. value of the a.c. component and degree of asymmetry);

11) load making and breaking current;

12) if applicable, out-of-phase switching conditions;

13) transient recovery voltages (TRV) for the switching conditions according to indents 9), 10), 11) and 12) above;

14) mechanical operation endurance capability.

d) Characteristics of the operating mechanism of generator circuit-breaker and associated equipment, in particular:

1) number and type of spare auxiliary switches;

2) rated supply voltage and rated supply frequency;

3) number of releases for tripping, if more than one;

4) number of releases for closing, if more than one.

e) Requirements or restrictions concerning the use of compressed gas and requirements for design and tests of pressure vessels.

f) Information of any special conditions not included above, that might influence the tender or order (see also Clause 8).

10 Rules for transport, storage, installation, operation and maintenance

Clause 10 of IEC 62271-1:2007 is not applicable and is replaced with the following:

It is essential that the transport, storage and installation of generator circuit-breakers, as well as their operation and maintenance in service, be performed in accordance with instructions given by the manufacturer.

In addition commissioning tests shall be performed as part of the installation according to 10.2.101 taking into consideration the routine tests to be performed after final assembly.

Consequently, the manufacturer should provide the appropriate version of the instruction manual for the transport, storage, installation including any routine tests to be performed during commissioning as well as for the operation and maintenance of the generator circuit-breaker. The instructions for the transport and storage should be given at a convenient time before delivery, and the instructions for the installation, commissioning, operation and maintenance should be given by the time of delivery at the latest. It is preferable that the operation manual be a separate document from the installation, commissioning and maintenance manual.

It is impossible, here, to cover in detail the complete rules for the installation, commissioning, operation and maintenance of each one of the different types of generator circuit-breakers manufactured; however, the following information is given relative to the most important points to be considered for the instructions provided by the manufacturer.

NOTE Refer also to IEEE C37.12.1™-2007 [28].

10.1 Conditions during transport, storage and installation

Subclause 10.1 of IEC 62271-1:2007 is not applicable and is replaced with the following:

A special agreement should be made between manufacturer and user if the service conditions of temperature and humidity defined in the order cannot be guaranteed during transport, storage and installation.

Special precautions may be essential for the protection of insulation during transport, storage and installation, and prior to energizing, to prevent moisture absorption due, for instance, to rain, snow or condensation.

Vibrations during transport shall be considered. Shock recorders with the appropriate measuring characteristics should be installed during the shipment. Appropriate instructions should be given.

10.2 Installation

10.2.1 Unpacking and lifting

Subclause 10.2.1 of IEC 62271-1:2007 is not applicable and is replaced with the following:

Each complete equipment shall be provided with adequate lifting facilities and labelled (externally) to show the correct method of lifting. The equipment shall be labelled (externally) to indicate its shipping mass in kg or in "kg and [weight lb]", when fully equipped. Special lifting devices shall be capable of lifting the mass of each transport unit and special precautions shall be detailed in the installation manual (for example lifting brackets/bolts that are not intended to be used only temporarily shall be removed at site).

Required information for unpacking should be given.

10.2.2 Assembly

Subclause 10.2.2 of IEC 62271-1:2007 is not applicable and is replaced with the following:

When the generator circuit-breaker is not fully assembled for transport, all transport units should be clearly marked. Drawings showing assembly of these parts should be provided with the generator circuit-breaker.

10.2.3 Mounting

Subclause 10.2.3 of IEC 62271-1:2007 is not applicable and is replaced with the following:

Instructions for the mounting of the generator circuit-breaker, the operating device and the auxiliary equipment should include sufficient details of locations and foundations to enable site preparation to be completed.

These instructions should also indicate

– the total mass of the apparatus inclusive of extinguishing or insulating fluids;
– the mass of extinguishing or insulating fluids;
– the mass of the heaviest part of the apparatus to be lifted separately if it exceeds 100 kg [weighs more than 220 lb].

10.2.4 Connections

Subclause 10.2.4 of IEC 62271-1:2007 is not applicable and is replaced with the following:

Instructions should include information on

a) connection of conductors, comprising the necessary advice to prevent overheating and unnecessary strain on the generator circuit-breaker and to provide adequate clearance distances;
b) connection of auxiliary circuits;
c) connection of liquid or gas systems, if any, including size and arrangement of piping;
d) connection for earthing.

10.2.5 Final installation inspection

Subclause 10.2.5 of IEC 62271-1:2007 is not applicable and is replaced with the following:

Instructions should be provided for inspection and tests which should be made after the generator circuit-breaker has been installed and all connections have been completed.

These instructions should include

– a schedule of recommended site tests to establish correct operation;
– procedures for carrying out any adjustment that may be necessary to obtain correct operation;
– recommendations for any relevant measurements that should be made and recorded to help with future maintenance decisions;
– instructions for final inspection and putting into service.

10.2.6 Basic input data by the user

Subclause 10.2.6 of IEC 62271-1:2007 is not applicable and is replaced with the following:

a) Specific pressure vessel rules and procedures that may apply during installation and commissioning tests.
b) Interface requirements for high-voltage cables and transformers.
c) In-service conditions or operating restrictions that shall be respected;
d) Safety regulations that shall be adhered to.

NOTE The following information is rarely provided in the instructions relating to the generator circuit-breaker; however, it is usually given as part of the work plan for the site.

e) Access limitations to the local site.
f) Local working conditions and any restrictions that may apply (for example, safety equipment, normal working hours, union requirements for supervisor, manufacturer's and local installation crew, etc.).
g) Availability and capacity of lifting and handling equipment.
h) Availability, number and experience of local personnel.

10.2.7 Basic input data by the manufacturer

Subclause 10.2.7 of IEC 62271-1:2007 is not applicable and is replaced with the following:

a) Space necessary for installation and assembly.
b) Size and mass [weight] of components and testing equipment.
c) Site conditions regarding cleanliness and temperature for clean installation and preparation area.
d) Number and experience of local personnel required for installation.
e) Time and activity schedules for installation and commissioning.
f) Electric power, lighting, water and other needs for installation and commissioning.
g) Proposed training of installation and service personnel.
h) In case of extension to existing generator circuit-breaker
   - out-of-service requirements of existing components related to the installation schedule;
   - safety precautions.

10.2.101 Commissioning tests

After a generator circuit-breaker has been installed and all connections have been completed, commissioning tests shall be performed.

The purpose of commissioning tests is for confirmation of

– absence of damage, due to transport and storage;
– compatibility of separate units;
– correct assembly;
– correct performance of the assembled generator circuit-breaker.

The manufacturer shall produce a programme of site commissioning checks and tests.

When generator circuit-breakers are shipped as complete units the commissioning tests shall 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. Repetition of the full programme of routine tests, already performed in the factory, shall be avoided.

When generator circuit-breakers are assembled and shipped as separate units, the commissioning tests shall additionally also include the full set of routine tests as given in Clause 7.

10.2.102 Commissioning checks and test programme

10.2.102.1 General checks

The following general checks shall be performed:

– 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.

10.2.102.2 Checks of electrical circuits

The following electrical circuits checks shall be performed:

– conformity to the wiring diagram;
– correct operation of signalling (position, alarms, lockouts, etc.);
– correct operation of heating and lighting.

10.2.102.3 Checks of the insulation and/or extinguishing fluid(s)

The following checks shall be performed as applicable:

– oil type;
– oil dielectric strength (IEC 60296:2012);
– oil level.
– gas/compressed air filling pressure/density;
– gas/compressed air quality checks, to confirm the manufacturer's acceptance levels.

The quality checks are not required on sealed generator circuit-breakers or if generator circuit-breakers are filled on site by using new gas from sealed bottles.

10.2.102.4 Checks on operating fluid(s), where filled or added on site

The following checks shall be performed as applicable:

– Hydraulic oil level;
– Unless otherwise agreed, confirmation that the moisture content of the hydraulic oil is sufficiently low to prevent internal corrosion or other damage to the hydraulic system.
– Nitrogen/compressed air filling pressure;
– Nitrogen/compressed air purity (for example oxygen free or 1 % tracer gas).

10.2.102.5 Mechanical tests and measurements

10.2.102.5.1 Measurements of the characteristic insulating and/or interrupting fluid pressures (where applicable)

10.2.102.5.1.1 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.

10.2.102.5.1.2 Verifications of alarm function

Where applicable, on rising pressure: disappearance of the low-pressure or low-density alarm.

10.2.102.5.2 Measurements of characteristic operating fluid pressures (if applicable)

10.2.102.5.2.1 General

The following measurements (list to be adapted as necessary) shall 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.).

10.2.102.5.2.2 Verifications

The following verifications shall be made as applicable:

a) On a rise in pressure with the pumping device (pump, compressor, controlled valve, etc.) in service:
   – disappearance of the low-pressure alarm;
   – cut-off of the pumping device;
   – opening of the safety valve (if applicable).

   NOTE The measurements can be combined with the measurements of the recharging time of the operating mechanism (see 10.2.102.5.4.2).

b) On a drop in pressure with the pumping device switched off:

– losing of the safety valve (if applicable);
– starting of the pumping device;
– appearance of the low-pressure alarm.

10.2.102.5.3 Verification of the standard operating sequence

The ability of the generator circuit-breaker to perform its specified standard operating sequence mechanically should be verified under de-energized conditions. The tests should be performed with the recharging device in service, with site supply voltage.

The site supply voltage is the on-load voltage available at the generator circuit-breaker from the normal site supply and should be compatible with the rated supply voltage of auxiliary and control circuits.

10.2.102.5.4 Verification of time quantities

10.2.102.5.4.1 Characteristic time quantities of the generator circuit-breaker

The following time quantities shall be verified:

a) Closing and opening times, time spread

The following measurements shall 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, the 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 shall be carried out for separate opening and closing operations and for the opening and closing operations of a CO operating cycle.

NOTE The simultaneity of poles during the opening operation of a CO operating cycle can be different from the simultaneity of poles during a separate opening operation.

In the case of multiple trip coils, all shall 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 generator circuit-breaker.

10.2.102.5.4.2 Recharging time of the operating mechanism

The following recharging time shall be verified as applicable:

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;
– CO three-pole.

b) Spring-operated mechanism

The recharging time of the motor after a closing operation should be measured at the site supply voltage.

10.2.102.5.5 Record of mechanical travel characteristics

If the generator circuit-breaker has been assembled as a complete generator circuit-breaker for the first time on site or where all or part of the routine tests are performed on site, then, as required by 7.101, a record shall be made of the mechanical travel characteristics to confirm satisfactory performance by comparison with the reference mechanical travel characteristics obtained during the reference no-load tests detailed in 6.101.1.1.

If the generator circuit-breaker has been assembled as a complete circuit-breaker at the factory and the mechanical travel characteristics recorded according to 7.101 no further record on site is required.

10.2.102.5.6 Simulation of fault-making operation and check of anti-pumping device

A CO operation shall be performed with the trip circuit energised by the closing of the auxiliary contact. The closing command shall be maintained for at least 1 s in order that the anti-pumping device can be checked for effective operation.

The test also verifies the proper function during the rapid application of the opening command.

NOTE A simplified anti-pumping test can also be executed, using the local control. In this case, a closing command is applied and maintained, while a consecutive opening command is applied.

10.2.102.6 Electrical tests and measurements

10.2.102.6.1 Dielectric tests

Dielectric tests on auxiliary circuits shall be performed to confirm that transportation and storage of the generator 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.

Power frequency withstand voltage tests on the main circuits according to 7.1 are required only if the interrupting units have been assembled on site.

If the generator circuit-breaker is equipped with additional components (e.g. surge arresters, surge capacitors, voltage transformers, etc.), then those components can be disconnected or removed prior to the on-site dielectric test.

10.2.102.6.2 Measurement of the resistance of the main circuit

Measurement of the resistance of the main circuit need only be made if the interrupting units have been assembled on site. The measurement shall be made with a direct current in accordance with 7.3.

10.3 Operation

The instructions given by the manufacturer should contain the following information:

- a general description of the equipment with particular attention to the technical description of its characteristics and operation so that the user has an adequate understanding of the main principles involved;
- a description of the safety features of the equipment and the operation of the interlocks and padlocking facilities;
- as relevant, a description of the action to be taken to manipulate the equipment for operation isolation, earthing, maintenance, and testing;
- as relevant, measures against corrosion should be given.

10.4 Maintenance

10.4.1 General

The effectiveness of maintenance depends mainly on the way instructions are prepared by the manufacturer and implemented by the user.

10.4.2 Recommendations for the manufacturer

a) The manufacturer’s maintenance manual should include the following information.

1) Extent and frequency of maintenance. For this purpose the following factors should be considered:
   - switching operations (current and number);
   - total number of operations;
   - time in service (periodic intervals);
   - environmental conditions;
   - measurements and diagnostic tests, (if any).
2) Detailed description of the maintenance work:
   - recommended place for the maintenance work (indoor, outdoor, in factory, on site, etc.);
   - procedures for inspection, diagnostic tests, examination, overhaul;
   - reference to drawings;
   - reference to part numbers;
   - use of special equipment or tools;
   - precautions to be observed (for example cleanliness and possible effects of harmful arcing by-products);
   - lubrication procedures.
3) Comprehensive drawings of the details of the generator circuit-breaker important for maintenance, with clear identification (part number and description) of assemblies, subassemblies and significant parts.

   Expanded detail drawings which indicate the relative position of components in assemblies and subassemblies are a recommended illustration method.
4) Limits of values and tolerances which, when exceeded, make corrective action necessary, for example,
   - pressures, density levels;
   - resistors and capacitors (of the main circuit);
   - operating times;
   - resistance of the main circuits;
   - insulating liquid or gas characteristics;
   - quantities and quality of liquid or gas (see IEC 60480:2004 and IEC 62271-4:2013 for SF_6);
   - permissible erosion of parts subject to wear;

- torques;
- important dimensions.

5) Specifications for auxiliary maintenance materials, including warning of known non-compatibility of materials:
   - grease;
   - oil;
   - fluid;
   - cleaning and degreasing agents.
6) List of special tools, lifting and access equipment.
7) Tests after the maintenance work.
8) List of the recommended spare parts (description, reference number, quantities) and advice for storage.
9) Estimate of active scheduled maintenance time.
10) How to proceed with the equipment at the end of its operating life, taking into consideration environmental requirements.

b) The manufacturer should inform the purchasers of a particular type of generator circuit-breaker about corrective actions required by systematic defects and failures detected in service.

c) Availability of spares:

The manufacturer should be responsible for ensuring the continued availability of spare parts required for maintenance for a period of not less than 10 years from the date of final manufacture of the generator circuit-breaker.

10.4.3 Recommendations for the user

a) The user should prepare maintenance plans based on the maintenance manual of the manufacturer.

b) The user should record the following information:
   - the serial number and the type of the generator circuit-breaker;
   - the date when the generator circuit-breaker is put in service;
   - the results of all measurements and tests including diagnostic tests carried out during the life of the generator circuit-breaker;
   - dates and extent of the maintenance work carried out;
   - the history of service, periodical records of the operation counters and other indications (for example short-circuit operations);
   - references to any failure report.

c) In case of failure and defects, the user should make a failure report and should inform the manufacturer by stating the special circumstances and measures taken. Depending upon the nature of the failure, an analysis of the failure should be made in collaboration with the manufacturer.

10.4.4 Failure report

NOTE Refer also to IEEE C37.10™-2011 [16].

The purpose of the failure report is to standardize the recording of the generator circuit-breaker failures with the following objectives:

- to describe the failure using a common terminology;
- to provide data for the user statistics;
- to provide a meaningful feedback to the manufacturer.

The following gives guidance on how to make a failure report.

A failure report should include

a) identification of the generator circuit-breaker which failed:
   - substation name;
   - identification of the generator circuit-breaker (manufacturer, type, serial number, ratings);
   - generator circuit-breaker family (air blast, minimum oil, SF_6, vacuum);
   - location (indoor, outdoor);
   - enclosure;
   - operating mechanism, if applicable (hydraulic, pneumatic, spring, motor).
b) history of the generator circuit-breaker:
   - date of commissioning of the equipment;
   - date of failure/defect;
   - total number of operating cycles, if applicable;
   - date of last maintenance;
   - details of any changes made to the equipment since manufacture;
   - total number of operating cycles since last maintenance;
   - condition of the generator circuit-breaker when the failure/defect was discovered (in service, maintenance, etc.).
c) identification of the subassembly/component responsible for the primary failure/defect
   - high-voltage stressed components;
   - electrical control and auxiliary circuits;
   - operating mechanism, if applicable;
   - other components.
d) stresses presumed to contribute to the failure/defect:
   - environmental conditions (temperature, wind, rain, snow, ice, pollution, lightning, etc.).
e) classification of the failure/defect:
   - major failure;
   - minor failure;
   - defect.
f) origin and cause of the failure/defect:
   - origin (mechanical, electrical, tightness if applicable);
   - cause (design, manufacture, inadequate instructions, incorrect mounting, incorrect maintenance, stresses beyond those specified, etc.).
g) consequences of the failure or defect:
   - generator circuit-breaker down-time;
   - time consumption for repair;
   - labour cost;
   - cost of spare parts.

A failure report may include the following information:

- drawings, sketches;
- photographs of defective components;

– single-line station diagram;
– operation and timing sequences;
– records or plots;
– references to maintenance or operating manuals.

11 Safety

Clause 11 of IEC 62271-1:2007 is not applicable and is replaced with the following:

Generator circuit-breakers can be considered safe when installed in accordance with the relevant installation rules including those provided by the manufacturers and used and maintained in accordance with the manufacturer's instructions (see Clause 10).

A generator circuit-breaker is normally only accessible by qualified persons. It shall be operated and maintained by skilled persons. When unrestricted access is available to the generator circuit-breaker, additional safety features may be required.

Generator circuit-breakers in accordance with this standard offer a high level of safety with regard to external effects that might harm personnel. Nevertheless, high power equipment, can present some potential risks, some examples are:

– the enclosures, if any, may be pressurized with gas;
– opening of pressure-relief devices due to an internal arc, originated by exceptional conditions. In extreme circumstances, the arc can burn through the enclosures. Both result in the sudden release of hot gas;
– sudden events, which are in themselves with low risk to humans, may alarm personnel and lead to accidents (for example, a fall);
– commissioning, maintenance and extension activities may require special attention due to the complexity of the equipment and its internal parts which are mostly not visible.

Experience has shown that human error is a factor that shall be considered (for example, closing an earthing switch on an energized conductor).

11.1 Precautions by manufacturers

Subclause 11.1 of IEC 62271-1:2007 is not applicable and is replaced with the following:

The following list is an example of precautions that may be taken by manufacturers.

– Design and test of pressurized enclosures, pressure relief devices and relevant elements to international electrical standards such as IEC, ANSI, CENELEC, and JIS.
– Provide adequate and easy means to check interlocking systems (the most reasonable way to avoid human error).
– Explain safe operation of the generator circuit-breaker clearly in instruction manuals. Explain precautions to prevent improper operation and the consequences of improper operation.
– Provide the user and/or contractor with appropriate information related to design of the surrounding area and, in the case of gas insulated generator circuit-breaker in a building, ventilation and gas detection information, to minimize personnel risks in case a failure occurs.

11.2 Precautions by users

Subclause 11.2 of IEC 62271-1:2007 is not applicable and is replaced with the following:

The following list is an example of precautions that may be taken by users.

– Limit access to the installation to people who are trained and authorized.
– Keep operators and other personnel instructed regarding risks and safety requirements including local regulations.
– Keep generator circuit-breaker maintained and up to date in terms of technical standards, especially interlocking and protection devices.
– Use remote control and have the interlocking system working as intended.
– Select equipment that minimizes the risk to personnel from improper operation (for example, fast acting earthing switches on lines, motor operators to allow remote operation).
– Coordinate the protection system with product properties (for example, do not reclose on internal faults).
– Prepare earthing procedures considering the difficulty of referring to and understanding the complex arrangement and operation of the switchgear and controlgear.
– Label equipment clearly for easy identification of individual devices and gas compartments.

Especially during maintenance, repair or extension work:

– Ensure that maintenance, repair and extension work is carried out only by qualified and trained personnel.
– Prepare a safety and protection plan for the work. Indicate who is responsible for planning, implementing and enforcing safety and protection measures.
– Check interlocking and protection devices before starting.
– Pay special attention to manual operations, especially when the generator circuit-breaker is energized.
– Inform personnel who may be near the generator circuit-breaker before operating the equipment (for example, a horn or flashing light).
– Mark emergency exits and keep passages clear of obstructions.
– Instruct the people involved how to work safely in a generator circuit-breaker environment and what to do in an emergency.

The following specifications of this standard provide personal safety measures for generator circuit-breakers against various hazards.

11.3 Electrical aspects

Subclause 11.3 of IEC 62271-1:2007 is not applicable and is replaced with the following:

– insulation of the isolating distance (refer to 4.2);
– earthing (indirect contact) (refer to 5.3);
– separation of HV and LV circuits (refer to 5.4);
– IP coding (direct contact) (refer to 5.13.1 of IEC 62271-1:2007)

11.4 Mechanical aspects

Subclause 11.4 of IEC 62271-1:2007 is not applicable and is replaced with the following:

– pressurized components (refer to 5.2);
– manual actuating force (refer to 5.6.3 of IEC 62271-1:2007);
– IP coding (moving parts) (refer to 5.13.1 of IEC 62271-1:2007);
– mechanical impact protection (refer to 5.13.3 of IEC 62271-1:2007).

11.5 Thermal aspects

Subclause 11.5 of IEC 62271-1:2007 is not applicable and is replaced with the following:

– maximum temperature of accessible parts (refer to Table 3 of IEC 62271-1:2007);
– flammability (refer to 5.17)

11.6 Operation aspects

Subclause 11.6 of IEC 62271-1:2007 is not applicable and is replaced with the following:

– manual charging (refer to 5.6.3 of IEC 62271-1:2007);
– interlocking devices (refer to 5.11);
– position indication (refer to 5.12).

The manufacturer shall give guidance on request, concerning disassembly and end-of-life procedures for the different materials of the equipment and indicate the possibility to recycle.

12 Influence of the product on the environment

Clause 12 of IEC 62271-1:2007 is not applicable and is replaced with the following:

The manufacturer shall be prepared to provide on request, the following relevant information about the environmental impact of the generator circuit-breaker.

When fluids are used in the generator circuit-breaker, as far as is practicable, instructions should be provided in order to allow the user to

– minimize the leakage rate;
– control the handling of the new and used fluids.

The manufacturer shall give guidance on request, concerning disassembly and end-of-life procedures for the different materials of the equipment and indicate the possibility to recycle.

Annex A
(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 A.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.

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.

Table A.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	Power-frequency withstand 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 I r.m.s. value =	±5 %	
6.2.6.2	Lightning impulse voltage test	Peak value	Rated lightning impulse voltage	±3 % for procedure B –0 % to +3 % for procedure C	
		Front time	1,2 µs	±30 %	
		Time to half-value	50 µs	±20 %	
6.4	Measurement of the resistance of the main circuit	DC test current I_{DC}	–	100 A ≤ I_{DC} ≤ rated normal current	IEC 62271-1
6.5	Temperature-rise tests Test tolerances and limits shall be kept only for the last two hours of the testing period.	Ambient air velocity	–	≤0,5 m/s	IEC 62271-1
		Test current frequency	Rated frequency	±2 %	
		Test current	Rated normal current	+2 % / 0 %	
		Temperature rises of IPB conductor and enclosure	see Table 9	±5 K	
		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	See tolerances for I^2t in 6.6.2	
		The ratio of the a.c. component of test current in any phase to the average	1	± 10 %	
		Duration of short-circuit	Rated duration of short-circuit	See tolerances for I^2t	
		Value of I^2t	Rated value I^2t	+10 % / 0 %	
6.101.3	Low and high temperature tests	Variation in ambient air temperature	–	≤5 K	
		Ambient air temperature for recording characteristics before test	20 °C	±5 K	

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/limits of test values	Reference to
		Minimum and maximum ambient air temperature during tests	According to class of generator circuit-breaker (see 2.1)	±3 K	
6.102.10	Demonstration of the most severe switching conditions	Maximum arcing time to be controlled	Specified test value	±1 ms	
6.103	System-source short circuit making and breaking tests				
6.103.2	Frequency of test circuit	Frequency	Rated frequency	–2 % to +5 %	
6.103.5	Applied voltage before system-source short-circuit making tests	Applied voltage	See 6.103.5	+10 % / 0 %	
		Applied phase voltage / average (three-phase)	1	±5 %	
6.103.6 and 6.103.7	System-source short-circuit making current and System-source short-circuit breaking current	a.c. component of any phase / average	1	±10 %	
		Peak making current	See Tables 16 and 17	–0 % to +10 %	
		a.c. component of the prospective current at final arc extinction in last-pole-to-clear	Specified breaking current for the relevant test-duty	≥90 %	
		Average of the a.c. components of the prospective current at contact separation	Specified breaking current for the relevant test-duty	≥100 %	
6.103.8	Transient recovery voltage (TRV) for system-source short-circuit breaking tests	Peak value of TRV:	See Table 3	+10 % / 0 %	
		Rate of rise of TRV:	See Table 3	+15 % / 0 %	
		Time delay	See Table 3	±20 %	
6.103.10	Power frequency recovery voltage	Power frequency recovery voltage	See Table 16 and Table 17	±5 %	
6.104	Load current breaking tests	Peak value of TRV:	See Table 5	+10 % / 0 %	
		Rate of rise of TRV:	See Table 5	+15 % / 0 %	
		Time delay	See Table 5	±20 %	
6.105	Generator-source short-circuit current making and breaking tests				
6.105.2	Frequency of test circuit	Frequency	Rated frequency	–2 % to +5 %	
6.105.6 and 6.105.7	Generator-source short-circuit making current and Generator-source short-circuit	a.c. component of any phase / average	1	±10 %	
		Peak making current	See Tables 18 and 19	–0 % to +10 %	

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/limits of test values	Reference to
	breaking current	a.c. component of the prospective current at final arc extinction in last-pole-to-clear	Specified breaking current for the relevant test-duty	≥90 %	
		Average of the a.c. components of the prospective current at contact separation	Specified breaking current for the relevant test-duty	≥100 %	
6.105.8	Transient recovery voltage (TRV) for generator-source short-circuit breaking tests	Peak value of TRV:	See Table 4	+10 % / 0 %	
		Rate of rise of TRV:	See Table 4	+15 % / 0 %	
		Time delay	See Table 4	±20 %	
6.105.10	Power frequency recovery voltage	Power frequency recovery voltage	See Table 18 and Table 19	±5 %	
6.105.12.4	Asymmetrical current breaking test-duties	Arcing time for test-duty 5	≥ 1 cycle	≥1 cycle – 2 ms	
6.105.12.4	Asymmetrical current breaking test-duties	Arcing time for test-duty 6A ad 6B	≥ 1,5 cycles	≥1,5 cycles – 3 ms	
6.106	Out-of-phase making and breaking tests	Frequency	Rated frequency	–2 % to +5 %	
		Degree of asymmetry of breaking current	75 %	–0 % to +5 %	
		Applied voltage and power frequency recovery voltage	See Tables 20 and 21	±5 %	
		Peak value of TRV:	See Table 6	+10 % / 0 %	
		Rate of rise of TRV:	See Table 6	+15 % / 0 %	
		Time delay	See Table 6	±20 %	
		Instant of closing in one of the operations of test duty OP1	At crest of applied voltage in one pole	±20°	
		Breaking current for test duties OP1 and OP2	See Table 20 and Table 21	+10 % / 0 %	

Annex B
(normative)

Records and reports of type tests according to 6.6, 6.103, 6.104, 6.105 and 6.106

B.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 B.2 shall be made of all 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 generator circuit-breaker during each test-duty and of the condition of the generator 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 generator circuit-breaker, giving details of any replacements or adjustments made and condition of contacts, 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.

B.2 Information to be included in type test reports

B.2.1 General

The following information shall be included in the type test reports:

a) date of tests;
b) reference of report number;
c) test numbers;
d) oscillogram numbers.

B.2.2 Apparatus tested

Subclause 6.1.3 and A.2 of IEC 62271-1:2007 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.

B.2.3 Rated characteristics of generator 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.

B.2.4 Test conditions (for each series of tests)

The following information shall be included in the type test reports:

a) number of poles;
b) frequency, in Hz;
c) generator neutral (earthed or isolated);
d) transformer neutral (earthed or isolated);
e) short-circuit point or load side neutral (earthed or isolated);
f) diagram of test circuit including connection(s) to earth;
g) details of connection of generator circuit-breaker to the test circuit (e.g. orientation);
h) pressure of fluid for insulation and/or interruption;
i) pressure of fluid for operation.

B.2.5 Short-circuit making and breaking tests

The following information shall be included in the type test reports:

a) operating sequence and time intervals;
b) applied voltage, in kV;
c) making current (peak value), in kA;
d) prospective current for test duties 2, 5, 6A and 6B:
   1) r.m.s. value of a.c. component in kA for each phase and average;
   2) degree of asymmetry at intended contact separation (applicable to test-duties 5, 6A and 6B);
   3) peak current in the expected last current loop (applicable only to test-duty 2 for the phase having the highest degree of asymmetry);
   4) loop duration of the expected last current loop (applicable only to test-duty 2 for the phase having the highest degree of asymmetry and first-pole-to-clear);
   5) the number of current peaks and relative minimums until the first current zero crossing (applicable to test-duties 5, 6A and 6B only).
e) breaking current:
   1) r.m.s. value of a.c. component in kA for each phase and average
   2) degree of asymmetry at contact separation;
   3) peak current in the last current loop;
   4) loop duration of the last current loop;
f) power frequency recovery voltage, in kV;
g) transient recovery voltage:
   1) prospective transient recovery voltage in accordance with requirements of 6.103.8 and 6.105.8;
   2) transient recovery voltage during the actual test;
h) arc parameters:
   1) arcing time, in ms;
   2) arc-voltage (applicable to test-duties 5, 6A and 6B only);
i) opening time, in ms;
j) 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.

k) closing time, in ms;

l) make time, in ms;

m) behaviour of generator circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDD's shall be noted;

n) condition after tests;

o) parts renewed or reconditioned during the tests.

B.2.6 Short-time withstand current test

The following information shall be included in the type test reports:

a) current
   1) r.m.s. value, in kA,
   2) value of the first major peak, in kA;

b) duration in s;

c) equivalent duration in s based on the specified short-time current;

d) behaviour of generator circuit-breaker during tests;

e) condition after tests;

f) resistance of the main circuit before and after tests, in $\mu\Omega$.

B.2.7 No-load operation

The following information shall be included in the type test reports:

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).

B.2.8 Out-of-phase making and breaking tests

The following information shall be included in the type test reports:

a) prospective current for test-duties OP1 and OP2:
   1) r.m.s. value of a.c. component in kA for each phase and average;
   2) peak current in the expected last current loop (applicable only to test duty OP2 for the phase having the highest degree of asymmetry);
   3) loop duration of the expected last current loop (applicable only to test duty OP2 for the phase having the highest degree of asymmetry and first-pole-to-clear).

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) degree of asymmetry at contact separation;
   3) peak current in the last current loop;
   4) loop duration of the last current loop.

e) power frequency recovery voltage, in kV;

f) transient recovery voltage:
   1) prospective transient recovery voltage in accordance with requirements of 6.106.6;
   2) transient recovery voltage during the actual test;

g) arcing time, in ms;

h) opening time, in ms;

i) break-time, in ms;

j) closing time, in ms;

k) make-time, in ms;

l) duration of resistor current (where applicable), in ms;

m) behaviour of generator circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDD's shall be noted;

n) condition after tests;

o) parts renewed or reconditioned during the tests.

B.2.9 Load current switching tests

The following information shall be included in the type test reports:

a) r.m.s. value of a.c. component of the breaking current in A for each phase and average;

b) power frequency recovery voltage, in kV;

c) transient recovery voltage:

   1) prospective transient recovery voltage in accordance with requirements of 6.104.2;

   2) transient recovery voltage during the actual test;

d) arcing time, in ms;

e) opening time, in ms;

f) break-time, in ms;

g) behaviour of generator circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDD's shall be noted;

h) condition after tests;

i) parts renewed or reconditioned during the tests.

B.2.10 Oscillographic and other records

Oscillograms shall record the whole of the operation including the prospective tests. 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;

d) current and/or voltage in closing coil;

e) current and/or voltage 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 C
(…)

This Annex is left blank intentionally.

Annex D
(normative)

Use of mechanical characteristics and related requirements

At the beginning of the type tests, the mechanical characteristics of the generator 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 generator 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 17. In case of generator 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 generator circuit-breakers, these methods may be unsuitable, as for example for vacuum generator circuit-breakers. In such cases the manufacturer shall define an appropriate method to verify the proper operation of the generator 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 16 through 19 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 18 and 19. 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 %.

Annex E
(informative)

Example of the application of a generator circuit-breaker

E.1 General

The application guide appearing in Clause 8 was used in developing this example.

When requesting proposals for a.c. generator circuit-breakers, it is important that the purchaser provide the manufacturer with a specification containing the information outlined in Clause 9. This information alerts the manufacturer to the application conditions in 8.102 and 8.103.

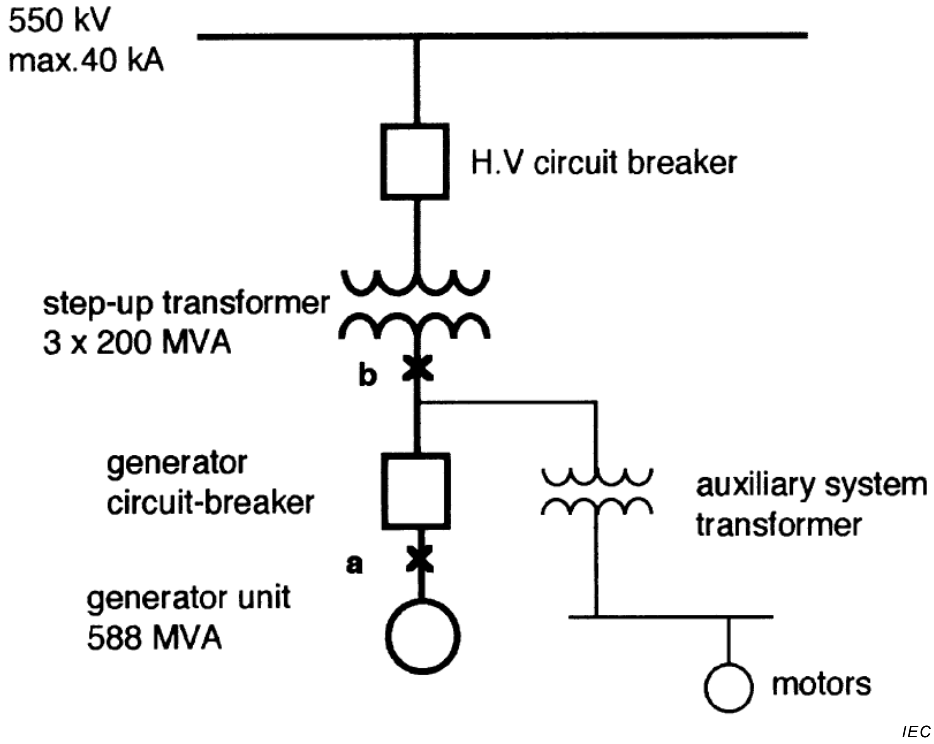


Figure E.1 – Single-line station diagram

The example given in E.2 describes an actual indoor generator circuit-breaker application for a 588 MVA, coal-fired, continuous-load power plant. The generator circuit-breaker is forced-air cooled.

E.2 System characteristics

System characteristics are described in Table E.1.

Table E.1 – System characteristics

Item	Corresponding IEC (IEEE) Symbol	Value
a) Single-line diagram		See Figure E.1
b) Maximum generator line-to-line voltage (kV)	U_{mG}	22,05
c) Rated frequency (Hz)	f_r	60
d) Generator data (rated values):		
1) Rated power (MVA)	S_{rG}	588
2) Rated voltage (kV)	U_{rG} (in IEEE called V_{nG})	21
3) Reactance values in p.u.:		At rated voltage (saturated)
i) Synchronous direct axis	$x_{d\ sat}$ (in IEEE called X_{dv})	2,0
ii) Transient direct axis	$x'_{d\ sat}$ (in IEEE called X'_{dv})	0,31
iii) Subtransient direct axis	$x''_{d\ sat}$ (in IEEE called X''_{dv})	0,24
iv) Synchronous quadrature axis	$x_{q\ sat}$ (in IEEE called X_{qv})	2,04
v) Transient quadrature axis	$x'_{q\ sat}$ (in IEEE called X'_{qv})	0,5
vi) Subtransient quadrature axis	$x''_{q\ sat}$ (in IEEE called X''_{qv})	0,25
vii) Negative sequence	$x_{2\ sat}$ (in IEEE called X_{2v})	0,24
viii) Zero sequence	$x_{0\ sat}$ (in IEEE called X_{0v})	0,1
4) Time constants in seconds:		
i) Transient open-circuit	τ'_{do} (in IEEE called T'_{do})	5,63
ii) Transient short-circuit	τ'_{d} (in IEEE called T'_{d})	0,84
iii) Subtransient open-circuit	τ''_{do} (in IEEE called T''_{d0})	0,034
iv) Subtransient short-circuit	τ''_{d} (in IEEE called T''_{d})	0,025
v) Transient open-circuit quadrature	τ'_{qo} (in IEEE called T'_{q0})	–
vi) Transient short-circuit quadrature	τ'_{q} (in IEEE called T'_{q})	0,255
vii) Subtransient open-circuit quadrature	τ''_{qo} (in IEEE called T''_{q0})	–
viii) Subtransient short-circuit quadrature	τ''_{q} (in IEEE called T''_{q})	0,025
ix) Armature short-circuit	τ_a (in IEEE called T_a)	0,31
5) Generator earthing		Earthed with high resistance through distribution transformer
6) Moment of inertia (kgm^2)	J	28 300
7) Capacitance of armature winding-to-earth (all phases tied together) (μF)		0,9
e) Generator step-up transformer data (rated values):		
1) Rated voltage (kV)	U_{rTHV}/U_{rTLV}	550/21
2) Rated power (MVA)	S_{rT}	3 × 200
3) Connection		Wye Star effectively earthed/delta
4) Short-circuit reactance at rated voltage (p.u.)	u_{krT}	0,14
5) Tap changer range on HV side (1,25 % steps)		–10 % /+5 %
Change in short-circuit reactance		–5 % /+ 2,5 %
6) Time constant $X/\omega R$ (ms)	τ_T	160

Item	Corresponding IEC (IEEE) Symbol	Value
f) System-source initial symmetrical short-circuit current on high-voltage side of generator step-up transformer (future requirement) (kA)	$I''_{\text{k sys}}$	40
g) Time constant $X/\omega R$ of the high-voltage system (ms)	τ_{sys}	45
h) Maximum service voltage of the high-voltage system (kV)	$U_{\text{m sys}}$	577,5
i) Unit auxiliary transformer data (rated values):		
1) Rated voltage (kV)	$U_{\text{r aux transf HV}}/U_{\text{r aux transf LV}}$	21/6,3
2) Rated power (MVA)	$S_{\text{r aux transf}}$	35
3) Short-circuit reactance at rated voltage (p.u.)	$u_{\text{kr aux transf}}$	0,08
4) Time constant $X/\omega R$ (ms)	$\tau_{\text{aux transf}}$	100

E.3 System-source short-circuit current

E.3.1 AC component of the system-source short-circuit breaking current

The following example is based on a fault at location "a" (see Figure E.1)

The r.m.s. value of the a.c. component of the system-source short-circuit breaking current is the highest r.m.s. value of the symmetrical component of the polyphase short-circuit current that the generator circuit-breaker has to interrupt at rated voltage and rated duty cycle.

For a 40 kA system-source short-circuit current contribution on the 550 kV side, the required system short-circuit reactance seen from the 21 kV low-voltage side is as follows:

$$X_{\text{sys}} \cong \frac{550}{40\sqrt{3}}\left(\frac{21}{550}\right)^2 = 11,57 \times 10^{-3}\Omega$$

The short-circuit reactance of the main transformer with a rated power of 600 MVA and a short-circuit reactance of 0,14 p.u. yields a reactance of the following:

$$X_{\text{t}} \cong 0,14 \times \frac{21}{600}^{2} = 102,9 \times 10^{-3}\Omega$$

The calculation of the system-source short-circuit breaking current shall be based on the maximum service voltage of the high-voltage system. Therefore, the short-circuit contribution from the system side is as follows:

$$I_{\text{sc}_{\text{sys+ t}}} = \frac{22,05}{\sqrt{3}\left((11,57 + 102,9) \times 10^{-3}\right)} = 111,21\text{kA}$$

The contribution to the short-circuit current from the auxiliary system motors is a small fraction of the current from the high-voltage system. It can be determined as follows if the motors are connected through two auxiliary transformers each rated 35 MVA, 0,08 p.u. short-circuit reactance, and with a time constant of 100 ms (X/R ratio of 37,7). The maximum rating of all motors combined is 60 MVA with the conservative assumption that all are in service at the same time. The rated voltage of the motors U_{rM} in this example is assumed to be equal to the rated voltage of the LV-winding of the unit auxiliary transformer.

The motor short-circuit impedance is as follows:

$$Z_{\mathrm{M}} = \frac{I_{\mathrm{rM}}}{I_{\mathrm{LR}}} \times \frac{U_{\mathrm{rM}}^2}{S_{\mathrm{rM}}} \times \left(\frac{U_{\mathrm{r\,aux\,transf HV}}}{U_{\mathrm{r\,aux\,transf LV}}} \right)^2 = 0{,}2 \times \frac{6{,}3^2}{60} \left(\frac{21}{6{,}3} \right)^2 \cong X_{\mathrm{M}} = 1{,}47\ \Omega$$

with $I_{\mathrm{rM}}/I_{\mathrm{LR}}$ being the ratio of rated motor current to the locked rotor motor current and equal to approximately 0,2 in the given example.

$$X_{\mathrm{aux\ transf}} \cong 0{,}08 \times \frac{21^2}{70} = 0{,}504\ \Omega$$

The initial symmetrical r.m.s. short-circuit current contribution from the auxiliary system is as follows:

$$I''_{\mathrm{k\ aux\ sys}} \times \frac{22{,}05}{\sqrt{3}\left(1{,}47 + 0{,}504\right)} = 6{,}45\ \mathrm{kA}$$

This initial current decays and the current interrupted at a contact separation time of 40 ms to 80 ms can be estimated as being equal to 0,7 to 0,85 times the initial current $I''_{\mathrm{k\ aux\ sys}}$. If the factor is 0,8, which is based on the selected generator circuit-breaker having a 58,3 ms (opening time 50 ms plus a tripping delay of 0,5 cycles) contact separation time, the contribution from the auxiliary system to the r.m.s. value of the a.c. component of the system-source short-circuit breaking current will be 5,16 kA.

The r.m.s. value of the a.c. component of the total system-source short-circuit breaking current seen by the generator circuit-breaker is as follows:

$I_{\mathrm{sc\ tot\ cs}}$ = 111,21 + 5,16 = 116,37 kA

E.3.2 System-source asymmetrical short-circuit breaking current

The following example is based on a fault at location “a” (see Figure E.1), and on the calculations in E.3.1. The d.c. component of the system-source short-circuit current is equal to the following:

$$I_{\mathrm{dc}} = \left(\sqrt{2}\, I''_{\mathrm{k}}\right) e^{-t/\tau}$$

where

I''_{k} is the system-source initial symmetrical short-circuit current. Assuming that the r.m.s. value of the a.c. component of the system-source short-circuit current is constant with time I''_{k} is equal to the r.m.s. value of the a.c. component of the system-source short-circuit breaking current $I_{\mathrm{sc\ sys\ +\ t}}$ that was determined to be 111,21 kA through the step-up transformer for a 40 kA system short-circuit current contribution on the high-voltage side of the step-up transformer;

I_{dc} is the d.c. component of the system-source short-circuit current;

τ is $\left(\frac{1}{\omega} \times \frac{X}{R} \right)$;

X is the short-circuit reactance of system elements;

R is the resistance of system elements;

ω is the angular frequency corresponding to the rated frequency.

As for the a.c. component of the system-source short-circuit current the d.c. component is composed of the contribution from the high-voltage system through the step-up transformer and the d.c. component of the auxiliary system. It has to be determined at contact separation.

The high-voltage system time constant is 45 ms, and its short-circuit reactance is determined as follows: $X_{sys} = 11{,}57 \times 10^{-3}\ \Omega$ (see E.3.1).

It follows that:

$$R_{sys} = \frac{11{,}57 \times 10^{-3}}{377 \times 45 \times 10^{-3}} = 0{,}682 \times 10^{-3} \Omega$$

The time constant of the generator step-up transformer is 160 ms and the transformer short-circuit reactance was calculated to be $X_t = 102{,}9 \times 10^{-3}\ \Omega$.

This leads to the following step-up transformer resistance:

$$R_t = \frac{102{,}9 \times 10^{-3}}{377 \times 160 \times 10^{-3}} = 1{,}706 \times 10^{-3} \Omega$$

The total reactance and resistance which have to be considered for the calculation of the high-voltage system contribution to the system-source short-circuit current through the step-up transformer are:

$$X_{sys+t} = X_{sys} + X_t = 11{,}57 \times 10^{-3} + 102{,}9 \times 10^{-3} = 114{,}47 \times 10^{-3} \Omega$$

$$R_{sys+t} = R_{sys} + R_t = 0{,}682 \times 10^{-3} + 1{,}706 \times 10^{-3} = 2{,}39 \times 10^{-3} \Omega$$

Therefore, the time constant τ_{sys} tot of the decay of the d.c. component of the short-circuit current from the high-voltage system through the step-up transformer is as follows:

$$\tau_{sys+t} = \frac{114{,}47 \times 10^{-3}}{377 \times 2{,}39 \times 10^{-3}} = 127{,}04 \text{ ms}$$

The auxiliary system transformer's short-circuit reactance was evaluated to be 0,504 Ω and is assumed to have a time constant of 100 ms [$(X/R)_{aux\ transf}$ = 37,7]. Therefore, the resistance is as follows:

$R_{aux\ transf}$ = 0,013 4 Ω

For the motors a reactance of X_M = 1,47 Ω was calculated. The resistance R_M for motors greater than 1 MW rated power is approximately 0,1 times X_M. Therefore,

R_M = 0,147 Ω

The time constant of the decrement of the d.c. component from the auxiliary system is as follows:

$$\tau_{aux\ sys} = \frac{X_{aux\ transf} + X_M}{\omega \times \left(R_{aux\ transf} + R_M\right)} = \frac{0{,}504 + 1{,}47}{377 \times \left(0{,}0134 + 0{,}147\right)} = 32{,}64 \text{ ms}$$

The d.c. component of the total system-source short-circuit current (including the d.c. component of the auxiliary system contribution), at a contact separation of the generator circuit-breaker of 58,3 ms (opening time 50 ms plus a tripping delay of 0,5 cycles), is the sum of the contribution from the high-voltage system through the step-up transformer and the auxiliary system contribution.

$$I_{\text{dc sys + t cs}} = 111{,}21 \times \sqrt{2} \times e^{-58{,}3/127{,}04} = 99{,}39 \text{ kA}$$

$$I_{\text{dc aux sys cs}} = 6{,}45 \times \sqrt{2} \times e^{-58{,}3/32{,}64} = 1{,}53 \text{ kA}$$

$$I_{\text{dc tot cs}} = 99{,}39 + 1{,}53 = 100{,}92 \text{ kA}$$

The degree of asymmetry at contact separation is therefore 61,3 %.

The asymmetrical short-circuit breaking current can be calculated using the equation described in 8.103.6.3.3 thus resulting in

$$I_{\text{sc asym tot cs}} = \sqrt{I_{\text{sc tot cs}}^2 + I_{\text{dc tot cs}}^2} = 154{,}04 \text{ kA}$$

E.4 Generator-source short-circuit current

E.4.1 AC component of the generator-source short-circuit breaking current

This current is measured from the envelope of the current excursion at the moment of contact separation when the source of the short-circuit current is entirely from a generator without transformation.

As mentioned in 8.103.6.3.4 this envelope has to be calculated from a full-load rated power factor condition taking the generator constants into account. Calculations are generally complex and are often performed with computer simulations.

Consequently the equations displayed below shall not be considered as exhaustive but they can be used to estimate the magnitude of the fault current when the generator is unloaded prior to fault.

The r.m.s. value of the a.c. component of the generator-source short-circuit breaking current can be calculated using the following equation for no-load conditions:

$$I_{\text{gen sym}} = \frac{U_{\text{mG}} S_{\text{rG}}}{\sqrt{3} U_{\text{rG}}^2} \left[\left(\frac{1}{x''_{\text{d}}} - \frac{1}{x'_{\text{d}}} \right) e^{-t/\tau''_{\text{d}}} + \left(\frac{1}{x'_{\text{d}}} - \frac{1}{x_{\text{d}}} \right) e^{-t/\tau'_{\text{d}}} + \frac{1}{x_{\text{d}}} \right]$$

where

U_{mG} is the maximum generator line-to-line voltage;

S_{rG} is the rated power of the generator;

U_{rG} is the rated voltage of the generator;

x''_{d} is the saturated value of the direct axis subtransient reactance in p.u.;

x'_{d} is the saturated value of the direct axis transient reactance in p.u.;

τ''_{d} is the direct axis subtransient short-circuit time constant;

τ'_{d} is the direct axis transient short-circuit time constant.

Using the data given for the generator in this example, the r.m.s. value of the a.c. component of the generator-source short-circuit breaking current at a contact separation equal to 58,3 ms results in the following when the generator is unloaded prior to fault:

$$I_{\text{scg cs}} = 53{,}2 \text{ kA.}$$

E.4.2 Generator-source asymmetrical short-circuit breaking current

The generator-source asymmetrical short-circuit current for the phase with the highest asymmetry, the generator being in the no-load mode, can be calculated by the following equation:

$$I_{\text{gen asym}} = \frac{\sqrt{2}U_{\text{mG}}S_{\text{rG}}}{\sqrt{3}U_{\text{rG}}^2}\left\{\left[\left(\frac{1}{x''_{\text{d}}}-\frac{1}{x'_{\text{d}}}\right)e^{-t/\tau''_{\text{d}}}+\left(\frac{1}{x'_{\text{d}}}-\frac{1}{x_{\text{d}}}\right)e^{-t/\tau'_{\text{d}}}+\frac{1}{x_{\text{d}}}\right]\cos(\omega t)\right\}$$

$$-\frac{\sqrt{2}U_{\text{mG}}S_{\text{rG}}}{\sqrt{3}U_{\text{rG}}^2}\left[\frac{1}{2}\left(\frac{1}{x''_{\text{d}}}+\frac{1}{x''_{\text{q}}}\right)e^{-t/\tau_{\text{a}}}+\frac{1}{2}\left(\frac{1}{x''_{\text{d}}}-\frac{1}{x''_{\text{q}}}\right)e^{-t/\tau_{\text{a}}}\cos(2\omega t)\right]$$

where

U_{mG} is the maximum generator line-to-line voltage;

S_{rG} is the rated power of the generator;

U_{rG} is the rated voltage of the generator;

x''_{d} s the saturated value of the direct axis subtransient reactance in p.u.;

x''_{q} is the saturated value of the quadrature axis subtransient reactance in p.u.;

x'_{d} is the saturated value of the direct axis transient reactance in p.u.;

τ''_{d} is the direct axis subtransient short-circuit time constant;

τ'_{d} is the direct axis transient short-circuit time constant;

τ_{a} is the armature time constant.

Since x''_{d} is approximately equal to x''_{q} for turbo generators, the equation can be written as follows:

$$I_{\text{gen asym}} = \frac{\sqrt{2}U_{\text{mG}}S_{\text{rG}}}{\sqrt{3}U_{\text{rG}}^2}\left\{\left[\left(\frac{1}{x''_{\text{d}}}-\frac{1}{x'_{\text{d}}}\right)e^{-t/\tau''_{\text{d}}}+\left(\frac{1}{x'_{\text{d}}}-\frac{1}{x_{\text{d}}}\right)e^{-t/\tau'_{\text{d}}}+\frac{1}{x_{\text{d}}}\right]\cos(\omega t)-\left(\frac{1}{x''_{\text{d}}}\right)e^{-t/\tau_{\text{a}}}\right\}$$

Figure E.2 shows a computer calculation of the three-phase asymmetrical short-circuit current for the example in this annex, assuming that the pre-fault voltage is the generator rated voltage and the fault occurs with the generator in the no-load mode. This case may occur when the generator circuit-breaker is closed into a bolted fault such as a closed earthing switch. At the location of the fault therefore, no arcing is taken into account. The asymmetry at the contact separation of the generator circuit-breaker is 110,1 %.

The asymmetrical short-circuit breaking current can be calculated using the equation described in 8.103.6.3.3 thus resulting in 98,5 kA.

Figure E.3 exhibits for comparison the calculated asymmetrical three-phase short-circuit current but with the assumption of an arc at the fault location influencing the asymmetry of the short-circuit current. Due to the arc voltage, the asymmetry is reduced to 68 % in comparison to Figure E.2 with an asymmetry of 110,1 %.

A free-burning arc in air has an arc voltage of 10 V/cm, which means that the arc voltage of a fault in the bus is at least 300 V. In the case of a failure occurring in a transformer, an arc would burn in oil with a considerably higher arc voltage.

The influence of the generator circuit-breaker arc on the phase with the maximum asymmetry is illustrated in the computer calculation in Figure 46.

The generator-source asymmetrical short-circuit current is normally calculated by using appropriate computer programs. For the generator-source short-circuit current with maximum degree of asymmetry and with the generator in an underexcited or overexcited mode, no approximate equation can be given so the short-circuit current is calculated using appropriate computer programs.

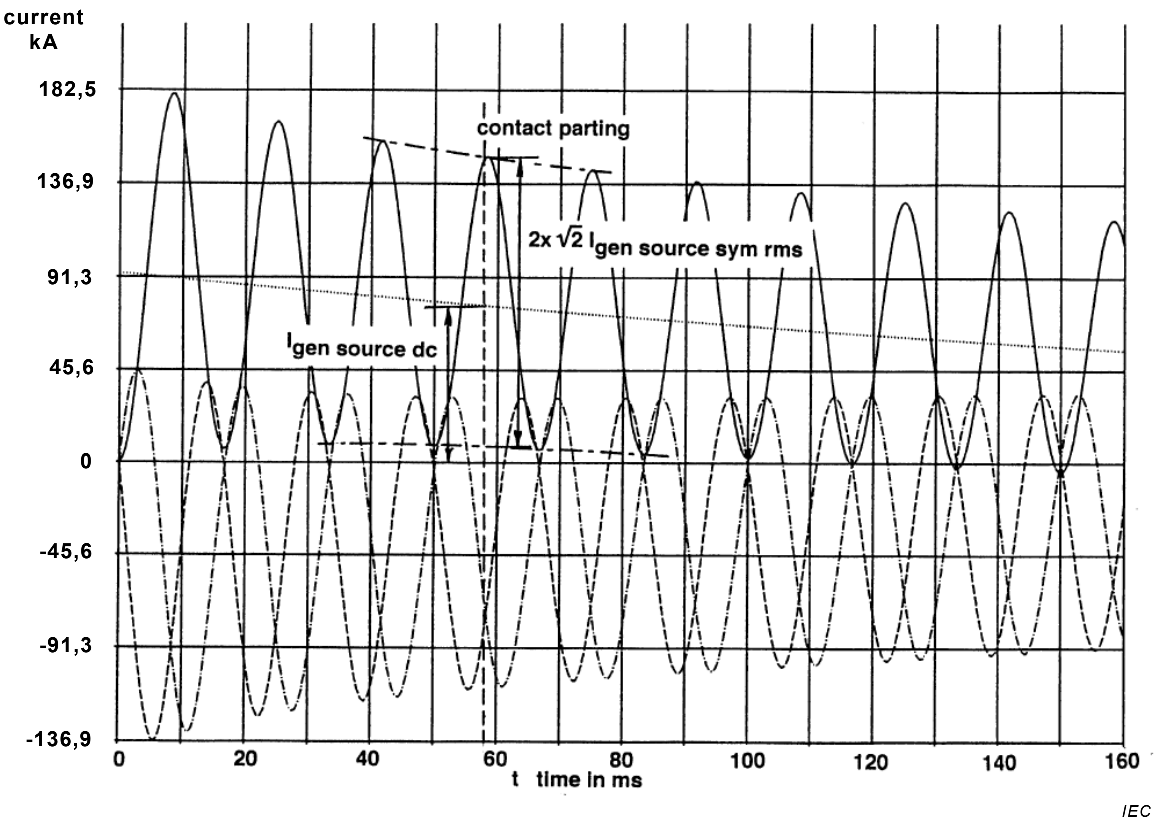


Figure E.2 – Asymmetrical generator-source short-circuit current with no arc at the fault location

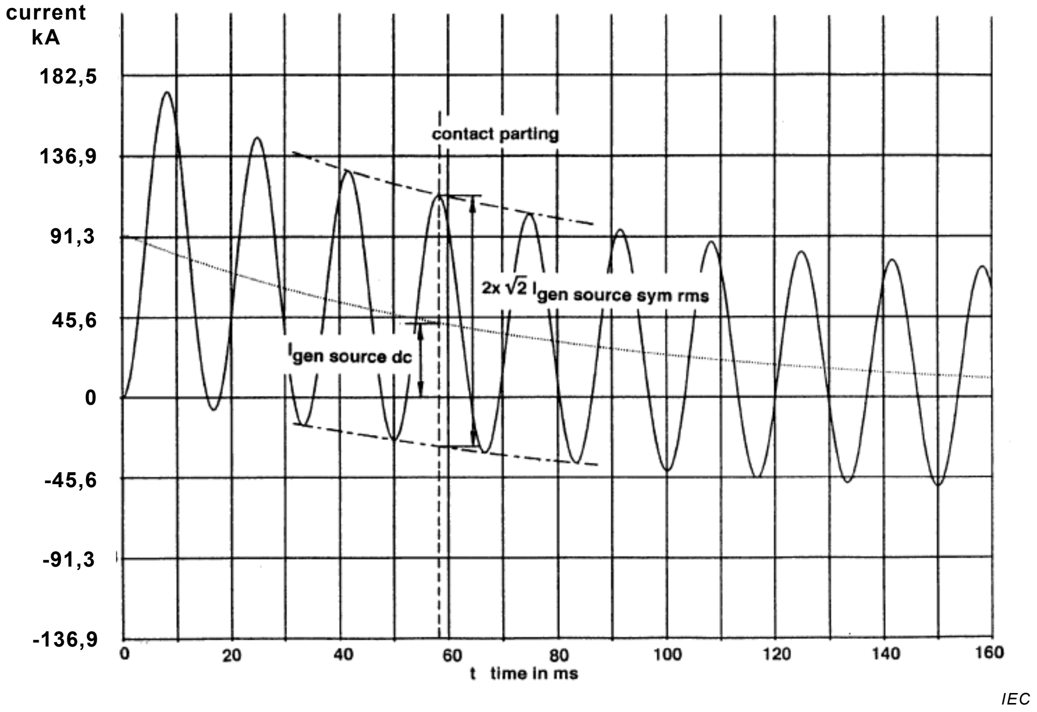


Figure E.3 – Asymmetrical generator-source short-circuit current with arc at the fault location

E.5 Transient recovery voltage

The prospective TRV for the system-source fault can be determined in the same manner as a transformer fed fault. The natural frequency of the transformer in the short-circuit mode has to be known. This frequency can be measured by means of a low-voltage injection method. When capacitors are used, they have to be accounted for in the actual TRV.

The TRV parameters given in this standard are the result of data from a large number of transformers and generators, normally from measurements, and they cover the most severe cases. See [2] and [3].

A calculation of the TRV for the system-source fault, as well as for the generator-source fault, may be inaccurate because the appropriate modelling is complicated and the necessary accurate data, which are partially frequency dependent, may not be available.

E.6 Out-of-phase conditions

An out-of-phase condition can occur under the following two conditions:

a) Instability in a high-voltage transmission system where the high-voltage circuit-breakers are tripped by the relevant protective scheme before a maximum 180° phase opposition is reached. This case can be disregarded for generator circuit-breakers;

b) Synchronizing with the generator circuit-breaker, if performed incorrectly, can result in an out-of-phase condition if the generator circuit-breaker has to be tripped.

The r.m.s. value of the a.c. component of the out-of-phase current (I_{oph}) for the latter case at the moment of current initiation (t = 0), can be estimated using the following expressions:

$$I_{oph} = \frac{U_{oph}}{X''_{d} + X_{t} + X_{s}}$$

where

U_{oph} is the out-of-phase voltage;

X''_{d} is the subtransient reactance of the generator in Ω;

X_{t} is the transformer short-circuit reactance in Ω;

X_{s} is the short-circuit system reactance in Ω;

NOTE The synchronization is generally performed with the generator voltage at its rated value.

This equation is valid for system diagrams such as Figure 48 or schematic diagram, Figure E.4, with generator and generator step-up transformer in series.

The ultimate out-of-phase current is lower than the initial out-of-phase current at $t = 0$ because it decreases based on the time constants of the generator, the transformer and the system.

As a better approach, for power station single-line diagrams such as Figure 48, the out-of-phase current can be approximately calculated using the following equation when the generator is in a no-load situation prior to the out-of-phase condition (see Figure E.4).

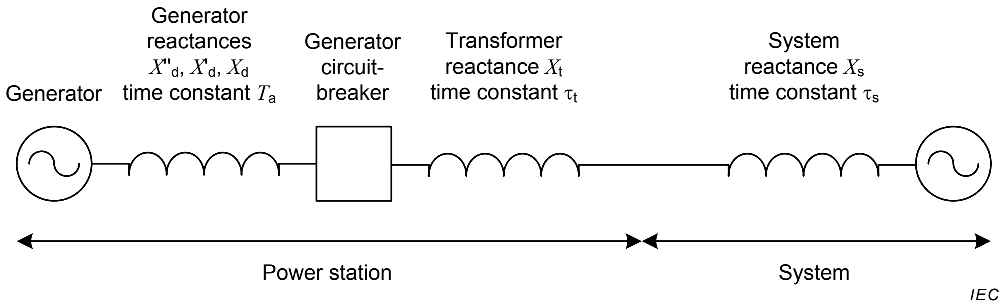


Figure E.4 – Schematic diagram of power station (single-line diagram as in Figure 48)

$$I_{oph} = \frac{\sqrt{2}U_{oph}S_{rG}}{\sqrt{3}U_{rG}^{2}}\left\{\left[\left(\frac{1}{x''_{d}+x_{s}+x_{t}} - \frac{1}{x'_{d}+x_{s}+x_{t}}\right)e^{-t/\tau''} + \left(\frac{1}{x'_{d}+x_{s}+x_{t}} - \frac{1}{x_{d}+x_{s}+x_{t}}\right)e^{-t/\tau'} + \frac{1}{x_{d}+x_{s}+x_{t}}\right]\cos(\omega t)\right\}$$

$$- \frac{\sqrt{2}U_{oph}S_{rG}}{\sqrt{3}U_{rG}^{2}}\left(\frac{1}{x''_{d}+x_{s}+x_{t}}\right)e^{-t/\tau}$$

where

$$\tau'' = \tau''_{d0}\left(\frac{x''_{d}+x_{s}+x_{t}}{x'_{d}+x_{s}+x_{t}}\right) = \tau''_{d}\left(\frac{x'_{d}}{x''_{d}} \times \frac{x''_{d}+x_{s}+x_{t}}{x'_{d}+x_{s}+x_{t}}\right) \text{ because } \tau''_{d0} \cong \tau''_{d}\left(\frac{x'_{d}}{x''_{d}}\right)$$

$$\tau' = \tau'_{d0}\left(\frac{x'_{d}+x_{s}+x_{t}}{x_{d}+x_{s}+x_{t}}\right) = \tau'_{d}\left(\frac{x_{d}}{x'_{d}} \times \frac{x'_{d}+x_{s}+x_{t}}{x_{d}+x_{s}+x_{t}}\right) \text{ because } \tau'_{d0} \cong \tau'_{d}\left(\frac{x_{d}}{x'_{d}}\right)$$

$$\tau = \frac{x''_{d}+x_{s}+x_{t}}{\frac{x''_{d}}{\tau_{a}} + \frac{x_{s}}{\tau_{s}} + \frac{x_{t}}{\tau_{t}}} = \frac{x''_{d}+x_{s}+x_{t}}{\frac{x''_{d}}{\tau_{a}} + x_{s} \times \frac{\omega}{(X/R)_{s}} + x_{t} \times \frac{\omega}{(X/R)_{t}}}$$

U_{oph} is the out-of-phase voltage which is equal to $\delta \times$ generator operating voltage prior to synchronization

δ is the out-of-phase factor and it is the ratio of the r.m.s. value of the voltage across the open contacts of the generator circuit-breaker and the relating generator operating voltage prior to synchronization

The reactances x''_d, x'_d, x_d, x_t, and x_s are p.u. values on generator MVA base

$\tau_s = (X/R)_s/\omega$ is the time constant of the high-voltage system

$\tau_t = (X/R)_t/\omega$ is the time constant of the step-up transformer

For a 180° out-of-phase condition, δ is equal to 2. Under this condition for the phase with full asymmetry one-half cycle after current initiation, the peak current is 234 kA plus some percentage contribution from the auxiliary system. This current peak is considerably higher than the generator terminal fault peak short-circuit current of 190 kA (calculated according to E.4.2). Such a high out-of-phase short-circuit current would damage the generator, taking into account that the mechanical forces increase as the square of the current. Consequently, the 180° out-of-phase condition shall be avoided by appropriate relay protection.

The contribution of the auxiliary system to the out-of-phase switching current should be taken into consideration depending upon power plant operation.

For the 90° out-of-phase condition, δ is equal to $\sqrt{2}$; the out-of-phase asymmetrical peak current after one-half cycle is 166 kA, which is lower than the generator terminal fault peak short-circuit current.

The calculated out-of-phase current at the contact separation for this example is 51 kA.

For a TRV calculation, the same considerations apply as in E.5. The TRV requirements are given in Table 6.

The calculation of the out-of-phase current waveshape shall be performed by computer programs that simulate the generator behaviour more completely. The current resulting from out-of-phase synchronizing can result in delayed current zeros whose causes are totally different compared to generator terminal faults (see 8.103.9.1). The rapid movement of the rotor from initial out-of-phase angle φ_0 to $\varphi = 0$ results in a very small a.c. component of the fault current and a dominant d.c. component when the condition of $\varphi = 0$ is reached. The current resulting from out-of-phase synchronizing has to include an accurate description of the behaviour of the synchronous machine. The instant when the $\varphi = 0$ condition is reached is determined by the movement of the rotor. Therefore the moment of inertia of turbine, rotor and excitation equipment of the generator are of special importance. Figure E.5 shows a computer simulation of the fault current resulting from synchronizing under out-of-phase conditions. In this example the synchronization occurs when the voltage across the open contacts of pole A (U_A) of the generator circuit-breaker is zero. From Figure E.5 it is evident that at the time when $\varphi = 0$ (about 150 ms after synchronization) the fault current is dominated by a d.c. component.

In case the fault current shows delayed current zeros the capability of the generator circuit-breaker to force current zeros has to be demonstrated by means of a calculation considering the effect of arc voltage. The procedure described in 8.103.9.1 applies.

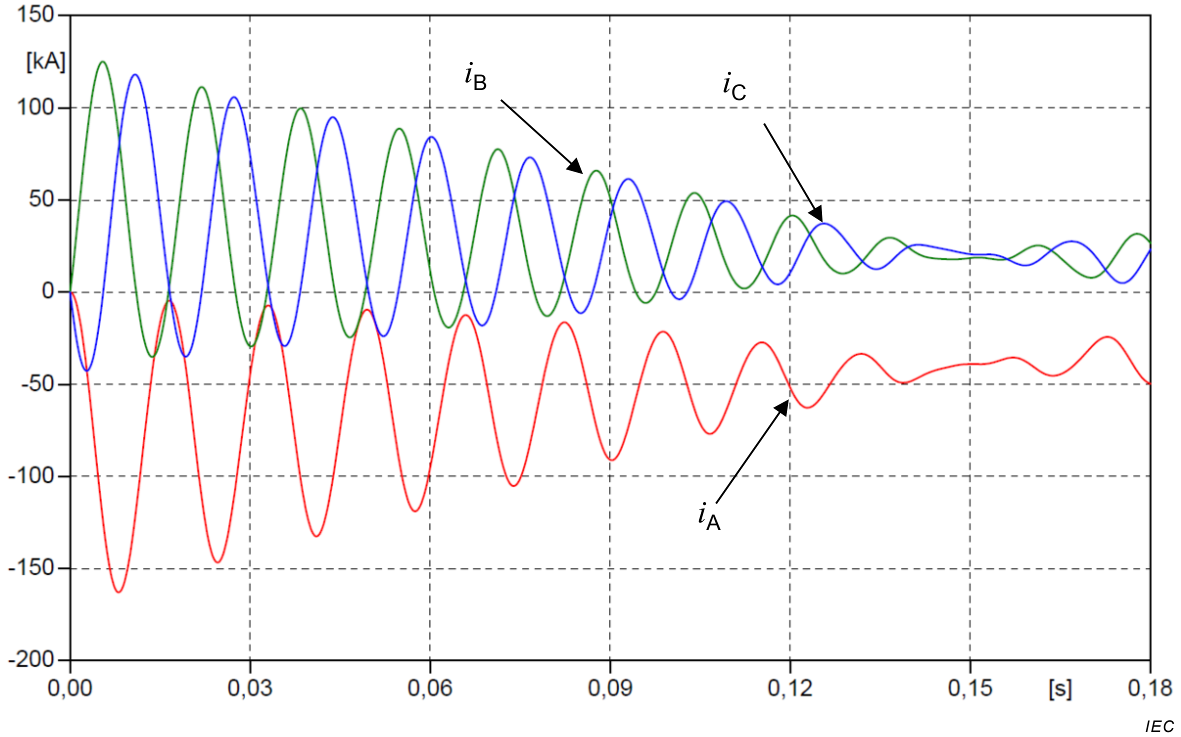


Figure E.5 – Prospective fault current considering the moment of inertia of the synchronous machine and resulting from synchronizing under out-of-phase conditions (out-of-phase angle φ_0 = 90°, fault initiation at U_A = 0)

E.7 Normal current application

The rated current of the generator at the rated voltage of 21 kV is as follows:

588 MVA / (21 √3 kV) = 16 200 A

Assuming a minimum operating voltage of 19,95 kV (i.e. 0,95 × 21 kV) the maximum r.m.s. value of the current which shall be carried continuously by the generator circuit-breaker is as follows:

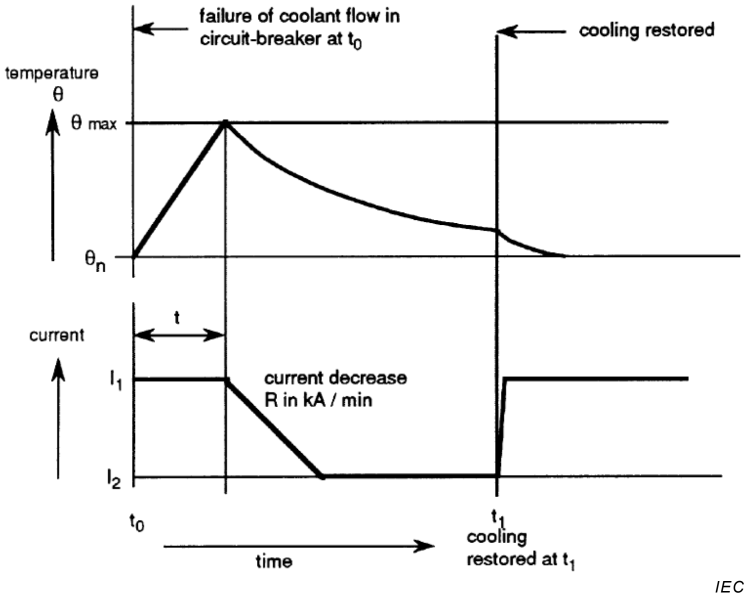
588 MVA / (0,95 × 21 × √3 kV) = 17 020 A

The generator circuit-breaker in this example is forced-air-cooled. Figure E.6 illustrates the procedure for calculating the normal current rating of the generator circuit-breaker when the forced-air-cooling fails.

With the forced-air-cooling in operation, the generator circuit-breaker can carry the rated current of the generator. If a failure occurs in the cooling system, the current shall be reduced, starting after the time t, with a decreasing rate R in kA/min, in order that the temperature of the circuit-breaker does not exceed the allowable hottest spot total temperature, θ_{max}. The allowable total temperature is limited by the materials used in the generator circuit-breaker (see Table 3 of IEC 62271-1:2007) so that there is no deterioration of any parts of the generator circuit-breaker.

The temperature decreases due to the lower current, tending toward the allowable hottest spot temperature, θ_n. The cooling is restored at a time t_1, and the current is increased to the rated current of the generator. Consequently, the temperature decreases to the allowable hottest spot temperature, θ_n. This emergency procedure has to be established with the manufacturer.

A similar procedure is used when the cooling system is more complicated (e.g., the generator circuit-breaker is water-cooled and the bus is forced-air-cooled). The emergency schedule contains, in such a case, the procedure for a failure in each of the cooling systems as indicated in Figure 9.



Key

θ_{max}	allowable hottest spot total temperature
θ_n	allowable hottest spot temperature at generator rated current
t	allowable time without reduction of current and without exceeding θ_{max}
I_1	rated current of the generator
I_2	allowable current with failure of coolant flow

Figure E.6 – Generator circuit-breaker temperature and load current with loss of coolant

E.8 Generator circuit-breaker electrical characteristics

The following are electrical characteristics to be specified for the generator circuit-breaker in the example:

Rated voltage	22,05 kV
Rated insulation level:	
Rated power frequency withstand voltage	60 kVrms
Rated lightning impulse withstand voltage	125 kVpeak
Rated normal current	17 020 A
Rated making current	321 kA
Rated system-source short-circuit breaking current	
r.m.s. value of the a.c. component	116,4 kA
degree of asymmetry	61,3 %

The following electrical characteristics have been estimated by using the equations in E.4 and E.6.

Generator-source short-circuit breaking current

r.m.s. value of the a.c. component	53,2 kA
degree of asymmetry	110,1 %

Out-of-phase breaking current

r.m.s. value of the a.c. component	51,0 kA
degree of asymmetry	89,4 %

In order to select the proper generator circuit-breaker for the application the calculations shall be performed by computer programs that simulate the generator behaviour correctly. The results of the last simulation in E.6 (see Figure E.5) take into account the moment of inertia of the synchronous machine and show the following:

Out-of-phase breaking current

Generator terminal voltage lagging system voltage referred to the LV-side of the step-up transformer

r.m.s. value of the a.c. component	37,9 kA
degree of asymmetry	120,6 %

Generator terminal voltage leading system voltage referred to the LV-side of the step-up transformer

r.m.s. value of the a.c. component	34,9 kA
degree of asymmetry	128,3 %

From the above results it is evident the decrement of the a.c. component of the out-of-phase fault current which in turns leads to a degree of asymmetry at contact separation higher than 100 % and hence to delayed current zeros. Specifically the a.c. component of the fault current is higher in case of generator terminal voltage lagging the system voltage than in case of generator terminal voltage leading the system voltage. On the other hand the degree of asymmetry is higher in case of generator terminal voltage leading the system voltage than in case of generator terminal voltage lagging the system voltage.

Annex F
(informative)

For generator circuit-breakers connected to the step-up transformer by shielded cables - An example of the effects of added capacitance on TRV requirements for a system-source fault

The prospective Transient Recovery Voltage (TRV) requirements for generator circuit-breakers under system-source fault conditions are listed in Table 3. They are based on the assumption that the step-up transformer will be connected to the generator circuit-breaker by bus. Although this assumption is true for many applications, several smaller installations also exist where the connection is made with shielded cables. One way of determining the effects of the capacitance added by shielded cables on the TRV that the generator circuit-breaker would experience while trying to clear a three-phase fault current, fed from a non-effectively earthed source, has been described by Dufournet and Montillet [5]. This method illustrates that the added capacitance of shielded cables used to connect the transformer to the generator circuit-breaker can have two significant effects on the TRV, as follows:

a) The rate of rise of the recovery voltage (RRRV), or “TRV rate,” is reduced.

b) The TRV peak (called u_c in Figure F.2 and in Figure F.4) is increased.

The significance of these effects can be illustrated in the following four figures:

– Figure F.1 shows the effect on the TRV rate-of-rise, associated with switching faulted transformers rated in the range of 65,5 MVA to 100 MVA.
– Figure F.2 shows the effect on the TRV peak, u_c, associated with switching faulted transformers rated in the range of 65,5 MVA to 100 MVA.
– Figure F.3 shows the effect on the TRV rate-of-rise, associated with switching faulted transformers rated in the range of 10 MVA to 50 MVA.
– Figure F.4 shows the effect on the TRV peak, u_c, associated with switching faulted transformers rated in the range of 10 MVA to 50 MVA.

These calculations are illustrative of a method to evaluate the effects of capacitance associated with cable connections. Certain other assumptions, such as the transformer short-circuit impedance of 14 %, although consistent with the other illustrative calculations in this document, are not intended to be completely representative of all applications.The user should carefully consider all the parameters of the particular circuit and determine the appropriate TRV values based on the actual parameters of the circuit under consideration.

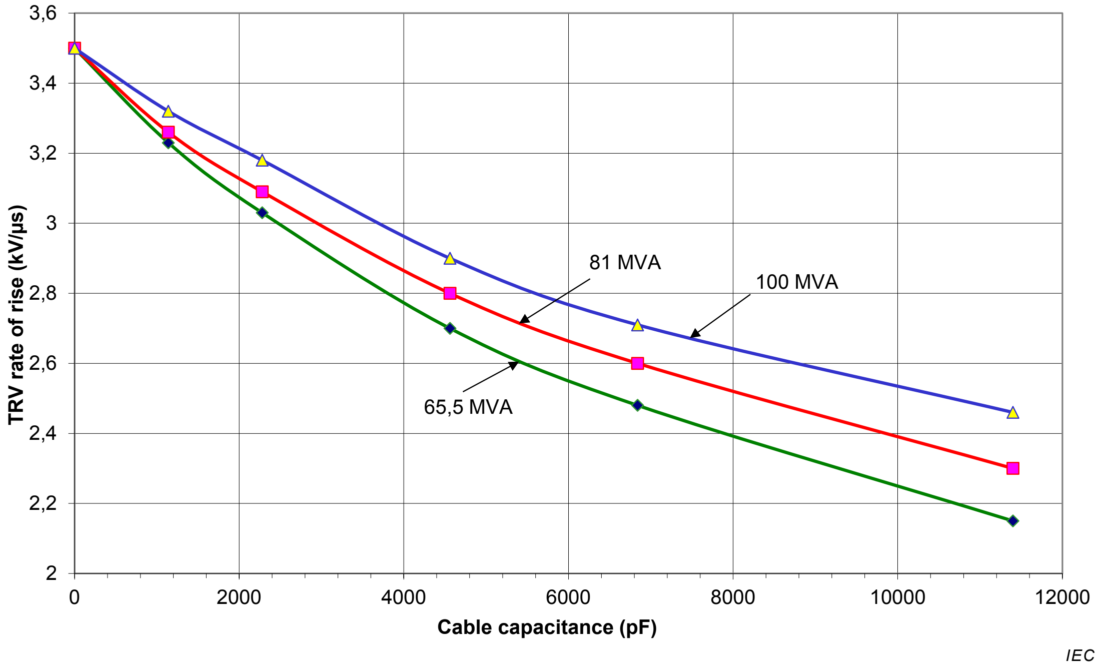


Figure F.1 – TRV rate-of-rise for system-source faults: transformers rated from 65,5 MVA to 100 MVA

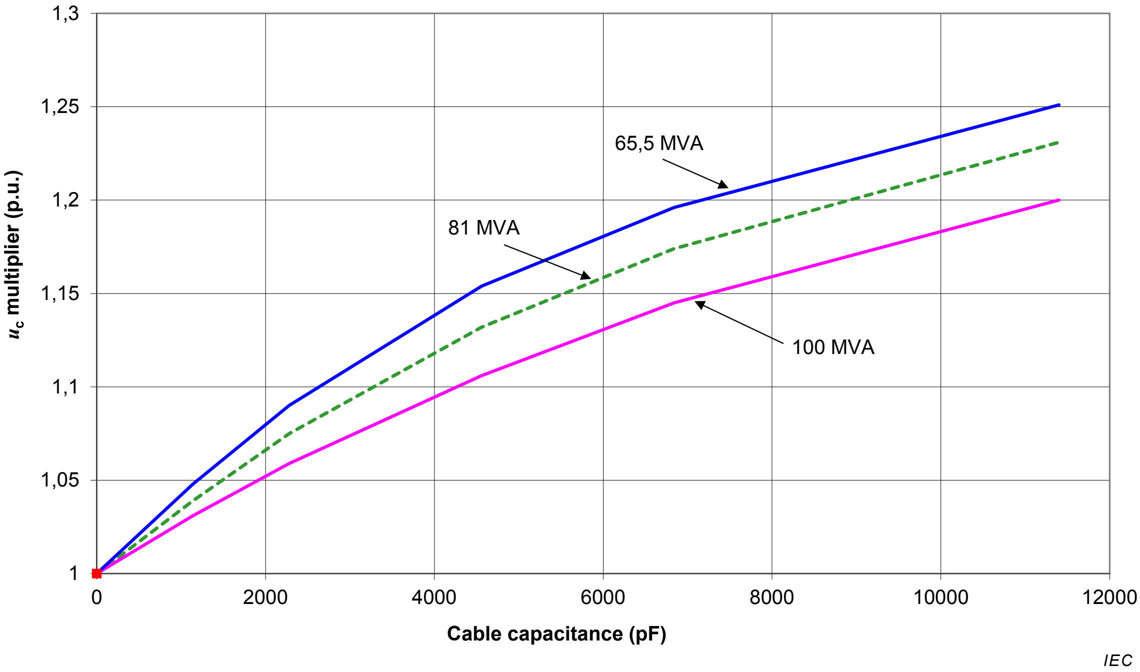


Figure F.2 – TRV peak (u_c) multipliers for system-source faults: transformers rated from 65,5 MVA to 100 MVA

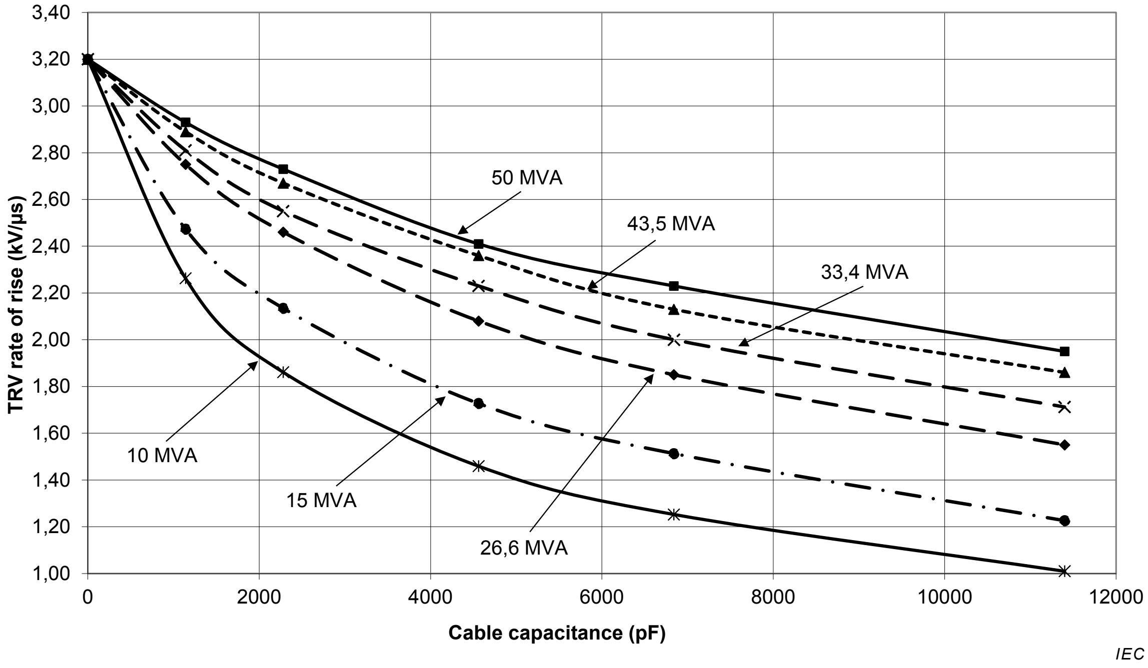


Figure F.3 – TRV rate-of-rise for system-source faults: transformers rated from 10 MVA to 50 MVA

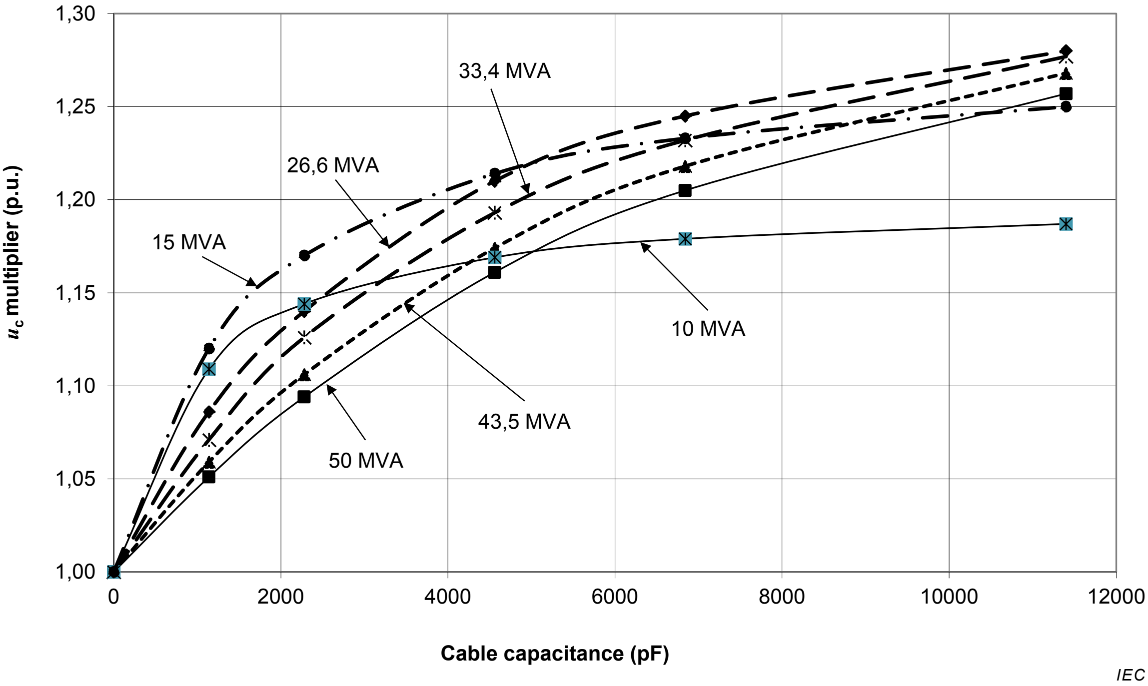


Figure F.4 – TRV peak (u_c) multipliers for system-source faults: transformers rated from 10 MVA to 50 MVA

Annex G
(informative)

Symbols and related terminology

G.1 Comparison of IEEE and IEC electrical terms and symbols

Table G.1 provides a listing of the most common terms and their respective abbreviations as used in IEEE and IEC.

NOTE The user is cautioned to the fact that some of the terms are very similar but have slightly different definitions between IEEE and IEC.

Table G.1 – Comparison of IEEE and IEC electrical terms and symbols

Abbreviation		Definition	Customary units	Appearing first in
IEEE	IEC			
V	U_r	Rated maximum voltage (IEEE); Rated voltage (IEC)	V rms	4.1
None	U_p	Rated lightning impulse withstand voltage	V peak	4.2.103
None	I_r	Rated continuous current (IEEE); Rated normal current (IEC)	A rms	4.4.1
None	Not used	Rated momentary withstand current	kA asymmetrical	Not used
None	I_p	Rated peak withstand current	kA peak	4.6
None	I_k	Rated short-time withstand current	kA symmetrical	4.5
None	t_k	Rated duration of short circuit	s	4.7
None	U_a	Rated supply voltage of closing and opening devices and auxiliary circuits	V rms	4.8
None	U_d	Rated power frequency withstand voltage	V rms	4.2.102
Grounded	Effectively earthed	System neutral is effectively connected to ground or earth		3.1.114
Ungrounded	Non-effectively earthed	System neutral is not connected to ground or earth, that is, the neutral is isolated or connected to ground or earth through a high impedance		3.1.115
		Rated dielectric strength (IEEE) Rated insulation level (IEC)		4.2.101
None	f_r	Rated power frequency (IEEE) Rated frequency (IEC)	Hz	4.3
		Rated short-circuit current duty cycle (IEEE) Rated short-circuit current operating sequence (IEC)		4.106.2
V_{nG}	U_{rG}	Rated voltage of the generator	kV	E.2
X_{dv}	$x_{d\ sat}$	Synchronous reactance direct axis – saturated value	Per Unit (p.u.)	E.2
X'_{dv}	$x'_{d\ sat}$	Transient reactance direct axis – saturated value	Per Unit (p.u.)	E.2
X''_{dv}	$x''_{d\ sat}$	Subtransient reactance direct axis – saturated value	Per Unit (p.u.)	E.2
X_{qv}	$x_{q\ sat}$	Synchronous reactance quadrature axis – saturated value	Per Unit (p.u.)	E.2
X'_{qv}	$x'_{q\ sat}$	Transient reactance quadrature axis – saturated value	Per Unit (p.u.)	E.2

Abbreviation		Definition	Customary units	Appearing first in
IEEE	IEC			
$X"_{qv}$	$x"_{q\ sat}$	Subtransient reactance quadrature axis – saturated value	Per Unit (p.u.)	E.2
X_{2v}	$x_{2\ sat}$	Negative sequence reactance – saturated value	Per Unit (p.u.)	E.2
X_{0v}	$x_{0\ sat}$	Zero sequence reactance – saturated value	Per Unit (p.u.)	E.2
T'_{do}	τ'_{do}	Transient open-circuit time constant direct axis	s	E.2
T'_{d}	τ'_{d}	Transient short-circuit time constant direct axis	s	E.2
$T"_{do}$	$\tau"_{do}$	Subtransient open-circuit time constant direct axis	s	E.2
$T"_{d}$	$\tau"_{d}$	Subtransient short-circuit time constant direct axis	s	E.2
T'_{qo}	τ'_{qo}	Transient open-circuit time constant quadrature axis	s	E.2
T'_{q}	τ'_{q}	Transient short-circuit time constant quadrature axis	s	E.2
$T"_{do}$	$\tau"_{qo}$	Subtransient open-circuit time constant quadrature axis	s	E.2
$T"_{d}$	$\tau"_{q}$	Subtransient short-circuit time constant quadrature axis	s	E.2
T_{a}	τ_{a}	Armature short-circuit time constant	s	E.2
	I_{MC}	Closing, latching and carry current (IEEE) Short-circuit making current (IEC)		4.102
		Out-of-phase switching current (IEEE) Out-of-phase making and breaking current (IEC)		4.104
		Rated Interrupting time (IEEE) Rated break time (IEC)		4.107.2
		Usual service condition (IEEE) Normal service condition (IEC)		2.1
		Unusual service condition (IEEE) Special service condition (IEC)		2.2
		Design test (IEEE) Type test (IEC)		Clause 6
		Production test (IEEE) Routine test (IEC)		Clause 7
		Phase – A, B, C (IEEE) Phase – R, S, T (IEC)		Figure 6

G.2 Comparison between TRV terminology and symbols

Table G.2 and Figure G.1 provide a comparison between the TRV terminology and symbols used in IEC 62271-100 with those used in older IEEE/ANSI standards.

Table G.2 – A comparison between the TRV terminology and symbols used in IEC 62271-100 with those used in older IEEE/ANSI standards

No.	Terms	Symbol per IEC 62271-100	Symbol per older IEEE/ANSI standards
1	Rated maximum voltage (IEEE); Rated voltage (IEC)	U_r	V
2	Voltages, general—some are uppercase and some are lowercase	u	v, e or u
3	Times, general – some are upper case and some are lower case	t	t
4	Rate of rise of recovery voltage	u/t or RRRV	R or RRRV
5	u_c = TRV peak	u_c	E2
6	T2 = time to reach the peak of the 1-cosine TRV, E2, NOTE For the two-parameter construction lines, the line from the origin to point u_c, t_3, and the horizontal line at u_c, is tangent to the ANSI/IEEE 1-cosine TRV, and then T2 = 1,138 × t_3 or t_3 = 0,88 × T2 (see Figure G.1)		T2
7	first-pole-to-clear factor (k_{pp})	k_{pp}	k_f
8	amplitude factor (k_{af}) [the term “transient amplitude factor (k_a)” is replaced by amplitude factor (k_{af})]	k_{af}	k_a
9	Time delay t_d	t_d	t_d
10	Delay line, a line from 0, t_d to u', t' that is parallel to the line from 0,0 to u_c, t_3 (see Figure G.1). Provides a lower limit to TRV.	Delay line	N A.
11	Rated TRV wave shape	Two-parameter reference line	1-cosine envelope
12	t_3, time to reach u_c for two-parameter TRVs. Time t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3.	t_3	
13	Z_b, Bus surge impedance in ohms.	Z_b	Z_b

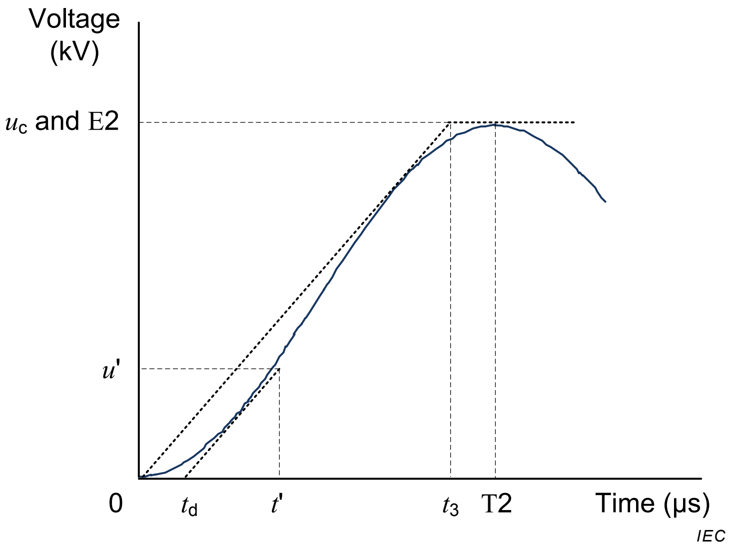


Figure G.1 – 2-parameter TRV envelope representation of 1-cosine TRV when interrupting three-phase symmetrical fault currents

Annex H
(informative)

Determination of the degree of asymmetry for generator-source short-circuit breaking tests

The degree of asymmetry of a current is defined as the ratio of the d.c. component to the peak value of the a.c. component determined from the envelope of the current wave at that time (see 3.7.144). The a.c. component of the generator-source short-circuit current may decay faster than the d.c. component. The decay of the a.c. component is governed by the subtransient and transient time constants of the generator and the decay of the d.c. component by the armature time constant. As a consequence, the d.c. component at contact separation can be higher than the peak value of the a.c. component. In such a case the degree of asymmetry of the fault current is higher than 100 %, thus leading to delayed current zeros. In addition the magnitude of the a.c. component of the generator-source short-circuit current and its degree of asymmetry can vary if the generator is unloaded or delivering power with lagging or leading power factor prior to fault. If fault initiation takes place when the voltage in one phase passes through zero the resulting fault current in that phase exhibits the maximum degree of asymmetry. A survey of many generators with different ratings revealed that the degree of asymmetry can be very high and exceed 130 %.

A typical wave shape of generator-source short-circuit current in case of fault initiation at voltage zero is shown in Figure H.1. The degree of asymmetry initially increases due to the rapid decay of the a.c. component, it reaches a value of approx 148 % and it subsequently decays when the a.c. component is approaching its steady state.

Reproducing such a current wave shape and especially the decay of the a.c. component can be very difficult in high power testing stations. In addition, depending on the pre-loading of the generator in a power plant the degree of asymmetry may be far higher than the one being adjustable in a laboratory. Therefore in order to reproduce interrupting conditions which are similar to the ones observed in power plant applications, the test requirement for the degree of asymmetry is set to a constant value irrespectively of the instant of contact separation. The dotted line in Figure H.1 represents a degree of asymmetry of 130 % which is set as a requirement for test-duties 6A and 6B (see Tables 18 and 19).

Considering that various designs of generators behave differently and it may not be possible to simulate the required current shape in the testing station. Therefore the capability of a generator circuit-breaker to interrupt a short-circuit current with delayed current zero crossings shall be ascertained by calculations (see 8.103.6.3.6.3) taking into account results derived from a limited number of appropriate tests (see 6.105).

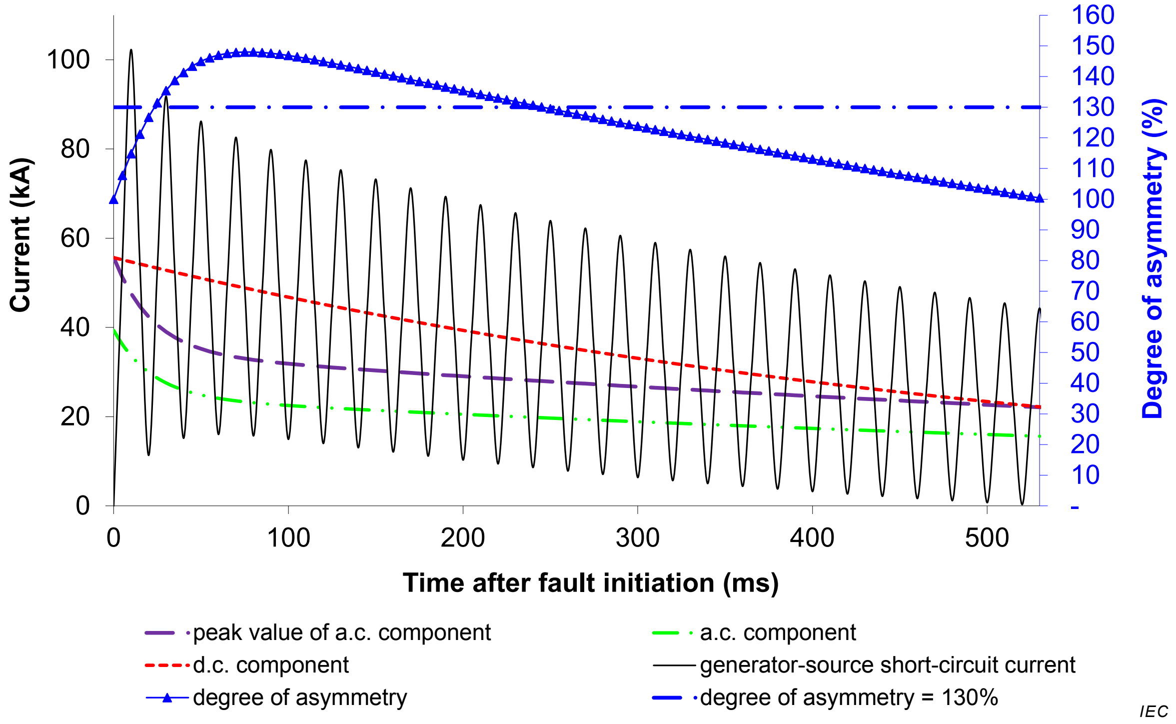


Figure H.1 – Prospective generator-source short-circuit current (fault initiation at voltage zero)

Annex I
(informative)

Faults in case of three-winding step-up transformer

When two generators are connected to the high-voltage system by means of a three-winding step-up transformer, special attention should be paid to the system-source short-circuit current. In case of three-phase earthed fault occurring at location F in Figure I.1, both the a.c. component and the degree of asymmetry of the system-source short-circuit current which should be interrupted by Generator circuit-breaker #1 can attain very high values because of the additional contribution to the current of Generator #2.

Because the a.c. component of the fault current fed by Generator #2 is not constant, the ratio of the peak value of the short-circuit current seen by Generator circuit-breaker #1 to the r.m.s. value of the a.c. component of the short-circuit breaking current (at contact separation of Generator circuit-breaker #1) could exceed the standard value of 2,74.

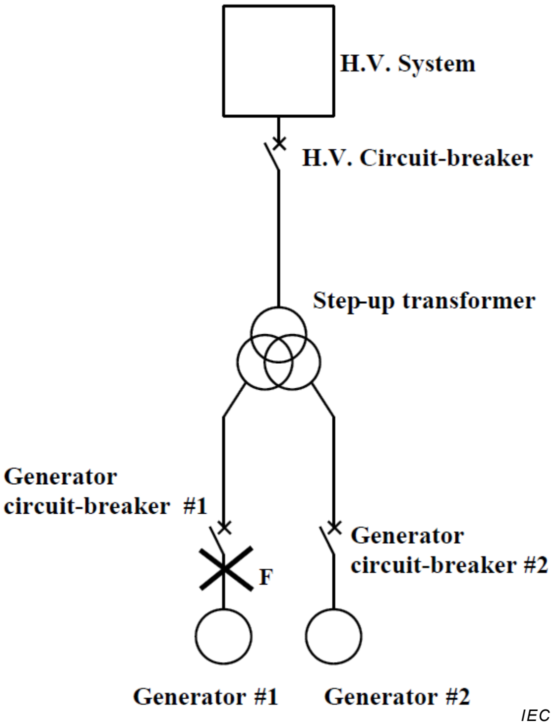


Figure I.1 – Single-line diagram of a power station with two generators connected to the high-voltage system by means of a three-winding step-up transformer

The system-source short-circuit in case of three-phase earthed fault occurring at location F in Figure I.1, has been calculated considering Generator circuit-breaker #2 either open or closed. In the latter case the contribution of Generator #2 to the fault current to be interrupted by Generator circuit-breaker #1 has been taken into account. It has been assumed that fault initiation occurs at voltage zero in one phase. The resulting short-circuit current waveform is depicted in Figure I.2. Only the current in the phase with the highest degree of asymmetry is shown. The upper and the lower curves refer to the case of Generator circuit-breaker #2 closed and open respectively. The results are summarized in Table I.1.

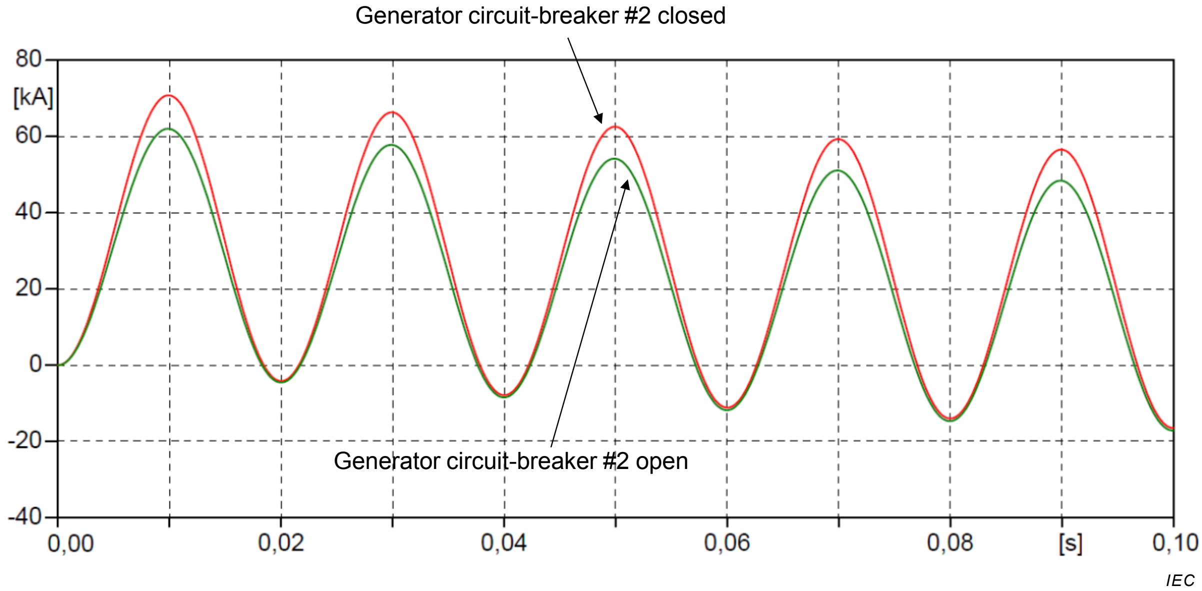


Figure I.2 – Prospective system-source short-circuit current to be interrupted by Generator circuit-breaker #1 in case of three-phase earthed fault occurring at location F in Figure I.1 (only the current in the phase with the highest degree of asymmetry is shown – fault initiation at voltage = 0)

Table I.1 – A comparison between prospective system-source short-circuit currents to be interrupted by Generator circuit-breaker 1 in case of three-phase earthed fault occurring at location F in Figure I.1

Terms	Generator circuit-breaker #2 opened	Generator circuit-breaker #2 closed
Making current (kA)	62,1	70,8
R.m.s. value of the a.c. component of the system-source short-circuit current at intended contact separation (kA)	22,7	25,5
Degree of asymmetry of the system-source short-circuit current at intended contact separation	68,5 %	73,6 %
Ratio of making current to r.m.s. value of the a.c. component of the system-source short-circuit current at intended contact separation	2,74	2,78

The case of Generator circuit-breaker 2 closed leads to higher current magnitudes because of the additional contribution of Generator 2. The fault current fed by Generator 2 features a relatively small magnitude and a very high degree of asymmetry and it exhibits several cycles without natural zero crossing. These delayed current zeros have totally different causes and are extremely dissimilar in comparison with the currents associated with generator terminal faults and out-of-phase synchronising. The waveform of this current is obtained as the superposition of two contributions, i.e. one oscillating at power frequency and a transient one whose course is dictated by the time constants of the circuit. The transient component consists of two decaying exponential functions: this waveform is over-damped as the damping contribution prevails over the oscillating one as it can be seen in Figure I.3. If the Generator circuit-breaker 2 has to interrupt this current the capability to force current to zero shall be demonstrated by means of calculations considering the effect of the arc voltage of the generator circuit-breaker on the prospective short-circuit current.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum permissible arcing time).

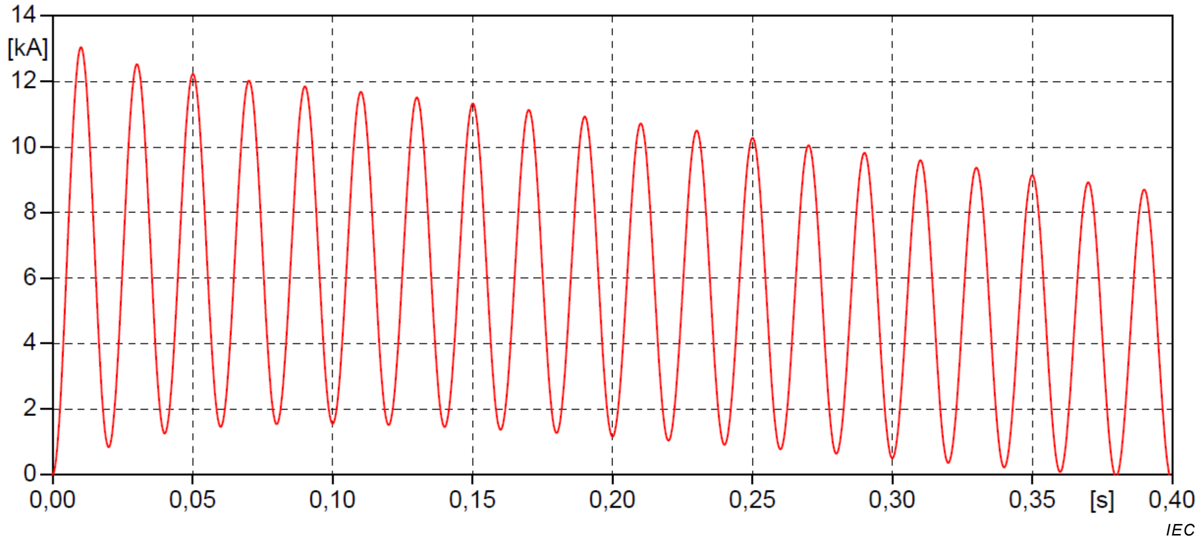


Figure I.3 – Prospective fault current fed by Generator 2 to be interrupted by Generator circuit-breaker 2 in case of three-phase earthed fault occurring at location F in Figure I.1 (only the current in the phase with the highest degree of asymmetry is shown – fault initiation at voltage = 0)

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5 This publication was withdrawn and replaced by IEC 62271-4:2013

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