INTERNATIONAL STANDARD

IEC 60044-8

First edition
2002-07

Instrument transformers –

Part 8: Electronic current transformers

Transformateurs de mesure –

Partie 8:
Transformateurs de courant électroniques

Reference number
IEC 60044-8:2002(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE XB

For price, see current catalogue

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INSTRUMENT TRANSFORMERS –

Part 8: Electronic current transformers

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.
5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.
6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60044-8 has been prepared by IEC technical committee 38: Instrument transformers.

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

FDIS	Report on voting
38/280/FDIS	38/282/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.

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

Annexes A, B, C and E are for information only.

Annex D forms an integral part of this standard.

The committee has decided that the contents of this publication will remain unchanged until 2005. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

INSTRUMENT TRANSFORMERS –

Part 8: Electronic current transformers

1 Scope

1.1 General

This part of IEC 60044 applies to newly manufactured electronic current transformers having an analogue voltage output or a digital output, for use with electrical measuring instruments and electrical protective devices at nominal frequencies from 15 Hz to 100 Hz.

NOTE Additional requirements due to the bandwidth are considered. The accuracy requirements on harmonics are given in annex D.

Clause 12 covers the accuracy requirements that are necessary for electronic current transformers for use with electrical measuring instruments.

Clause 13 covers the accuracy requirements that are necessary for electronic current transformers for use with electrical protective relays, and particularly for forms of protection in which the prime requirement is to maintain the accuracy up to several times the rated current. If required, the transient accuracy of an electronic current transformer during fault is also given in this clause.

Electronic current transformers intended for both measurement and protection should comply with all the clauses of this standard and are called multipurpose electronic current transformers.

The transformer technology can be based on optical arrangements equipped with electrical components, on air-core coils (with or without a built-in integrator), or on iron-core coils with integrated shunt used as a current-to-voltage converter, alone or equipped with electronic components.

For analogue output, the electronic current transformer may include the secondary signal cable. Examples of electronic current transformer technologies using air-core coils and iron-core coils with integrated shunt are given in annex C.

For digital output, this standard takes into account a point-to-point connection from the electronic transformer to electrical measuring instruments and electrical devices (see annex B).

Some information has been added in order to ensure the compatibility of this point-to-point link with the overall system of communication in the substation, thus allowing data exchange between all kinds of substation devices. This information builds what is called the mapping of the link layer of the point-to-point serial link. Processbus communication is under consideration.

This mapping allows interoperability between devices from different manufacturers.

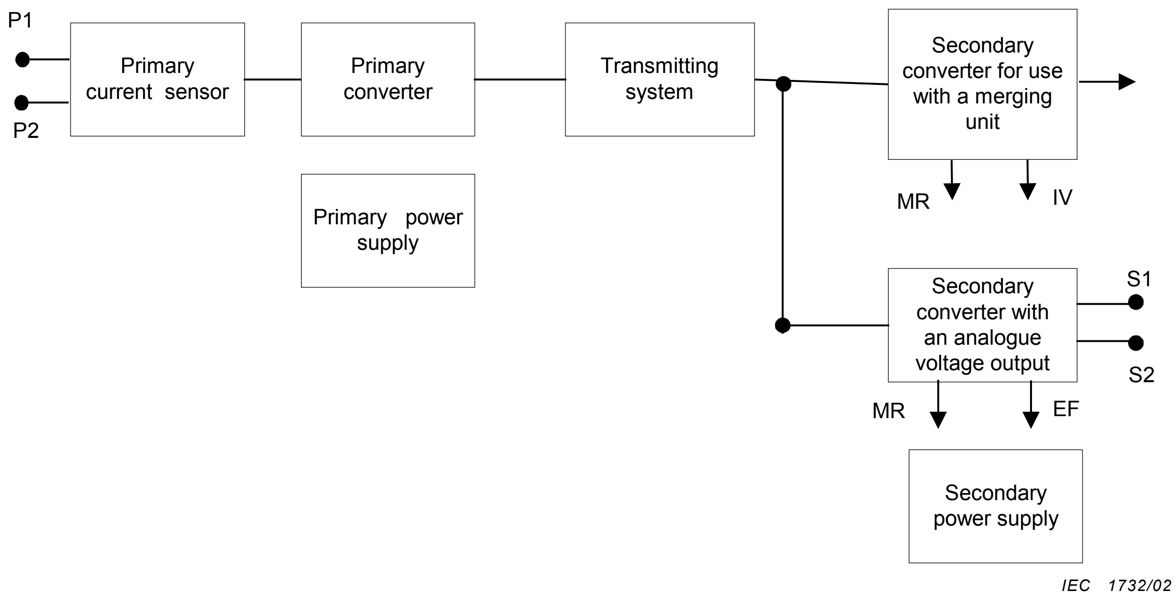
This standard does not specify individual implementations or products, nor does it constrain the implementation of entities and interfaces within a computer system. This standard specifies the externally visible functionality of implementations together with conformance requirements for such functionalities.

NOTE 1 Translation of the analogue requirements on CT and VT into digital parameters, such as the number of bits and the sampling speed, has been carried out as far as was reasonable, since the requirements on the conventional CT and VT are expressed according to the actual technologies used and their shortcomings, rather than on needs from the equipment using the information on current and voltage.

NOTE 2 The approach chosen is to concentrate on what is needed by the secondary equipment and how the performance can be calibrated. The concept is compatible with a processbus.

1.2 General block diagram of electronic current transformers

The applied technology decides which parts are necessary for the realization of an electronic current transformer, i.e. it is not absolutely necessary that all the parts described in figures 1 and 2 be included in the transformer.



Key

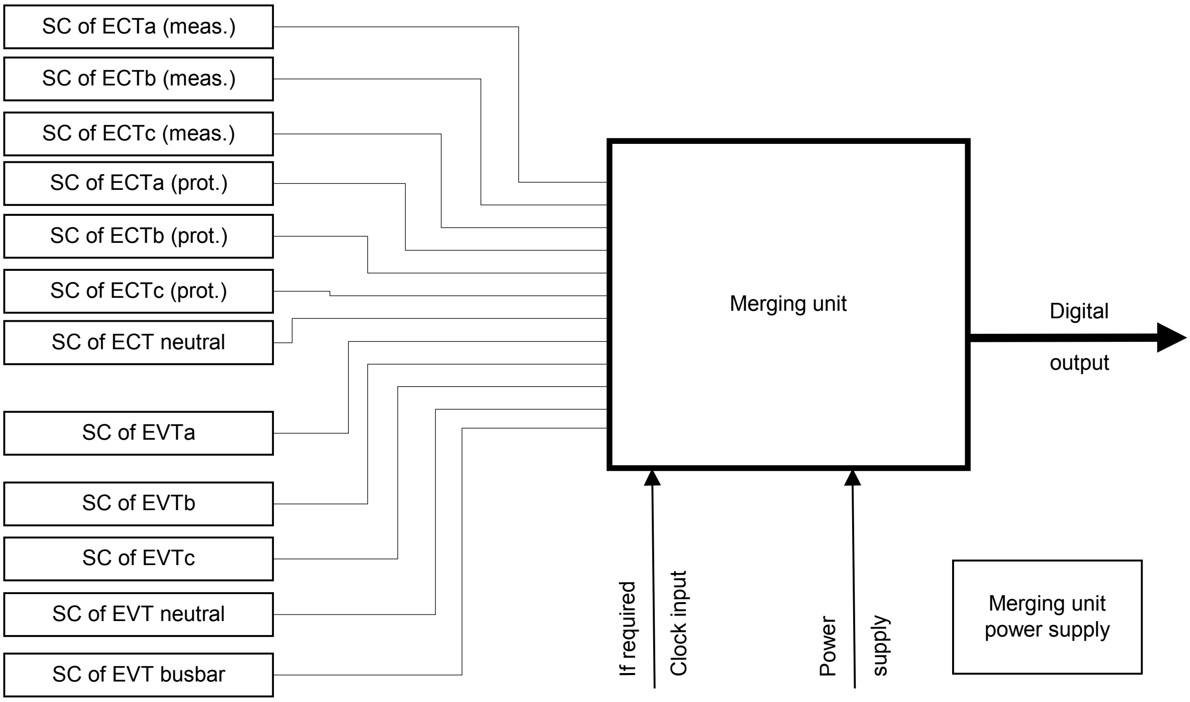
IV Output invalid

EF Equipment failure

MR Maintenance request

Figure 1 – General block diagram of a single-phase electronic current transformer

1.3 General block diagram of electronic transformers with a digital output



NOTE SC of EVTa is the secondary converter of the electronic voltage transformer of phase a (see IEC 60044-7). SC of ECTa is the secondary converter of the electronic current transformer of phase a. Other data channel mappings are possible (see 6.2.3).

Figure 2 – Example of digital interface block diagram

Up to 12 secondary converter data channels are grouped together (merged) using a merging unit (MU). A data channel carries a single stream of sampled measurement values from an electronic current transformer or an electronic voltage transformer (see figure 2). Several data channels may be transmitted via one physical interface from the secondary converter to the merging unit in case of multiphase or combined units. The merging unit supplies the secondary equipment with a time-coherent set of current and voltage samples. A secondary converter can be used also for the acquisition of signals coming from conventional voltage instrument transformers or current instrument transformers and may be integrated into the merging unit.

2 Normative references

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

IEC 60028:1925, *International standard of resistance for copper*

IEC 60044-1, *Instrument transformers – Part 1: Current transformers*

IEC 60044-6, *Instrument transformers – Part 6: Requirements for protective current transformers for transient performance*

IEC 60044-7: *Instrument transformers – Part 7: Electronic voltage transformers*

IEC 60050(161):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

IEC 60050(321):1986, *International Electrotechnical Vocabulary – Chapter 321: Instrument transformers*

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

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

IEC 60056, *High voltage alternating current circuit-breakers*

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

IEC 60068-2-6:1995, *Environmental testing – Part 2: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-17*: Environmental testing – Part 2: Tests – Test Q: Sealing*

IEC 60068-2-75: *Environmental testing – Part 2: Tests – Test Eh: Hammer test*

IEC 60071-1:1993, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60085:1984, *Thermal evaluation and classification of electrical insulation*

IEC 60121, *Recommendation for commercial annealed aluminium electrical conductor wire*

IEC 60255-5:2000, *Electrical relays – Part 5: Insulation coordination for measuring relays and protection equipment – Requirements and tests*

IEC 60255-22-1:1988, *Electrical relays – Part 22: Electrical disturbance tests for measuring relays and protection equipment – Section 2: Electrostatic discharge tests*

IEC 60296:1982, *Specification for unused mineral insulating oils for transformers and switchgear*

IEC 60304:1982, *Standard colours for insulation for low-frequency cables and wires*

IEC 60376:1971, *Specification and acceptance of new sulphur hexafluoride*

IEC 60376B:1974, *Specification and acceptance of new sulphur hexafluoride – Second supplement – Clause 26*

IEC 60417 (all parts), *Graphical symbols for use on equipment*

IEC 60480:1974, *Guide to the checking of sulphur hexafluoride (SF6) taken from electrical equipment*

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

IEC 60664-1:1992, *Insulation co-ordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 60694, *Common specifications for high-voltage switchgear and controlgear standards*

IEC 60707:1999, *Flammability of solid non-metallic materials when exposed to flame sources – List of test methods*

IEC 60721-3-3:1994, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 3: Stationary use at weather-protected locations*

IEC 60721-3-4:1995, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 4: Stationary use at non-weather-protected locations*

IEC 60794 (all parts), *Optical fibre cables*

IEC 60812:1985, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*

IEC 60815:1986, *Guide for the selection of insulators in respect of polluted conditions*

IEC 60870-5-1:1990, *Telecontrol equipment and systems – Part 5: Transmission protocols – Section One: Transmission frame formats*

IEC 61000-4-1:2000, *Electromagnetic compatibility (EMC) – Part 4-1: Testing and measurement techniques – Overview of IEC 61000-4 series*

IEC 61000-4-2: *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3: *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4:1995, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 4: Electrical fast transient/burst immunity test – Basic EMC publication*

IEC 61000-4-5: *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-7:1991, *Electromagnetic compatibility (EMC) – Part 4; Testing and measurement techniques – Section 7: General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

IEC 61000-4-8: *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test*

IEC 61000-4-9: *Electromagnetic compatibility (EMC) – Part 4-9: Testing and measurement techniques – Pulse magnetic field immunity test*

IEC 61000-4-10: *Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test*

IEC 61000-4-11: *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests*

IEC 61000-4-12: *Electromagnetic compatibility (EMC) – Part 4:12: Testing and measurement techniques – Oscillatory waves immunity test*

IEC 61000-4-13: *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*

IEC 61000-4-29:2000, *Electromagnetic compatibility (EMC) – Part 4-29: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests*

IEC 61025:1990, *Fault tree analysis (FTA)*

IEC 61166:1993, *High-voltage alternating circuit-breakers – Guide for seismic qualification of high-voltage alternating current*

IEC/TS 61462:1998, *Composite insulators – Hollow insulators for use in outdoor and indoor electrical equipment – Definitions, test methods, acceptance criteria and design recommendations*

IEC 61850-3: *Communication networks and systems in substations – Part 3: General requirements*

IEC 61850-9-1: *Communication networks and systems in substations – Part 9-1: Specific communication system mappings (SCSM) – Serial unidirectional multidrop point-to-point link* [1]

CISPR 11:1999, *Industrial scientific and medical (ISM) radio-frequency equipment – Electromagnetic disturbance characteristics – Limits and methods of measurement*

EIA RS-485: *Standard for electrical characteristics of generators and receivers for use in balanced digital multipoint systems*

EN 50160:2000, *Voltage characteristics of electricity supplied by public distribution system*

3 Definitions

For the purposes of this part of IEC 60044, the following definitions apply.

3.1 General definitions

3.1.1
electronic instrument transformer
arrangement consisting of one or more current or voltage sensor(s) which may be connected to transmitting systems and secondary converters, all intended to transmit a measuring quantity in a proportional quantity to supply measuring instruments, meters and protective or control devices. In case of a digital interface this is done by using a merging unit for a set of electronic instrument transformers

3.1.2
electronic current transformer (ECT)
electronic instrument transformer in which the output of the secondary converter in normal conditions of use is substantially proportional to the primary current and differs in phase from it by a known angle for an appropriate direction of the connections

3.1.3
primary terminals
terminals through which the current to be measured flows

3.1.4
primary current sensor
electric, electrical, optical or other device intended to transmit a signal corresponding to the current flowing through the primary terminals to the secondary converter, either directly or by means of a primary converter

3.1.5
primary converter
arrangement that converts the signal coming from one or more primary current sensors into a signal suitable for the transmitting system

3.1.6
primary power supply
power supply to the primary converter and/or primary current sensor (can be combined with secondary power supply (see 3.1.10)

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[1] To be published.

3.1.7
transmitting system
short- or long-distance coupling arrangement between primary and secondary parts intended to transmit the signal. Depending on the technology used, the transmitting system can also be used for power transmission

3.1.8
secondary converter (SC)
arrangement that converts the signal transmitted through the transmitting system into a quantity proportional to the current between the primary terminals, to supply measuring instruments, meters and protective or control devices. For ECTs with analogue output, the secondary converter directly supplies measuring instruments, meters and protective or control devices. For electronic instrument transformers with digital output the secondary converter is generally connected to a merging unit before supplying the secondary equipment

3.1.9
maintenance request (MR)
information indicating that the equipment needs maintenance

3.1.10
secondary power supply
power supply of the secondary converter (can be combined with primary power supply (see 3.1.6) or a power supply of other transformers)

3.1.11
rated auxiliary power supply voltage (U_{ar})
auxiliary power supply voltage value on which the requirements of a specification are based

3.1.12
rated supply current (I_{ar})
value of the current required from the auxiliary power supply, including the MU power supply if required, in the rated conditions

3.1.13
maximum supply current ($I_{a\ max}$)
maximum value of the current required by the auxiliary power supply, including the MU power supply if required, in the worst conditions

3.1.14
secondary circuit
external circuit receiving the information signals supplied by the secondary converter (or the merging unit) of an electronic instrument transformer

3.1.15
secondary terminals
terminals of the secondary converter (or the merging unit) which supply the secondary circuit

3.1.16
connecting point
point provided to connect electrical cables during site installation and test installation. Where shielded cables are used, only the external shield is considered to be a connecting point. The connecting points are specified by the manufacturer

3.1.17
low-voltage components
all electric or electrical components separated from the primary circuit at the full rated withstand voltage level

3.1.18
rated frequency (f_r)
value of the fundamental frequency on which the requirements of this standard are based

3.1.19
primary current in steady-state condition
in a steady-state condition, the primary current is defined by the following equation

[IEC 60044-7, modified]:

$$i_p(t) = I_p \times \sqrt{2} \times \sin(2\pi \times f \times t + \varphi_p) + i_{p\ res}(t);$$

where

I_p is the r.m.s. value of primary current at the fundamental frequency;

f is the fundamental frequency;

φ_p is the primary phase displacement;

$i_{p\ res}(t)$ is the primary residual current including harmonic and subharmonic components and primary direct current;

t is the instantaneous value of the time;

f, I_p, φ_p being constant for steady-state condition.

3.1.20
rated primary current (I_{pr})
r.m.s. value of the component of the primary current at rated frequency f_r on which the performance of the electronic current transformer is based

[IEV 321-01-11, modified].

3.1.21
secondary output in steady-state condition
for an analogue output: in an electrical steady-state condition, the secondary voltage is defined by the following equation:

$$u_s(t) = U_s \sqrt{2} .\sin(2\pi.f.t + \varphi_s) + U_{sdc} + u_{s\ res}(t);$$

where

U_s is the r.m.s. value of secondary converter output, when $U_{sdc} + u_{s\ res}(t) = 0$;

f is the frequency;

φ_s is the secondary phase displacement;

$U_{s\ dc}$ is the secondary direct voltage;

$u_{s\ res}(t)$ is the secondary residual voltage including harmonic and subharmonic components;

t is the instantaneous value of the time;

f, U_s, φ_s being constant for steady-state condition.

For a digital output:

$$i_s(n) = I_s \sqrt{2} .\sin(2\pi.f.t_n + \varphi_s) + I_{sdc}(n) + i_{s\ res}(t_n);$$

where

i_s is a digital number at the merging unit output representing the actual instantaneous value of the primary current;

I_s is the r.m.s. value of a certain digital merging unit output, when $I_{sdc}(n) + i_{s\ res}(t_n) = 0$;

f is the frequency;

φ_s is the secondary phase displacement;

$I_{sdc}(n)$ is the secondary direct output;

$i_{s\ res}(t_n)$ is the secondary residual output including harmonic and subharmonic components;

n is the data sample counter;

t_n is the time where primary current (and voltage) of the n^th data set have been sampled;

f, I_s, φ_s being constant for steady-state condition.

3.1.22
rated secondary output
for analogue output, the r.m.s. value of the component at frequency f_r of the secondary voltage output (U_{sr}) on which the performance of the electronic current transformer is based. For digital output, the hexadecimal number representing the rated primary current on the digital side

3.1.23
actual transformation ratio (K_a and K_d)
For analogue output, the ratio of the actual r.m.s. primary current to the actual r.m.s. secondary output of an electronic current transformer (abbreviation: K_a). For digital output, the ratio of the actual r.m.s. primary current to the actual r.m.s. secondary output, which is a numerical value (abbreviation: K_d)

NOTE 1 For stand-alone air-core coils, these definitions are only valid for steady-state condition for a pure sinusoidal wave at rated frequency. When the frequency f of the primary current differs to f_r, the actual transformation ratio is calculated according to $K_a(f) = f/f_r{*}K_{ra}$ (or $K_d(f) = f/f_r{*}K_{rd}$).

NOTE 2 For instantaneous and composite error measurement an integrator has to be used with the air-core coil. In this case K_a (or K_d) is the ratio of the primary current to the secondary output of the integrator.

3.1.24
rated transformation ratio (K_{ra} and K_{rd})
rated value of the transformation ratio

3.1.25
current error (ratio error) (ε %)
error which an electronic current transformer introduces into the measurement of a current and which arises from the fact that the actual transformation ratio is not equal to the rated transformation ratio

[IEV 321-01-21, modified].

For analogue output, the current error expressed in per cent is given by the formula:

$$\varepsilon\,\% = \frac{K_{ra}.U_s - I_p}{I_p} \times 100$$

where

K_{ra} is the rated transformation ratio;

I_p is the r.m.s. value of the actual primary current when $i_{p\ res}(t) = 0$;

U_s is the r.m.s. value of secondary converter output when $U_{sdc} + u_{s\ res}(t) = 0$.

NOTE This definition is only related to components at rated burden and rated frequency of both primary current and secondary voltage. This definition is compatible with IEC 60044-1.

For digital output, the current error expressed in per cent is given by the formula:

$$\varepsilon\,\% = \frac{K_{rd}.I_s - I_p}{I_p} \times 100$$

where

K_{rd} is the rated transformation ratio;

I_p is the r.m.s. value of the actual primary current when $i_{p\ res}(t) = 0$;

I_s is the r.m.s. value of the digital output when $I_{sdc}(n) + i_{s\ res}(t_n) = 0$.

NOTE The current error is the result of a digital calculation (see annex B).

3.1.26

phase displacement (φ)

for analogue output, the difference in phase between the primary current phasor and the secondary output phasor, the direction of the phasors being so chosen that the angle is equal to its rated value at the rated frequency for a perfect transformer. The phase displacement is said to be positive when the secondary output phasor leads the primary current phasor. It is usually expressed in minutes or centiradians

[IEV 321-01-23, modified]

$$\varphi = \varphi_s - \varphi_p$$

where

φ_p is the primary phase displacement;

φ_s is the secondary phase displacement.

For digital output, the time between the instant a certain current is present at the primary terminals and the instant the transmission of the relevant digital data set at the MV output starts (expressed in angular units relative to the rated frequency)

NOTE 1 This definition is strictly correct for sinusoidal current only.

NOTE 2 For both analogue and digital output, the phase displacement φ of an ideal transformer (see B6.1 and 3.1.29) can be considered to be made up of two components: the rated phase offset φ_{0r} and the rated delay time t_{dr}.

NOTE 3 See annex B for more explanation about phase-displacement calculation.

3.1.27

rated delay time (t_{dr})

rated value of time needed e.g. for digital data processing and transmission

3.1.28

rated phase offset (φ_{or})

rated phase displacement of the ECT due to the technology employed and which is not affected by the frequency

3.1.29

phase error (φ_e)

The phase error is the phase displacement φ minus the displacement caused by the rated phase offset and the rated delay time. The phase error is related to the rated frequency.

$$\varphi_e = \varphi - (\varphi_{0r} + \varphi_{tdr}) \quad \text{and} \quad \varphi_{tdr} = -2\pi . f . t_{dr}$$

For digital output intended to be synchronized with clock pulses, the phase error is the time between a clock pulse and the sampling of the primary current belonging to the corresponding digitally transmitted value (expressed in angular units relative to the rated frequency).

The phase error is usually expressed in minutes or centiradians

NOTE An explanation of the phase error and an explanatory drawing can be found in annex B.

3.1.30

accuracy class

designation assigned to an electronic current transformer, the current error and phase displacement of which remain within specified limits under prescribed conditions of use

3.1.31
highest voltage for equipment (U_m)
The highest r.m.s. phase-to-phase voltage for which an electronic current transformer is designed in respect of its insulation

[IEV 604-03-01, modified]

3.1.32
rated insulation level
combination of voltage values which characterizes the insulation of an electronic current transformer with regard to its capability to withstand dielectric stresses

3.1.33
isolated neutral system
system where the neutral point is not intentionally connected to earth, with the exception of high-impedance connections for protection or measurement purposes

[IEV 601-02-24]

3.1.34
resonant earthed (neutral) system
system in which one or more neutral points are connected to earth through a reactor which approximately compensates the capacitive component of a single phase-to-earth fault current

[IEV 601-02-27]

3.1.35
earth-fault factor
at a given location of a three-phase system and for a given system configuration, the ratio of the highest r.m.s phase-to-earth power-frequency voltage on a healthy phase during a fault to earth affecting one or more phases at any point on the system to the r.m.s value of phase-to-earth power-frequency voltage which would be obtained at the given location in the absence of any such fault

[IEV 604-03-06]

3.1.36
solidly earthed (neutral) system
system whose neutral point(s) is (are) earthed directly

[IEV 601-02-25]

3.1.37
impedance earthed (neutral) system
system whose neutral point(s) is (are) earthed through impedances to limit earth-fault currents

[IEV 601-02-26]

3.1.38
earthed neutral system
system in which the neutral is connected to earth either solidly or through a resistance or reactance of a value low enough to reduce transient oscillations and to give a current sufficient for selective earth-fault protection

a) A three-phase system with effectively earthed neutral at a given location is a system characterized by an earth-fault factor at this point which does not exceed 1.4.

   NOTE This condition is obtained approximately when, for all system configurations, the ratio of zero-sequence reactance to the positive-sequence reactance is less than three and the ratio of zero-sequence resistance to positive-sequence reactance is less than one.

b) A three-phase system with non-effectively earthed neutral at a given location is a system characterized by an earth-fault factor at this point that may exceed 1.4.

3.1.39
exposed installation
installation in which the apparatus is subject to overvoltages of atmospheric origin

NOTE Such installations are usually connected to overhead transmission lines, either directly, or through a short length of cable and not protected by surge arresters.

3.1.40
non-exposed installation
installation in which the apparatus is not subject to overvoltages of atmospheric origin

3.1.41
rated short-time thermal current (I_{th})
r.m.s. value of the primary current which an electronic current transformer will withstand for 1 s without suffering harmful effects

3.1.42
rated dynamic current (I_{dyn})
peak value of the primary current which an electronic current transformer will withstand, without being damaged electrically or mechanically by the resulting electromagnetic forces

3.1.43
rated continuous thermal current (I_{cth})
value of the current which can be permitted to flow continuously in the primary terminals, the analogue secondary output being connected to the rated burden, without the temperature rise exceeding the values specified

3.1.44
wake-up time
some electronic current transformers are powered by the line current. The power supply of such transformers needs a delay to establish after the primary current is switched on. This delay is called “wake-up time”. During this delay, the output of the electronic current transformer is zero

3.1.45
wake-up current
minimum r.m.s. value of the primary current necessary to wake up the electronic current transformer (see 3.1.44)

3.1.46
IP code
coding system to indicate the degrees of protection provided by an enclosure against access to hazardous parts, ingress of solid foreign objects, ingress of water and to give additional information in connection with such protection

[3.4 of IEC 60529]

3.1.47
degree of protection
extent of protection provided by an enclosure against access to hazardous parts, against ingress of solid foreign objects and/or ingress of water and verified by standardized test methods

[3.3 of IEC 60529]

3.1.48
rated filling pressure for gas insulation p_{re} (or density ρ_{re})
pressure in Pascals (Pa), for gas insulation, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, to which the electronic current transformer is filled before being put into service, or automatically replenished

[3.6.4.1 of IEC 60694, modified]

3.1.49
alarm pressure for gas insulation p_{ae} (or density ρ_{ae})
pressure (Pa), for insulation, referred to the standard atmospheric air conditions of +20 °C 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which a monitoring signal may be provided to indicate that replenishment is necessary in a relatively short time

[3.6.4.3 of IEC 60694, modified]

3.1.50
minimum functional pressure for gas insulation p_{me} (or density ρ_{me})
pressure (Pa), for insulation, referred to the standard atmospheric air conditions of +20 °C 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which and above which rated characteristics of electronic current transformer are maintained and at which a replenishment becomes necessary

[3.6.4.5 of IEC 60694, modified]

3.1.51
absolute leakage rate, F
amount of gas escaped by time unit, expressed in Pa.m^3/s

3.1.52
relative leakage rate, F_{rel}
absolute leakage rate related to the total amount of gas in the system at rated filling pressure (or density) expressed in percentage per year or per day

3.2 Additional definitions for measuring electronic current transformers

3.2.1
measuring electronic current transformer
electronic current transformer intended to transmit an information signal to indicating instruments, integrating meters and similar apparatus

3.2.2
rated extended primary current
primary current up to which the same accuracy as the accuracy at the rated primary current is guaranteed, and which cannot exceed the rated continuous thermal current I_{cth}

3.2.3
rated extended primary current factor (K_{pcr})
ratio of the rated extended primary current to the rated primary current

3.3 Additional definitions for protective electronic current transformers

3.3.1
protective electronic current transformer
electronic current transformer intended to transmit an information signal to protective or control devices

3.3.2
rated accuracy limit primary current
under steady-state conditions, value of primary current up to which the protective electronic current transformer will comply with the requirements for composite error

3.3.3
accuracy limit factor (K_{alf})
under steady-state conditions, the ratio of the rated accuracy limit primary current to the rated primary current

3.3.4
composite error (ε_c)
under steady-state conditions, the composite error is the r.m.s. value of the difference between

a) the instantaneous values of the primary current, and

b) the instantaneous values of the actual secondary output multiplied by the rated transformation ratio, the positive signs of the primary current and secondary output corresponding to the convention for terminal markings.

For analogue output, the composite error ε_c is generally expressed as a percentage of the r.m.s. values of the primary current according to the formula:

$$\varepsilon_c(\%) = \frac{100}{I_p}\sqrt{\frac{1}{T}\int_0^T \left[K_{ra}u_s(t) - i_p(t - t_{dr})\right]^2 dt}$$

where

K_{ra} is the rated transformation ratio;

I_p is the r.m.s. value of the primary current;

i_p is the primary current;

u_s is the secondary voltage;

T is the duration of one cycle;

t is the instantaneous value of the time;

t_{dr} is the rated delay time.

NOTE 1 For stand-alone air-core coils, secondary output is measured at the output of an integrator (see definition of K_{ra} or K_{rd} and annex C).

For digital output, the composite error ε_c is generally expressed as a percentage of the r.m.s. values of the primary current according to the formula:

$$\varepsilon_c(\%) = \frac{100}{I_p}\sqrt{\frac{T_s}{kT}\sum_{n=1}^{kT/T_s}\left[K_{rd}i_s(n) - i_p(t_n)\right]^2}$$

where

K_{rd} is the rated transformation ratio;

I_p is the r.m.s. value of the primary current;

i_p is the primary current;

i_s is the secondary digital output;

T is the duration of one power cycle;

n is the sample counter;

t_n is the time where primary currents and voltages of the n^{th} data set have been sampled;

k is the number of summation periods;

T_s is the distance in time between two samples of the primary current;

NOTE 2 For practical purposes the composite error is the result of a digital calculation, the algorithm of which is given in annex B.

3.3.5
rated primary short-circuit current for transient performance (I_{psc})
under transient conditions, the r.m.s. value of the primary symmetrical short-circuit current on which the rated accuracy performance of the electronic current transformer is based

[3.1 of IEC 60044-6, modified]

3.3.6
rated symmetrical short-circuit-current factor for transient performance (K_{ssc})
under transient conditions, the ratio:

$$K_{ssc} = I_{psc}/I_{pr}$$

[3.15 of IEC 60044-6, modified]

3.3.7
rated primary time constant for transient performance (τ_{pr})
under transient conditions, rated value of the time constant of the d.c. component of the primary current on which the performance of the current transformer is based

[3.6 of IEC 60044-6, modified].

3.3.8
dead time (t_{fr})
time interval between interruption and re-application of the primary short circuit during a breaker auto-reclosing duty cycle (refer also to IEC 60056)

[3.9 of IEC 60044-6]

3.3.9
rated duty cycle (C – O and/or C – O – C – O)
duty cycle in which during each specified energization, the primary current is assumed to be "fully offset" with the rated primary time constant (τ_{pr}) and be of rated amplitude (I_{psc})

[3.10 of IEC 60044-6, modified]

Duty cycles are as follows.

Single energization: C – t' – O

Double energization: C – t' – O – t_{fr} – C – t'' – O

(both energizations in the same polarity of magnetic flux when applicable)

where
t' is the duration of first current flow;
t'' is the duration of the second current flow.

3.3.10
transient response
response of the secondary output to a transient change of the primary current

[2.2.3 of IEC 60044-7, modified]

3.3.11
primary current in transient condition ($i_p(t)$)
in the transient condition, primary current is defined as follows

[A.1 of IEC 60044-6, modified]:

$$i_p(t) = I_{psc}\sqrt{2}\cdot(\sin(2\pi\cdot f\cdot t + \varphi_p) - \sin(\varphi_p)\cdot\exp(-t/\tau_p)) + i_{p\ res}(t);$$

where

I_{psc} is the r.m.s. value of the symmetrical component of primary current;

f is the frequency;

τ_p is the primary time constant;

φ_p is the primary phase displacement;

$i_{p\ res}(t)$ is the primary residual current including harmonic and subharmonic components and primary direct current;

t is the instantaneous value of time.

3.3.12
instantaneous error current ($i_\varepsilon(t)$, $i_\varepsilon(n)$)
difference between the instantaneous values of the secondary output multiplied by the rated transformation ratio and the primary current

[3.2 of IEC 60044-6, modified]

For an analogue output, the instantaneous error current is defined for $t \geq t_{dr}$ and is given by the following expression:

$$i_\varepsilon(t) = K_{ra}.u_s(t) - i_p(t - t_{dr})$$

NOTE 1 For stand-alone air-core coils the voltage $u_s(t)$ is measured at the output of an integrator (see definition of K_{ra} and K_{rd} and annex C).

For digital output, the instantaneous error current is defined for $t_n \geq t_{dr}$ and is given by the following expression:

$$i_\varepsilon(n) = K_{rd}.i_s(n) - i_p(t_n)$$

NOTE 2 For practical purposes, the instantaneous error is the result of a digital calculation, the algorithm of which is given in annex B.

NOTE 3 For stand-alone air-core coils, secondary output is measured at the output of an integrator. The integrator can be realized digitally in the evaluation unit. Since the integrator may influence the delay time, it is allowed in this test set-up that the rated delay time differs from the regular rated delay time of the transformer under test.

3.3.13
maximum peak instantaneous error ($\hat{\varepsilon}$)
maximum instantaneous error current, for the specified duty cycle, expressed as a percentage of the peak value of the rated primary short-circuit current.

[3.4 of IEC 60044-6, modified]

$$\hat{\varepsilon} = 100\ \hat{i}_\varepsilon / (\sqrt{2}\ .I_{psc}) \quad \%$$

3.4 Additional definitions for digital output

3.4.1
digital output
the digital output is made up of an optical or an electrical output interface at the merging unit.

It supplies measuring instruments, meters and protective or control devices with digitally coded time-coherent sets of current and/or voltage data

3.4.2
merging unit (MU)
physical unit used to do the time-coherent combination of the current and/or voltage data coming from the secondary converters. The merging unit can be part of one of the transformers in the field or may be a separate unit, for example, in the control room (see figure 2)

3.4.3
merging unit clock input
electrical or optical input of the merging unit that can be used to synchronize several merging units if required

3.4.4
merging unit power supply
power supply of the merging unit (can be combined with the secondary power supply (see 3.1.10)

3.4.5
data rate (1/T_s)
number of current and/or voltage data sets transmitted per second

3.4.6
output invalid (IV)
information indicating that the output signal of the electronic current transformer is invalid

3.5 Additional definitions for analogue voltage output

3.5.1
equipment failed (EF)
information indicating that the equipment has failed

3.5.2
burden
impedance of the secondary circuit expressed in ohms, at power factor of 1

3.5.3
rated burden (Rb_r)
value of the burden on which the accuracy requirements of a specification are based

3.5.4
secondary direct voltage offset (U_{sdc0})
direct voltage component of the secondary voltage of an electronic current transformer when $I_p(t)$ = 0

NOTE For a primary converter powered by the primary current, this definition is not applicable. In this case, the evaluation method should be agreed between manufacturer and purchaser (see annex E).

3.5.5
stand-alone air-core coil
transformer based on air-core coil technology without a built-in integrator (see annex C)

3.6 Index of main definitions and abbreviations

ECT	electronic current transformer, definition 3.1.2
EVT	electronic voltage transformer, see IEC 60044-7
EF	equipment failed, definition 3.5.1
IV	output invalid, definition 3.4.6
MR	maintenance request, definition 3.1.9
MU	merging unit, definition 3.4.2
Rb_r	rated burden, definition 3.5.3
SC	secondary converter, definition 3.1.8
f_r	rated frequency, definition 3.1.18
K_{ra}, K_{rd}	rated transformation ratio of an electronic current transformer, definition 3.1.24

K_{pcr}	rated extended primary current factor, definition 3.2.3
K_{alf}	accuracy limit factor, definition 3.3.3
K_{ssc}	rated symmetrical short-circuit factor, definition 3.3.6
t	instantaneous value of time, definition 3.1.19
t_{dr}	rated delay time, definition 3.1.27
t_{fr}	dead time, definition 3.3.8
T_{s}	time between two data sets, reciprocal of the data rate, definition 3.4.5
U_{m}	highest voltage for equipment, definition 3.1.31
U_{sr}	for analogue output, rated secondary output, definition 3.1.22
U_{sdco}	secondary direct voltage offset, definition 3.5.4
U_{ar}	rated auxiliary power supply voltage, definition 3.1.11
I_{ar}	rated supply current, definition 3.1.12
I_{amax}	maximum supply current, definition 3.1.13
I_{th}	rated short-time thermal current, definition 3.1.41
I_{cth}	rated continuous thermal current, definition 3.1.43
I_{dyn}	rated dynamic current, definition 3.1.42
I_{psc}	rated primary short-circuit current for transient, definition 3.3.5
I_{p}	r.m.s. value of primary current when $i_{\mathrm{p\ res(t)}} = 0$, definition 3.1.19
I_{pr}	rated primary current, definition 3.1.20
$i_{\mathrm{p(t)}}$	primary current, definitions 3.1.19 and 3.3.11
$i_{\mathrm{p\ res(t)}}$	primary residual current including harmonic and subharmonic components, definition 3.1.19
$i_{\varepsilon}(t)$, $i_{\varepsilon}(n)$	instantaneous error current for transient conditions, definition 3.3.12
φ	phase displacement, definition 3.1.26
φ_{or}	rated phase offset, definition 3.1.28
φ_{e}	phase error, definition 3.1.29
ε %	current error for steady state conditions, definition 3.1.25
ε_{c}	composite error, definition 3.3.4
$\hat{\varepsilon}$	maximum peak instantaneous error, definition 3.3.13
τ_{pr}	rated primary time constant, definition 3.3.7
p_{re}, ρ_{re}	rated filling pressure or density, definition 3.1.48
p_{ae}, ρ_{ae}	alarm pressure or density, definition 3.1.49
p_{me}, ρ_{me}	minimum functional pressure or density, definition 3.1.50

4 Normal and special service conditions

4.1 General

Unless otherwise specified, high-voltage electronic current transformers are intended to be used at their rated characteristics under the normal service conditions listed in 4.2

If the actual service conditions differ from these normal service conditions, high-voltage electronic current transformers shall be designed to comply with any special service conditions required by the user, or appropriate arrangements shall be made (see 4.3).

NOTE 1 In order to ensure proper operation of electronic components, these components should comply with the environmental requirements of IEC 60068-2.

NOTE 2 Detailed information concerning classification for environmental conditions is given in IEC 60721-3-3 (indoor) and IEC 60721-3-4 (outdoor).

4.2 Normal service conditions

4.2.1 Ambient air temperature

Electronic current transformers are classified into three categories as given in table 1.

Table 1 – Temperature categories

Category	Minimum temperature °C	Maximum temperature °C
–5/40	–5	40
–25/40	–25	40
–40/40	–40	40
NOTE When choosing the temperature category, storage and transportation conditions should also be considered.		

4.2.2 Altitude

The altitude does not exceed 1 000 m.

4.2.3 Vibrations or earth tremors

Vibrations may occur due to switchgear operations or short-circuit forces. It should be recognized that vibrations due to causes external to the electronic current transformer (for example, switching operations of circuit-breakers, etc.) must be regarded as normal service conditions. Tests should be performed to prove the correct operations of the ECT when subjected to such events (see 8.13). Vibrations due to earth tremors are considered as special service conditions.

4.2.4 Other service conditions for indoor electronic current transformers

Other service conditions considered are as follows.

a) The influence of solar radiation may be neglected.

b) The ambient air is not significantly polluted by dust, smoke, corrosive gases, vapours or salt.

c) The conditions of humidity are as follows:

   1) the average value of the relative humidity, measured during a period of 24 h does not exceed 95 %;
   2) the average value of the water vapour pressure for a period of 24 h does not exceed 2,2 kPa;
   3) the average value of the relative humidity for a period of one month does not exceed 90 %;
   4) the average value of the water vapour pressure for a period of one month does not exceed 1,8 kPa.

For these conditions, condensation may occasionally occur.

NOTE 1 Condensation can be expected where sudden temperature changes occur in periods of high humidity.

NOTE 2 In order to withstand the effects of high humidity and condensation, such as the breakdown of insulation or the corrosion of metallic parts, electronic voltage transformers designed for such conditions should be used.

NOTE 3 Condensation may be prevented by special design of the housing, by suitable ventilation and heating or by the use of dehumidifying equipment.

4.2.5 Other service conditions for outdoor electronic current transformers

Other service conditions considered are as follows.

a) The average value of the ambient air temperature, measured over a period of 24 h, does not exceed 35 °C.
b) Solar radiation up to a level of 1 000 W/m^2 (on a clear day at noon) should be considered.
c) The ambient air may be polluted by dust, smoke, corrosive gases, vapours or salt. The pollution does not exceed the pollution levels given in table 7.
d) The wind pressure does not exceed 700 Pa (corresponding to a 34 m/s wind speed).
e) The presence of condensation or precipitation should be taken into account.

4.2.5.1 Partially outdoor electronic current transformers

In the case of an electronic current transformer of the type which is partially indoors, partially outdoors, the manufacturer shall indicate which part of the equipment is indoors and which part of the equipment is outdoors.

4.3 Special service conditions

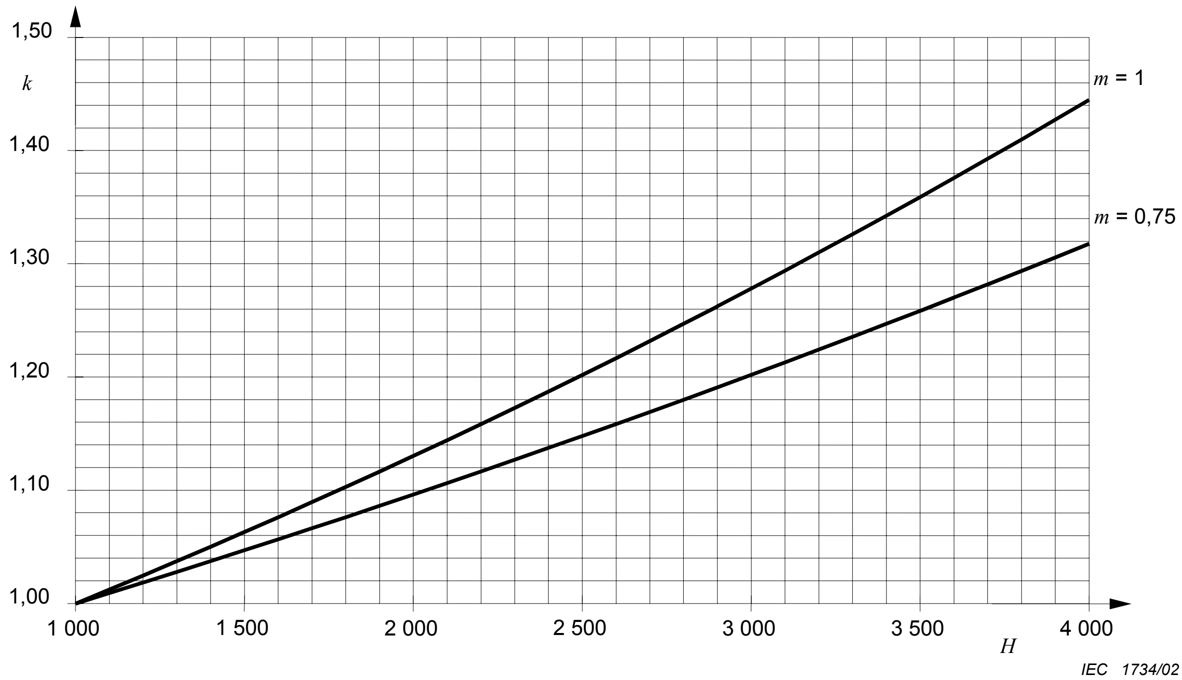
4.3.1 General

When electronic current transformers may be used under conditions different from the normal service conditions given in 4.2, the user's requirements should refer to the standardized steps given hereafter.

4.3.2 Altitude

For installations at an altitude higher than 1 000 m, the arcing distance under the standardized reference atmospheric conditions shall be determined by multiplying the withstand voltages required at the service location by a factor k in accordance with figure 3.

NOTE As for the internal insulation, the dielectric strength is not affected by altitude. The method used for checking the external insulation should be agreed between manufacturer and purchaser.



These factors can be calculated using the following equation:

$$k = e^{m(H - 1\,000)\,/\,8\,150}$$

where

H	is the altitude in meters;
m = 1	for power-frequency and lightning impulse voltage;
m = 0,75	for the switching impulse voltage.

Figure 3 – Altitude correction factor

4.3.3 Influence of altitude on temperature rise

For installation at an altitude higher than 1 000 metres, temperature rises of parts in air at atmospheric pressure shall be corrected as follows:

$$\Delta\Theta_c = \Delta\Theta_m \left[1 - 0.03 \frac{(H - 1000)}{1000} \right]$$

where:

$\Delta\Theta_c$	is the corrected value of temperature rise;
$\Delta\Theta_m$	is the value of temperature-rise measured at low altitude;
H	is the altitude of the service location, in metres.

NOTE For low-voltage auxiliary and control equipment, no special precautions need to be taken if the altitude is lower than 2 000 m. For higher altitude, see IEC 60664-1.

4.3.4 Ambient temperature

For installations located in a place where the ambient temperature can be significantly outside the normal service condition range stated in 4.2.1, the preferred ranges of minimum and maximum temperature to be specified should be

a) –50 °C and 40 °C for very cold climates;

b) –5 °C and 50 °C for very hot climates.

In certain regions with a frequent occurrence of warm humid winds, sudden changes of temperature may occur, resulting in condensation, even indoors.

NOTE Under certain conditions of solar radiation, appropriate measures, for example, roofing, forced ventilation, etc., may be necessary, in order not to exceed the specified temperature rises.

4.3.5 Earthquakes

Requirements and testing are under consideration (future edition of IEC 60044-1).

NOTE For installations where earthquakes are likely to occur, the relevant severity level in accordance with IEC 61166 shall be specified by the user.

4.4 System earthing

The considered system earthings are:

a) isolated neutral system (see 3.1.33);

b) resonant earthed system (see 3.1.34);

c) earthed neutral system (see 3.1.38);

   1) solidly earthed neutral system (see 3.1.36);

   2) impedance earthed neutral system (see 3.1.37).

5 Ratings

5.1 General ratings

5.1.1 Standard values for rated primary current (I_{pr})

The standard values of rated primary currents are:

$$\underline{10} – 12{,}5 – \underline{15} – \underline{20} – 25 – \underline{30} – 40 – \underline{50} – 60 – \underline{75} \text{ A},$$

and their decimal multiples or fractions. The preferred values are underlined.

5.1.2 Standard values for rated extended primary current factor (K_{pcr})

The standard values for K_{pcr} are:

$$\underline{1{,}2} – 1{,}5 – 2 – 5 – 10 – 20 – 50 – 100$$

The preferred value is underlined.

5.1.3 Rated continuous thermal current (I_{cth})

The rated continuous thermal current shall not be lower than the rated primary current or the rated extended primary current if specified.

5.1.4 Short-time current ratings

5.1.4.1 Standard values for symmetrical short-circuit current

5.1.4.1.1 Standard accuracy limit factors (K_{alf})

The standard accuracy limit factors are:

3 – 5 – 7,5 – 10 – 12,5 – 15 – 17,5 – 20 -25 – 30 – 40 – 63 – 80,

and their decimal multiples.

5.1.4.1.2 Rated short-time thermal current (I_{th})

The standard r.m.s. values, expressed in kiloamperes, are in accordance with IEC 60044-6:

6,3 – 8 – 10 – 12,5 – 16 – 20 – 25 – 31,5 – 40 – 50 – 63 – 80 – 100

5.1.4.1.3 Rated dynamic current (I_{dyn})

The value of the rated dynamic current (I_{dyn}) shall normally be 2,5 times the rated short-time thermal current (I_{th}), and it shall be indicated on the rating plate when it is different from this value (see 3.1.42).

5.1.4.2 Standard values for transient performance

5.1.4.2.1 Standard values for rated symmetrical short-circuit current factor (K_{ssc})

The standard values of K_{ssc} are:

3 – 5 – 7,5 – <u>10</u> – 12.5 – <u>15</u> – 17,5 – <u>20</u> – 25 – 30 – 40 – 63 – 80,

and their decimal multiples. The preferred values are underlined.

5.1.4.2.2 Rated primary short-circuit current (I_{psc})

The preferred values are derived from the product of I_{pr} and K_{ssc} selected from the values given in the above subclauses. The rated primary short-circuit current shall be lower than, or equal to, I_{th} (IEC 60044-6).

5.1.4.2.3 Standard values for rated primary time constant (τ_{pr})

The standard values of the rated primary time constant expressed in milliseconds are:

40 – 60 – 80 – 100 – 120 (IEC 60044-6)

NOTE For some applications, higher values of rated primary time constant may be required. An example is large turbo-generator circuits.

5.1.5 Standard frequency range

The ECT fulfils its accuracy class requirements inside the standard frequency range. The standard frequency range shall be from 99 % to 101 % of the rated frequency (f_r) for accuracy classes for measurement, and from 96 % to 102 % of the rated frequency for the accuracy classes for protection (IEC 60044-7).

The accuracy outside the standard frequency range, if specified, is defined in annex D.

5.1.6 Limits of temperature rise

The temperature rise of a ECT with a primary current equal to the rated continuous thermal current flowing through its terminals and with rated burden (for analogue voltage output), shall not exceed the appropriate value given in table 2. These values are based on the service conditions given in clause 4.

If ambient temperature in excess of the values given in 4.2 are specified, the permissible temperature rise in table 2 shall be reduced by an amount equal to the excess ambient temperature.

If a electronic current transformer is specified for service at an altitude in excess of 1 000 m, and tested at an altitude below 1 000 m, the limits of temperature rise given in table 2 shall be reduced by the amounts given in 4.3.3.

The temperature rise of the ECT is limited by the lowest class of insulation according to the technology used. The maximum temperature rises of the insulation classes are as given in table 2.

Table 2 – Limits of temperature rise of the transformer

Class of insulation (in accordance with IEC 60085)	Maximum temperature rise K
All classes immersed in oil	60
All classes immersed in oil and hermetically sealed	65
All classes immersed in bituminous compound	50
Classes not immersed in oil or bituminous compound	
Y	45
A	60
E	75
B	85
F	110
H	135
NOTE With some products (for example, resin) the manufacturer should specify the relevant insulation class.	

A representative measurement of the temperature rise of the expected hottest part of the ECT should be made. This measurement depends on the technology used (i.e. resistive measurement of the windings, thermal measurement of the primary conductor).

5.1.7 Rated auxiliary power supply voltage (U_{ar})

The rated auxiliary power supply voltage means the voltage measured at the power ports of the apparatus itself during its operation, including, if necessary, the auxiliary resistors or accessories supplied or required by the manufacturer to be installed in series with it, but not including the conductors for the connection to the electricity supply.

The rated auxiliary power supply voltage should be selected from the standard values given in tables 3 and 4.

Table 3 – DC voltage

V
24
<u>48</u>
60
<u>110</u> or 125
<u>220</u> or 250
NOTE The preferred values are underlined.

Table 4 – AC voltage

Three-phase, three-wire or four-wire systems V	Single-phase three-wire systems V	Single-phase two-wire systems V
-	120/240	120
(220/380)	-	(220)
230/400	-	230
(240/415)	-	(240)
277/480	-	277

NOTE 1 The lower values in the first column are voltages to neutral and the higher values are voltages between phases. The lower value in the second column is the voltage to neutral and the higher value is the voltage between lines.

NOTE 2 The value 230/400 V will be, in the future, the only IEC standard voltage and its adoption is recommended in new systems. The voltage variations of existing systems at 220/380 V and 240/415 V should be brought within the range 230/400 V ± 10 %. The reduction of this range will be considered in a later stage of standardization.

5.1.8 Rated auxiliary power supply frequency

The standard values of rated supply frequency are d.c., 50 Hz and 60 Hz.

5.1.9 Standard reference range of auxiliary power supply voltage

The standard reference range of auxiliary power supply is defined by slow voltage variations given in table 8.

5.1.10 Standard reference range of temperature

Unless otherwise specified, the standard reference range of temperature shall be from the lower limit to the upper limit of ambient air temperature given in clause 4.

5.1.11 Standard reference range for wake-up time

The standard maximum values for wake-up time at rated primary current are:

none – 1 ms – 2 ms – 5 ms

During wake-up time the output shall be zero for analogue output and invalid for digital output. Care shall be taken so that protection relay takes no tripping decision during this delay.

5.2 Standard values for rated phase offset

The standard values for rated phase offset are:

0° and 90° (for example, for stand-alone air-core coils).

5.3 Rating for digital output

5.3.1 Rated value for a digital output

Standard r.m.s. values of rated secondary output are given in table 5.

Table 5 – Rated values for digital output

	Measuring ECT (scaling factor SCM)	**Protective ECT (scaling factor SCP)**	**EVT (scaling factor SV)**
Rated value (range-flag = 0)	2D41 H (Decimal: 11 585)	01CF H (Decimal: 463)	2D41 H (Decimal: 11 585)
Rated value for scaled range (range-flag = 1)	2D41 H (Decimal: 11 585)	00E7 H (Decimal: 231)	2D41 H (Decimal: 11 585)

NOTE 1 The values given are hexadecimal numbers representing the rated primary current on the digital side (both are r.m.s. values).

NOTE 2 Protective ECT can measure currents up to 50 times the rated primary current (0 % offset) or 25 times the rated primary current (100 % offset) without any overflow. Measuring ECT and EVT can measure up to twice the rated primary range without any overflow.

NOTE 3 If the output of the transformer is the derivative of the primary current, the dynamic range is different from the dynamic range of a current output. The full scale of current transformers is related to the d.c. component induced by certain transient conditions. After derivation, the amplitude of this low-frequency component is reduced. Consequently, a protective ECT delivering the derivative of the current can be able to measure, for example with range-flag = 0, either 50 times the rated primary current with no d.c. component (0 % offset) or 25 times the rated primary current with full d.c. component (100 % offset).

NOTE 4 For protective ECT, the maximum primary current measurable without overflow is doubled when the range-flag is set.

5.3.2 Standard values for the rated delay time (t_{dr})

Standard values for rated delay time are:

$2 * T_s$, $3 * T_s$ (T_s being the inverse of the digital data rate).

NOTE 1 If the data frame contains only metering data, higher delay times, but limited to a maximum of 3.3 ms, are allowed to achieve optimum anti-aliasing filtering.

NOTE 2 If the merging unit is intended to be used with synchronization pulses, the rated delay time is 3 ms (+10 % – 100 %) for all data rates, since it is not relevant for phase error.

5.3.3 Rated values for the digital data rate ($1/T_s$)

Rated values for digital data rate are

$$80*f_r - 48*f_r - 20*f_r \quad \text{with} \quad f_r = 50 \text{ Hz or } 60 \text{ Hz},$$

$$\text{and} \quad 48*f_r \quad \text{with} \quad f_r = 16\ 2/3 \text{ Hz}.$$

NOTE 1 For $20*f_r$ and for $48*f_r$ not all accuracy requirements on harmonics are fulfilled for all accuracy classes (see annex D).

NOTE 2 In case of a system fed with higher data rate than needed, under-sampling techniques described in IEC 60255-24 (common format for transient data exchange for power systems) should be implemented within the secondary equipment.

5.4 Rating for analogue voltage output

5.4.1 Standard values for the rated delay time (t_{dr})

The standard values for rated delay time are:

none, 50 µs, 100 µs, 200 µs, 500 µs

5.4.2 Standard values of rated secondary voltage (U_{sr})

The standard r.m.s. values of rated secondary voltage, U_{sr} at rated primary current are:

22,5 mV – 150 mV – 200 mV – 225 mV – 4 V

For application without secondary converter (transmitting system directly connected to the low-voltage equipment – see figure 1) used in general in medium-voltage range, the standard rated values are:

- 22,5 mV and 225 mV for ECTs delivering an output voltage proportional to the current (e.g. transformer with iron core and integrated burden),
- 150 mV for ECTs delivering an output voltage proportional to the derivative of the current (e.g. air core coils).

NOTE The rated secondary voltages 40 mV, 100 mV and 1 V may be used for existing design.

For applications using electronic secondary converter (see figure 1), the standard rated value for protective application is 200 mV and is 4 V for measurement application.

NOTE 7The rated secondary voltages 200 mV is also recommended by ANSI for analogue protection output. For measurement output, 2 V is recommended by ANSI due to a measurement range of four times I_{pr}. With a clever choice of the specified value of I_{pr}, these standard values are compatible.

5.4.3 Rated burden (R_{br})

The standard values of rated burden in ohms are:

2 kΩ – 20 kΩ – 2 MΩ

The total burden has to be equal to, or higher than, the rated burden.

NOTE Attention should be paid to the parallel capacitance of electrical measuring instruments or electrical protective devices.

6 Design requirements

6.1 General design requirements

6.1.1 Insulation requirements

6.1.1.1 Rated insulation levels for primary terminals (IEC 60044-1, 5.1.1)

6.1.1.2 Other requirements for primary terminals insulation (IEC 60044-1, 5.1.2)

6.1.1.2.1 Power-frequency withstand voltage (IEC 60044-1, 5.1.2.1)

6.1.1.2.2 Partial discharges (IEC 60044-1, 5.1.2.2)

6.1.1.2.3 Chopped lightning impulse (IEC 60044-1, 5.1.2.3)

6.1.1.2.4 Capacitance and dielectric dissipation factor (IEC 60044-1, 5.1.2.4)

6.1.1.2.5 Multiple chopped impulses (IEC 60044-1, 5.1.2.5)

6.1.1.3 Low-voltage components voltage withstand capability

The low-voltage components like the merging unit and the secondary converters generally include several separated circuits with galvanic insulation between them. This insulation shall be capable of meeting the following requirements.

Table 6 – Low-voltage withstand capability

Ports to be tested	Designs and reference standards	Power-frequency voltage withstand capability	Impulse voltage withstand capability
Power supply inputs	In accordance with 6.2.10 of IEC 60694	2,0 kV a.c., 1 min for a.c. power supply input or 2,8 kV d.c., 1 min for d.c. power supply input	5 kV, 1,2/50 µs
Inputs and outputs connected to a galvanic link between the switchgear area and control cubicle (see figure 15)	*Design 1:*Double-shielded twisted paired cable when one or both of the shields and the signal wires are connected to the secondary devices with a plug assembled to the cable and only one shield is connected to the transformer	1,5 kV a.c., 1 min or 2,1 kV d.c., 1 min	5 kV, 1,2/50 µs
	Other designs: (in accordance with 6.2.10 of IEC 60694 clause 8 of IEC 60255-5)	2,0 kV a.c., 1 min or 2,8 kV d.c., 1 min	5 kV, 1,2/50 µs
Other inputs and outputs (see figure 15)	(in accordance with clause 6 of IEC 60255-5and IEC 61850-3)	500 V a.c., 1 min or 700 V d.c., 1 min	
NOTE The d.c. test is recommended only for electronic devices.			

6.1.1.4 Requirements for the external insulation

6.1.1.4.1 General

If the ECT is equipped with a porcelain insulator, the insulator should be according to IEC 60815. If the ECT is equipped with a composite hollow type insulator, the insulator should comply with IEC 61462.

6.1.1.4.2 Pollution

For outdoor electronic current transformers with ceramic high-voltage insulator, susceptible to contamination, the creepage distances for given pollution levels are given in table 7.

Table 7 – Creepage distances for given pollution levels

Pollution level	Minimum nominal specific creepage distance mm/kV [a, b]	Creepage distance/ arcing distance
I Light	16	≤ 3,5
II Medium	20	
III Heavy	25	≤ 4,0
IV Very heavy	31	

[a] Ratio of the leakage distance between phase and earth over the r.m.s. phase-to-phase value of the highest voltage for the equipment (see IEC 60071-1).

[b] For other information and manufacturing tolerances on the creepage distance, see IEC 60815.

NOTE 1 It is recognized that the performance of surface insulation is greatly affected by insulator shape.

NOTE 2 In very lightly polluted areas, specific nominal creepage distances lower than 16 mm/kV can be used depending on service experience, 12 mm/kV being the lower limit.

NOTE 3 In case of exceptional pollution severity, a specific nominal creepage distance of 31 mm/kV may not be adequate. Depending on service experience and/or laboratory test results, a higher value of specific creepage distance can be used, but in some cases the practicability of washing may have to be considered.

6.1.2 General requirements for temperature rise

The electronic current transformer shall be designed and constructed to withstand, without exceeding the specified limit for temperature rise and without damage, the thermal effects caused by the following conditions:

- maximum specified ambient temperature;
- rated frequency;
- rated continuous thermal current;
- the combination of auxiliary power supply voltage and secondary burden which causes the maximum internal power dissipation of the secondary converter.

6.1.3 Radio interference voltage requirements

The purpose of the radio interference voltage requirement is to verify the emission of corona discharges created by the electronic transformer. The main cause of corona discharges are HV parts and partial discharges at the surface of the insulator housing. This test is relevant for electronic transformers having $U_m \geq 123$ kV.

The requirement and test procedure are described in IEC 60044-1.

6.1.4 Transmitted overvoltage requirements

The purpose of the transmitted overvoltage requirement is to verify the transmission of over-voltages transmitted from the primary of the electronic transformer to the secondary output, the merging unit or to the power supply.

The main cause of overvoltages is the switching of HV equipment. This requirement is not applicable if a transmitting system providing galvanic insulation is used (see figure 1).

The requirement and test procedure are described in IEC 60044-1.

6.1.5 Electromagnetic compatibility requirements

6.1.5.1 General

EMC is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment (IEV 161-01-07). In order to assess the behaviour of an electronic transformer in this specific electromagnetic environment, it is necessary to set appropriate limits for emission and immunity. The purpose of each of the relevant tests is described in the following subclauses.

6.1.5.2 Emission requirements

Besides the emission requirements considered to be covered with a radio interference voltage test (RIV test) and transmitted overvoltage test, for electronic transformers also emission limits considered in CISPR 11 are relevant and shall be tested accordingly.

6.1.5.3 Immunity requirements.

Table 8 gives a list of type tests which can be considered relevant for electronic transformers with the associated severity class and assessment criteria. Other tests which can be of interest for this application are still under consideration.

6.1.5.3.1 Harmonic and interharmonic disturbance

The purpose is to verify the immunity of the electronic transformer against harmonic and interharmonic components of the low-voltage power supply of the electronic transformer. This test is only applicable for electronic transformers using a.c. power supply.

6.1.5.3.2 Slow voltage variation

The purpose is to verify the immunity of the electronic transformer against slow voltage variations of the low-voltage power supply of the electronic transformer. The requirement is relevant for a.c. or d.c. power supply.

6.1.5.3.3 Voltage dips and short interruption

The purpose of this test is to verify the immunity of the electronic transformer against voltage dips or voltage interruption of the low-voltage power supply of the electronic transformer. The requirement is relevant for a.c. or d.c. power supply.

6.1.5.3.4 Surge immunity

The purpose of this test is to verify the immunity of the electronic transformer against unidirectional transient caused by overvoltages from switching in the power network and lightning strokes (direct or indirect). This test is very important for HV and MV installations because of the high probability of lightning exposure.

Table 8 – Immunity requirements and tests

Test	Reference standard	Severity class	Assessment criteria
Harmonic and interharmonic test [a]	IEC 61000-4-13	2	A
Slow voltage variation test [a]	IEC 61000-4-11	From +10 % to –20 %	A
Slow voltage variation test [b]	IEC 61000-4-29	From +20 % to –20 %	A
Voltage dips and short interruption test [a]	IEC 61000-4-11	30 % dip × 0,1s [c] interruption × 0,02s [c]	A
Voltage dips and short interruption test [b]	IEC 61000-4-29	50 % dip × 0,1s [c] interruption × 0,05s [c]	A
Surge immunity test	IEC 61000-4-5	4	B
Electrical fast transient/burst test	IEC 61000-4-4	4	B
Oscillatory waves immunity test	IEC 61000-4-12	3	B
Electrostatic discharge test	IEC 61000-4-2	2	B
Power frequency magnetic field immunity test	IEC 61000-4-8	5	A
Pulse magnetic field immunity test	IEC 61000-4-9	5	B
Damped oscillatory magnetic field immunity test	IEC 61000-4-10	5	B
Radiated, radiofrequency, electro-magnetic field immunity test	IEC 61000-4-3	3	A

[a] Only applicable to electronic transformer with a.c. power port.

[b] Only applicable to electronic transformer with d.c. power port.

[c] Values are adapted to common protective devices.

A: Normal performance within the accuracy specification limits (steady-state conditions at rated primary current or lower).

B: Temporary degradation of performances of measurements, which are not relevant for protection or self-diagnosis which are self-recovered is allowed. A reset or restart is not allowed. No output overvoltage greater than 500 V is allowed. No degradation of performance causing false trips of protective devices is allowed for electronic protective transformers.

6.1.5.3.5 Electrical fast transient/burst

The purpose of this test is to verify the immunity of the electronic transformer against bursts of very short transients generated by the switching of small inductive loads, relay contact bouncing (conducted interference) or switching of HV switchgear – particularly SF6 or vacuum switchgear (radiated interferences).

6.1.5.3.6 Oscillatory wave immunity

The purpose of this test is to verify the immunity of the electronic transformer against repetitive damped oscillatory waves occurring in low-voltage circuits in HV and MV stations due to switching phenomena (isolators in HV/MV open-air stations, particularly HV busbar switching) or faults in HV or MV networks.

6.1.5.3.7 Electrostatic discharge

The purpose of this test is to verify the immunity of the electronic transformer against electrostatic discharges (ESD) generated by an operator touching (directly or with a tool) the equipment or its vicinity. In general, this is not of great concern because electronic parts of electronic transformers are located outdoors or indoors, generally standing on a bare concrete floor, without any synthetic carpet or furniture nearby. Moreover, the electronic parts are generally mounted inside a metallic cabinet well bonded to a well-controlled earthing network, for safety reasons. This makes the probability of ESD very low.

6.1.5.3.8 Power-frequency magnetic field immunity

The purpose of this test is to verify the immunity of the electronic transformer when subjected to power-frequency magnetic fields related to the proximity of power conductors, transformers, etc. in normal or faulted conditions; this test is important because of the expected vicinity of electronic parts of the electronic transformer to main circuits.

6.1.5.3.9 Pulse magnetic field immunity

The purpose of this test is to verify the immunity of the electronic transformer when subjected to impulse magnetic field generated by lightning strokes on buildings, metal structures and earth networks; this test is relevant to HV and MV installations because of the increased lightning exposition.

6.1.5.3.10 Damped oscillatory magnetic field immunity

The purpose of this test is to verify the immunity of the electronic transformer when subjected to damped oscillatory magnetic field generated the switching of HV busbars by isolators. This test is mainly applicable to electrical equipment installed in HV substations.

6.1.5.3.11 Radiated, radiofrequency, electromagnetic field immunity

The purpose of this test is to verify the immunity of the electronic transformer against electromagnetic fields generated by radio transmitters or any other device emitting wave-radiated electromagnetic energy. The most important concern in HV and MV installations comes from the possibility of the use of walkie-talkie and portable phones, as the probability of vicinity of broadcasting stations or amateur radios is, in general, very low.

6.1.6 Signal-to-noise ratio

The minimum signal-to-noise ratio of the ECT output shall be 30 dB (relative to rated secondary output) over the bandwidth specified by the manufacturer.

6.1.7 Wake-up current

If relevant, the wake-up current shall be specified by the manufacturer.

6.1.8 Mechanical requirements

These requirements generally only apply to free-standing electronic current transformers having $U_m \geq 72,5$ kV and above.

In table 9, guidance is given on the static loads that electronic current transformers shall be capable of withstanding. The figures include loads due to wind and ice.

The specified test loads are intended to be applied in any direction to the primary terminals.

Table 9 – Static withstand test loads

Highest voltage for equipment U_m kV	Static withstand test load F_R N	
	Load class I	Load class II
72,5 to 100	1 250	2 500
123 to 170	2 000	3 000
245 to 362	2 500	4 000
≥420	4 000	6 000

NOTE 1 The sum of the loads acting in routine operating conditions should not exceed 50 % of the specified withstand test load.

NOTE 2 In some applications, electronic current transformers with through current terminals should withstand rarely occurring extreme dynamic loads (for example, short circuits) not exceeding 1,4 times the static withstand test load.

NOTE 3 For some applications, it may be necessary to establish the resistance to rotation of the primary terminals. The moment to be applied during test shall be agreed between manufacturer and purchaser.

6.1.9 Reliability and dependability

The manufacturer should provide information according to relevant standards, like IEC 60812 and IEC 61025, on the dependability and reliability of the ECT. This includes assessment of mean time to failure (MTTF), mean time between failures (MTBF) and also a failure mode and effect analysis (FMEA) related to main parts subjected to maintenance. A block diagram will be provided describing relationship between sub-parts and how the redundancy, if any, is managed. Parts subjected to maintenance and relevant maintenance procedures must be identified.

NOTE A solution to improve the reliability and dependability could be the implementation of proper redundancy.

The manufacturer shall endeavour to provide all the control necessary to avoid any spurious operation as a result of loss of supply or insufficient supply, loss of an internal component or as a result of a component malfunction.

The reliability and dependability aspects of electronic current transformers are comparable to those of the electrical components in the substation. Hence, the reliability and dependability of electronic current transformer shall be treated similarly.

At least, the electronic current transformer shall be able to maintain its accuracy class when some of those components are replaced, which need not to be calibrated after installation. A replacement of components is allowed only with components specified by the manufacturer of the electronic current transformer.

Components (i.e. sub-parts), which can be replaced on site without requiring calibration, shall be specially identified by an appropriate mark. This capability shall be demonstrated by test.

No other component can be replaced without recalibration of the complete electronic current transformer.

6.1.10 Requirements for liquids in equipment

The manufacturer shall specify the type and the required quantity and quality of the liquid to be used in equipment and provide the user with necessary instructions for renewing the liquid and maintaining its required quantity and quality.

6.1.10.1 Liquid level

A device for checking the liquid level when appropriate, preferably during service, with indication of minimum and maximum limits admissible for correct operation, shall be provided.

6.1.10.2 Liquid quality

Liquids for use in equipment shall comply with the instructions of the manufacturer.

For oil-filled equipment, new insulating oil shall comply with IEC 60296.

6.1.11 Requirements for gases in equipment

The manufacturer shall specify the type and the required quantity, quality and density of the gas to be used in equipment and provide the user with necessary instructions for renewing the gas and maintaining its required quantity and quality, except for sealed pressure systems.

For sulphur hexafluoride-filled equipment, new sulphur hexafluoride shall comply with IEC 60376.

In order to prevent condensation, the maximum allowable moisture content within equipment filled with gas at rated filling density for insulation ρ_{re} shall be such that the dew point is not higher than –5 °C for a measurement at 20 °C. Adequate correction shall be made for measurement made at other temperatures. For the measurement and determination of the dew point, refer to IEC 60376B and IEC 60480.

Parts of high-voltage equipment housing compressed gas shall comply with the requirements laid down in the relevant IEC standards.

The tightness characteristic of a closed pressure ECT stated by the manufacturer shall be consistent with a minimum maintenance and inspection philosophy.

The tightness of closed pressure ECT for gas, specified by the relative leakage rate F_{rel}, shall not exceed 0,5 % per year.

NOTE These values can be used to calculate times between replenishments, T, outside extreme conditions of temperature or frequency of operations.

Means shall be provided to enable gas ECTs to be safely replenished whilst the ECT is in service.

NOTE Attention is drawn to the need to comply with local regulation relevant to pressure vessels.

6.1.12 Earthing of equipment

In the case of an electronic current transformer having highest voltage for equipment $U_m \geq$ 1,2 kV, the frame of each equipment device shall be provided with a reliable earthing terminal having a clamping screw or bolt for connection to an earthing conductor suitable for specified fault conditions.

The diameter of clamping screws or bolt shall be at least 8 mm and 12 mm for devices installed in a switchgear area with $U_m \geq 36$ kV.

Parts of metallic enclosures connected to the earthing system may be considered as an earthing conductor.

6.1.13 Degrees of protection by enclosures

Degrees of protection according to IEC 60529 shall be specified for all enclosures of high-voltage equipment containing parts of the main circuit allowing penetration from outside as well as for enclosures for appropriate low-voltage control and/or auxiliary circuits and mechanical operating equipment of all high-voltage equipment devices.

The degrees of protection apply to the service condition of the equipment.

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

6.1.13.1 Protection of persons against access to hazardous parts and protection of the equipment against ingress of solid foreign objects

The degree of protection of persons provided by an enclosure against access to hazardous parts of the main circuit, control and/or auxiliary circuits and to any hazardous moving parts (other than smooth rotating shafts and slowly moving linkages) shall be indicated by means of a designation specified in IEC 60529.

The first characteristic numeral indicates the degree of protection provided by the enclosure with respect to persons, as well as of protection of the equipment inside the enclosure against ingress of solid foreign bodies.

If the protection against access to hazardous parts only is requested or if it is higher than that indicated by the first characteristic numeral, an additional letter may be used as in IEC 60529.

IEC 60529 gives details of objects which will be “excluded” from the enclosure for each of the degrees of protection. The term “excluded” implies that solid foreign objects will not enter fully the enclosure and that a part of the body or an object held by a person, either will not enter the enclosure or, if it enters, that adequate clearance will be maintained and no hazardous part will be touched.

6.1.13.2 Protection against ingress of water

No degrees of protection against harmful ingress of water according to the second characteristic numeral of the IP-code is specified (second characteristic numeral X).

Equipment for outdoor installation provided with additional protection features against rain and other weather conditions shall be specified by means of the supplementary letter W placed after the second characteristic numeral, or after the additional letter, if any.

6.1.13.3 Protection of equipment against mechanical impact under normal service conditions

Enclosures of enclosed equipment shall be of sufficient mechanical strength (possible corresponding tests are specified in 8.11.2).

For indoor installation, the proposed impact level is 2 J.

For outdoor installation without additional mechanical protection, higher impact levels may be specified, subject to an agreement between manufacturer and user.

6.1.14 Flammability

Where possible, the materials shall be selected to comply with classification given in IEC 60707, and the parts designed such that they retard the propagation of any flame resulting from accidental overheating in the equipment.

6.1.15 Vibration

The output of protective electronic current transformer shall operate correctly when subject to vibration levels appropriate to its application. Different parts of the ECT may be subjected to different vibration levels.

The output of measuring electronic current transformer is only subjected to the vibration endurance test.

6.1.16 Requirements for transmitting system and output link

6.1.16.1 General

If used for transmitting system and/or output link, the optical fibre cables shall comply with IEC 60794. The fibre cables shall be metal-free, water-resistant. Those cables shall be mounted separately from wire cables in special ducts.

The transmitting system and output link cables should be protected against rodent attack.

6.1.16.2 Optical connectors

No optical fibre connectors are allowed outdoors without appropriate protective enclosure.

6.1.16.3 Fibre optic terminal box

Where a fibre optic terminal box is used it shall be directly accessible for inspection at ground level.

6.1.16.4 Total cable length

The ECT shall be capable of operating with maximum length of transmitting system cable and output link as specified by the manufacturer.

NOTE The manufacturer has to take into account that the total cable length could reach 1 km for very high-voltage air-insulated substations.

6.1.17 Maintenance

Some ECT designs require maintenance work. In order to evaluate the complexity of such maintenance and in order to be able to perform this maintenance efficiently, the manufacturer shall provide a maintenance manual according to 15.6.2.

6.1.18 Failure detection and maintenance announcement

ECT failure, where automatically detected, shall result in zero analogue output or activation of digital output data invalid flag. At least, the failure of the transmitting system shall be automatically detected or the transmitting system shall allow a monitoring by the relay. In the special case of cessation of output due to interruption of power supply the output shall be zero for voltage output and inactive for digital output. Following restoration of the ECT power supply, the operation of the ECT shall be automatically self-restored. ECT maintenance requirement, where detected, shall be announced. For digital output this shall result in the activation of the required maintenance flag (see 6.2.4.1.11)

6.1.19 Operability

In order to facilitate the operation and maintenance of the ECT, the position of user accessible parts shall be agreed between the user and the manufacturer. These parts may include switches, socket outlets, fuses, input and outputs, etc.

6.2 Design requirements for digital output

6.2.1 General

Regarding the physical and the link layer of the digital interface, two technical solutions are allowed. One uses Ethernet and is described in IEC 61850-9-1, the other is described here. The application layer is the same in both cases. With the realization described here either synchronize pulses or interpolation schemes can be used to get time-coherent primary current and voltage samples from several merging units. With the Ethernet link according to IEC 61850-9-1 synchronize pulses are usually used.

6.2.2 Physical layer

The connection of the merging unit to the secondary equipment may either be realized as a fibre optic transmission system or as a copper-wire-based transmission system. In the following subclauses, descriptions are given for both alternatives.

The standard transmission speed is 2,5 Mbit/s for the universal frame. Manchester coding is used. MSB are transmitted first.

Manchester coding: transition from low level to high level is binary 1, transition from high level to low level is binary 0, as explained in the following drawing

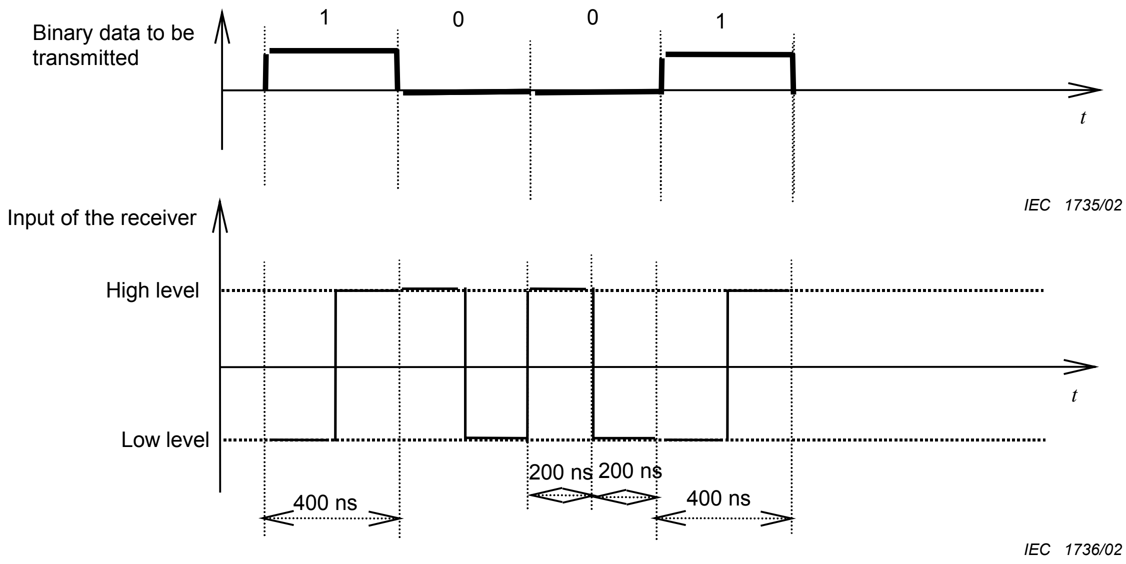


Figure 4 – Manchester coding

NOTE 1 General information on digital output is given in annex B.

NOTE 2 High levels and low levels are defined in 6.2.2.1 and 6.2.2.5.

6.2.2.1 Fibre optic transmission

If a fibre optic transmission system is used, the compatible interface is a fibre optic connector at the MU. The type of connector is specified in table 10. This table offers some guidelines which should help to build a safe fibre optic transmission link. Other mechanical specifications, for example, mounting position and cable layout, are manufacturer specific.

High level is defined as “light on” and low level is defined as “light off”.

Table 10 – The compatible fibre optic transmission system

Characteristics	Plastic fibre	Glass fibre
Connector	BFOC/2,5 [c]	BFOC/2,5 [a]
Cable type	Step index 980/1 000 μm	Graded index 62,5/125 μm [b]
Typical distance	Up to 5 m	Up to 1 000 m
Optical wavelength	660 nm	820 nm – 860 nm
Maximum transmission power [d e]	–10 dBm	–15 dBm
Minimum transmission power [d e]	–15 dBm	–20 dBm
Maximum receiving power [d]	–15 dBm	–15 dBm
Minimum receiving power [d]	–25 dBm	–30 dBm
System reserve [f]	Min. +3 dB	Min. +3 dB

[a] An LSH connector can be used in harsh environments.

[b] 50/125 μm optical fibres may be used. If this type of fibre is used, the transmitting power that can be input is reduced and therefore the distance, the receiving power, and the system reserve shall be specified separately.

[c] HP plastic connector can be used for plastic fibre applications.

[d] Power values are average values with 50 % duty cycle.

[e] Measurement of transmitted optical power shall be made at the output of an optical fibre of 10 m in length (for silica 62,5/125 μm) or 1 m in length (for plastic fibres). 0 dBm is defined as 1 mw of optical power r.m.s.

[f] When designing the transmission link, care should be taken that instantaneous (peak) values of the optical power on the receiver does not exceed its maximum ratings. If maximum ratings are exceeded, the receiver might not be able to detect the bit stream correctly (because it has been blinded), thus signalling a lot of errors on the transmission line (see also 6.2.2.2.2).

6.2.2.2 Optical driver characteristics

6.2.2.2.1 Rise and fall time

The rise and fall times, determined between the 10 % and 90 % amplitude points, shall be less than 20 ns.

6.2.2.2.2 Characteristics of the optical pulse

Overshoot shall be less than 30 % of the nominal output of the optical pulse, and the ripple limited to 10 % of the nominal output of the optical pulse during the second half of the pulse.

Overshoot and ripple are defined in the following drawing:

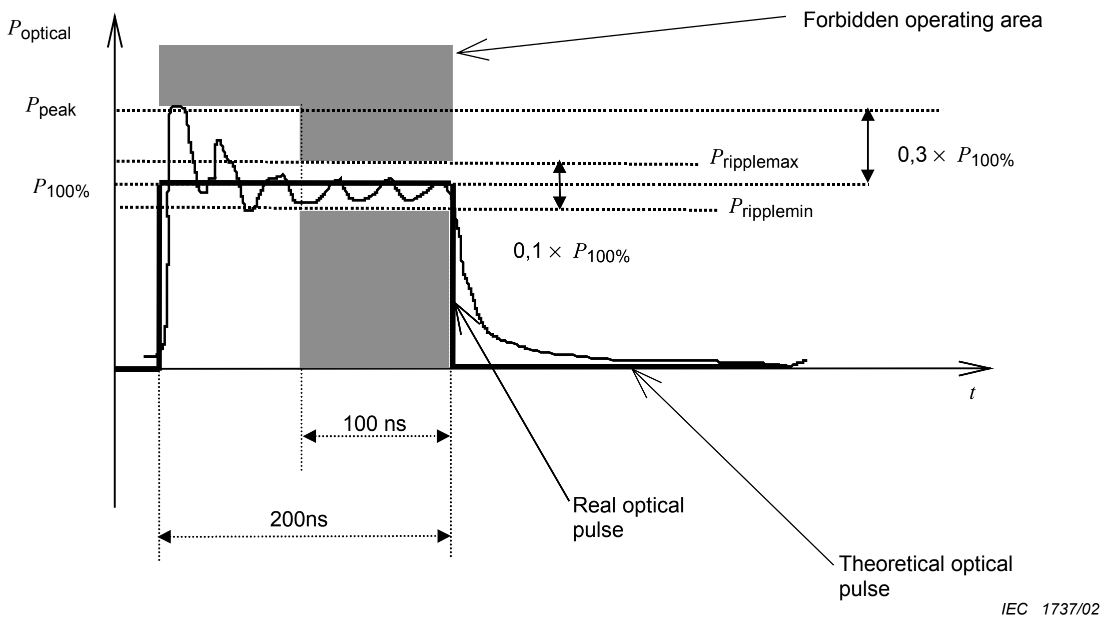


Figure 5 – Characteristics of the optical pulse

The overshoot is defined by overshoot $(P_{peak} - P_{100\,\%}) / P_{100\,\%}) * 100\ \%$

The ripple is defined by (MAX|P (100 ns < t < 200 ns) – $P_{100\,\%}$ |) / $P_{100\%}$ * 100 %

NOTE These measurements are made in order to check that the receiver is not affected by too high optical levels and that the output from the transmitter is stable enough for good detection of the optical levels.

6.2.2.2.3 Test circuit for the optical pulse

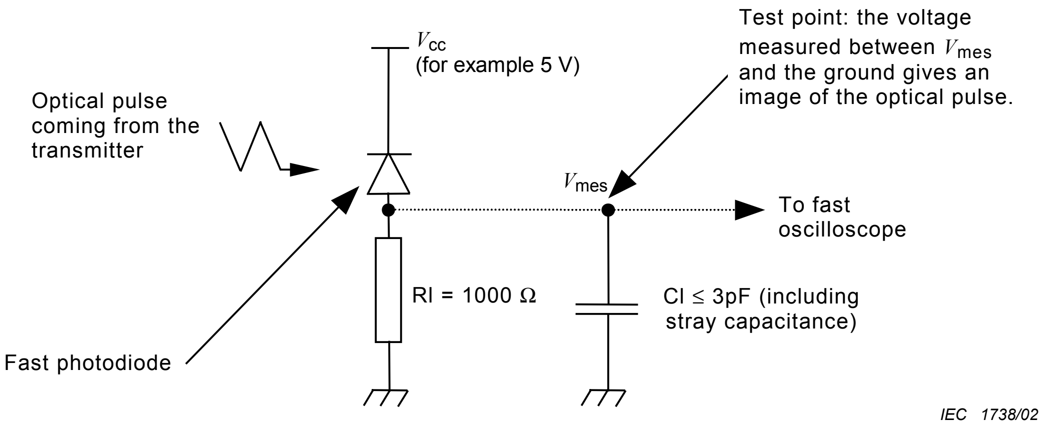


Figure 6 – Test circuit for the optical pulse

NOTE 1 This test circuit does not describe the decoupling networks which are necessary for the VCC supply.

NOTE 2 The oscilloscope and its associated probe should have a bandwidth of at least 500 MHz.

NOTE 3 The photodiode used for the test circuit should have a very small rise and fall time, typically ≤1,5 ns. A good example is the BPX65.

NOTE 4 The optical pulse should be taken at the output of an optical fibre of 10 m length (for silica 62,5/125 µm) or 1 m length (for plastic fibres).

6.2.2.3 Optical receiver characteristics

6.2.2.3.1 Rise and fall time of the receiver

The rise and fall times of the signal, determined between the 10 % and 90 % amplitude points, shall be less than 20 ns.

6.2.2.3.2 Pulse width distortion

Pulse width distortion shall be less than 25 ns.

6.2.2.4 Timing accuracy for optical transmission

6.2.2.4.1 Clock jitter

Data transitions shall occur within ±10 ns of the nominal clock period measured at the half-voltage points.

6.2.2.5 Copper wire interface

As an alternative to fibre optic transmission described above, a copper-wire-based transmission system may be used between the MU and electrical measuring instruments and electrical protective devices. This transmission system shall comply with the EIA RS-485 standard.

In this application, it is used only as an unidirectional link, from the ECT to the secondary equipment. Due to the characteristic of the EIA RS-485 standard, a maximum number of 32 units of load can be connected to one physical line.

Table 11 – The compatible copper-wire transmission system for simplex point-to-point link

	Characteristics
Connector	Sub D, 9 pin
Cable type	Shielded twisted pair
Typical distance	Up to 250 m

NOTE 1 As an alternative, RJ-45 connectors type with relevant EMC protection may be used.

NOTE 2 The case of multipoint connections is more complex: some indications are given in 6.2.2.6.4.3.

The type of the cable used is not defined in the EIA RS-485 standard. However, guidance on the choice of the cable is given in A.2.2 of the EIA RS-485 standard. Anyway, the interconnecting cable shall be shielded and have a characteristic impedance in the range of 90 Ω to 120 Ω at the frequency of 5 MHz.

All other mechanical specifications are manufacturer specific.

The output of the line driver is a three-point cable (see also 11.1.2). Low level is defined when the voltage at point A (Va) is greater than the voltage at point B(Vb) and Va′-Vb′ (at the input of the receiver) >200 mV peak. High level is defined when the voltage at point A (Va) is lower than the voltage at point B (Vb) and Va′-Vb′ (at the input of the receiver) <–200 mV peak.

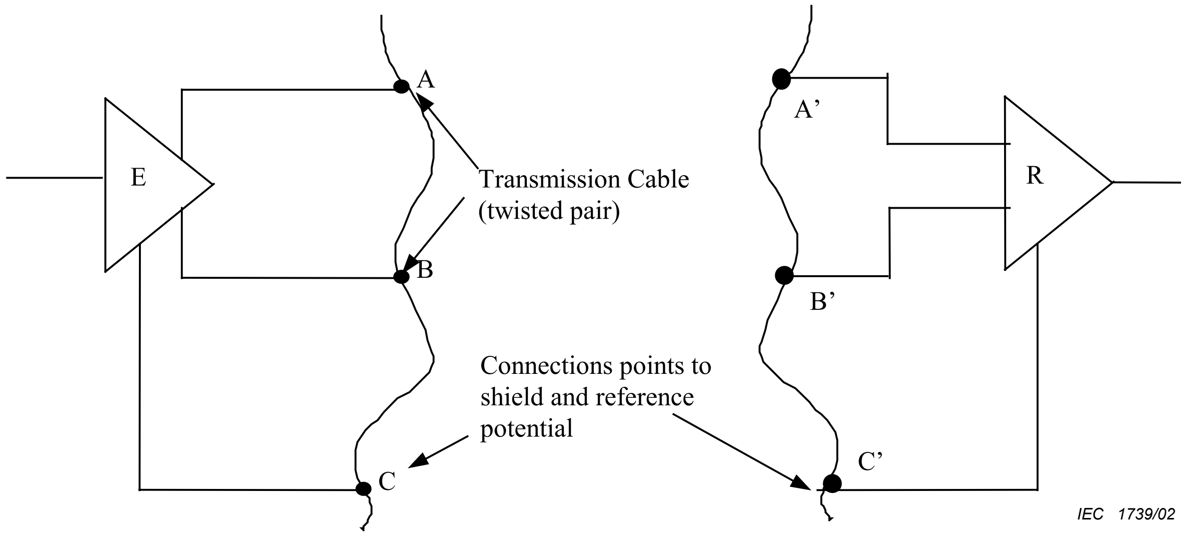


Figure 7 – Copper wire interface

NOTE 1 Copper-wire-based transmission systems are more susceptible to electromagnetic interference than fibre optic based systems. The inclusion of a copper-wire-based system should not degrade the performance of electronic measuring instruments and electrical protective devices.

NOTE 2 Circuits designed for RS422-type communication may also be used, but manufacturer and user have to agree on it.

NOTE 3 Special care should be taken for the specification of the mechanical connections of the cables in the case of several receivers linked to a transmitter through a daisy chain.

NOTE 4 Minimum sensitivity of the receiver is defined by the requirements of 6.2.2.6.2.3.

6.2.2.6 Electrical requirements for a copper wire transmission

NOTE More detailed information on the shape of waveforms, EMC requirements and test circuits can be found in standard EIA-RS 485.

6.2.2.6.1 Line driver characteristics

6.2.2.6.1.1 Output impedance

The line driver shall have a balanced output with an internal impedance of 110 Ω ± 20 % when measured at terminals to which the transmission line is connected, at frequencies from 0,1 MHz to 6 MHz.

6.2.2.6.1.2 Signal amplitude

The signal amplitude shall lie between 3 V and 10 V peak-to-peak, when measured across a resistor (110 Ω ± 1 %) connected on the output terminals, without any interconnecting cable present.

6.2.2.6.1.3 Rise and fall time

The maximum rise and fall times, determined between the 10 % and 90 % amplitude points, shall be 20 ns when measured across a 110 Ω resistor connected to the output terminals of the line driver.

6.2.2.6.2 Line receiver characteristics

6.2.2.6.2.1 Receiver input impedance

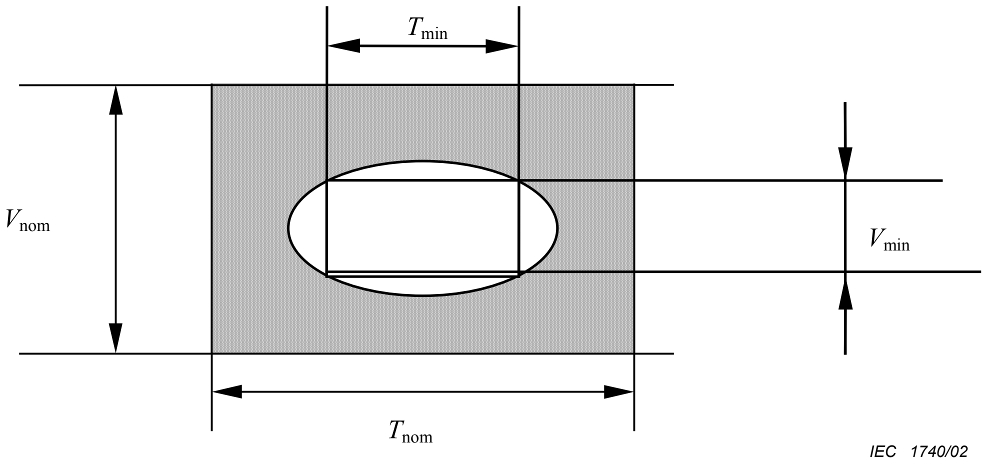
The receiver shall have a minimum input resistance of 12 kΩ.

6.2.2.6.2.2 Maximum input signals

The receiver shall correctly interpret the data when connected directly to a line driver working between the extreme voltage limits specified in 6.2.2.6.1.2.

6.2.2.6.2.3 Minimum input signals

The receiver shall correctly interpret the data when a random input signal produces the eye diagram characterized by a V_{min} of 200 mV and T_{min} which is equal to 50 % of the symbol period.



Key

V_{nom} in the range defined by 6.2.2.6.1.2 (signal amplitude);

V_{min} = 200 mV;

T_{nom} = 200 ns;

T_{min} = 0,5 * 200 ns = 100 ns.

Figure 8 – Eye diagram

6.2.2.6.3 Timing accuracy

6.2.2.6.3.1 Clock jitter

Data transitions shall occur within ±10 ns of the nominal clock period measured at the half-voltage points.

6.2.2.6.4 Miscellaneous

6.2.2.6.4.1 Adaptation of the line termination impedance

In order to ensure proper operation of the transmission line, especially at high speed, it is a common practice to add a terminating impedance to the transmission line. This terminating impedance avoids any reflections on the line which could degrade the quality of the signal. The general rule in this case is to adapt the output impedance of the line driver and the global input impedance of the receiver(s) to the characteristic impedance of the cable line. Depending on the choice of the cable, the values for this characteristic impedance can slightly vary, within the limits set in this standard. As a general rule, the best match between both output and input impedance and the characteristic impedance will guarantee the best transmission quality.

6.2.2.6.4.2 Simplex point-to-point connection

This consists of one driver and one receiver. In this case the easiest way to terminate the line properly is to connect a resistance whose value matches the characteristic impedance of the line in parallel to the inputs of the receiver.

6.2.2.6.4.3 Simplex multipoint connections

This consists of one driver and several receivers connected at different points of the transmission line. In this case the preferred architecture is the daisy-chain connection. The star architecture, however simpler and easier to implement, does not guarantee a proper quality of signal transmission for our application. The daisy-chain architecture is illustrated in the following figure:

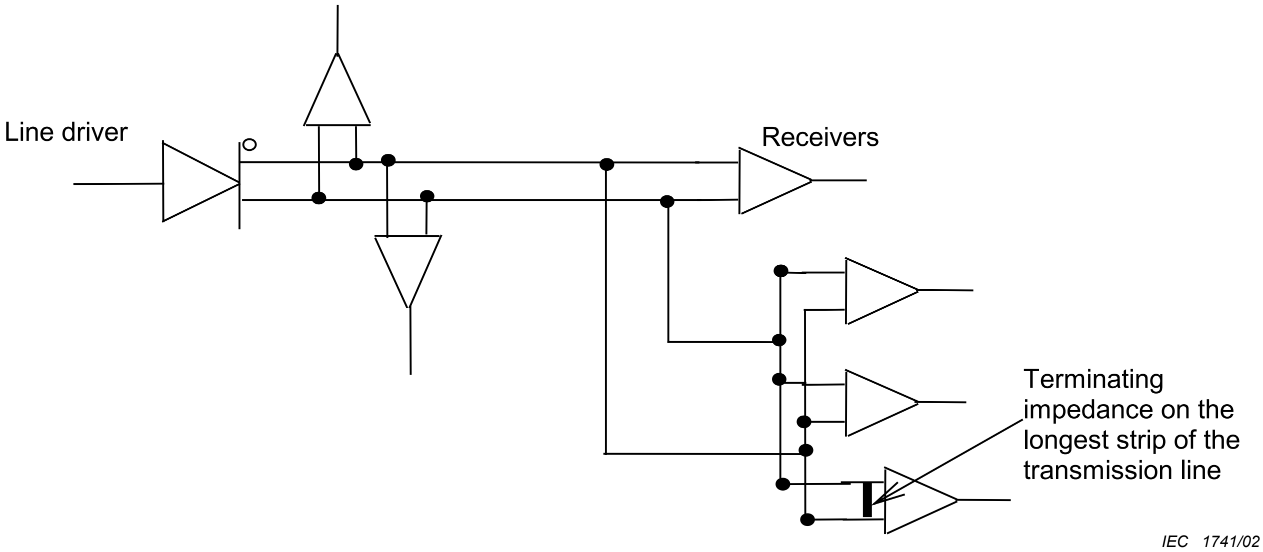


Figure 9 – Daisy-chain architecture

Some simple principles are to be respected in order to build a safe transmission link:

– only terminate the longest portion of the line cable. The other transmission links shall be considered as stubs and, as such, be limited in length (compared to the main transmission link, the length of the stubs shall typically be less than 10 m).

– the sum off all loads (impedances) seen by the driver (including input impedance of the receivers, terminating resistance, etc.) shall be 60 Ω minimum.

NOTE It is more difficult to find connectors suitable for multiplex point to point connections than to simplex connections. However connectors used by fieldbus such as Worldfipbus, Profibus, Interbus, Bitbus, CAN may be used. The connection of the cable shield should require special attention.

6.2.3 Link layer

This link layer has been adapted from the format FT3, described in IEC 60870-5-1. The advantages of this format are:

– good data integrity,

– the frame structure makes it possible to use it for multidrop synchronous data links, at high speed.

The link service class is S1: SEND/NO REPLY. This reflects the fact that the transformer transmits its values continuously and periodically, not needing any acknowledgement or answer from the secondary equipment.

Transmission rules

R1 Line idle is binary 1. This value 1 is continuously transmitted, in Manchester coding, between two frames in order to make the synchronization of the receiver's clock easier, thus increasing the reliability of the communication link. A minimum of 70 idle bits shall be transmitted between two frames.

R2 The first two octets of a frame represent a start character.

R3 16 user data octets are completed by a 16-bit check sequence. If necessary, the frame shall be filled up with pad bytes in order to complete the assigned number of bytes.

R4 The check sequence forms a code generated by the polynomial:

$$X16 + X13 + X12 + X11 + X10 + X8 + X6 + X5 + X2 +1.$$

The 16 bits of the check sequence generated by this specification are inverted.

R5 The receiver checks the signal quality, the start character, the check sequences and the frame length. The frame is rejected if one of these checks fails, otherwise it is released to the user.

NOTE 1 Rule R1: it is recommended to stuff as many idle bits as possible between two frames; some receiver synchronization methods can use a small blank interval just before start character, in order to prepare the receiver for the transmission to come.

NOTE 2 Rules R5 and R6 from IEC 60870-5-1 have been modified since the service class used is S1: there is no way for the emitter to know that an error has been detected by the receiver, so the specified minimum line idle interval defined by R5 of IEC 60870-5-1 is not needed and would lead to unnecessary high data rate. Minimum line idle interval is defined by rule R1 and can be used for checking purposes.

		2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
	Start	0	0	0	0	0	1	0	1
	Character	0	1	1	0	0	1	0	0
	Pay Load 1 (16 bytes)		DATA						
	CRC	msb	CRC for pay load 1						lsb
	Pay Load 2 (16 bytes)		DATA						
			Pad bytes if necessary						
			Pad bytes if necessary						
			Pad bytes if necessary						
	CRC	msb	CRC for pay load 2						lsb
Byte 38	Pay								
Byte 39	Load 3								
Byte 40									
Byte 41	(16 bytes)								
Byte 42									
Byte 43									
Byte 44									
Byte 45			DATA						
Byte 46									
Byte 47									
Byte 48									
Byte 49									
Byte 50									
Byte 51									
Byte 52									
Byte 53									
Byte 54	CRC	msb	CRC						
Byte 55			for pay load 3						lsb

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Figure 10 – Frame format according to FT3

6.2.4 Application layer

For compatibility with the future standard IEC 61850-9-1, several identifiers (for example, logical node name and logical device name) are defined and included in the data frame.

6.2.4.1 Data type specification

6.2.4.1.1 Length of data set

Length:= UI16[1..16], <0..65535>

The length field contains the length of the following data set. The length is given in octets and is calculated as the length of the data set without the header (length and data Group). For the point-to-point link as defined in this standard the length is always 44 (dec).

6.2.4.1.2 Logical Node Name (LNName)

LNName= ENUM8<0..255>,

For the point-to-point link defined in this standard the Logical Node Name (LNName) value is always 02.

6.2.4.1.3 Data Set Name (DataSetName)

DataSetName = ENUM 8<0...255>

The DataSetName is a unique number identifying the structure of the dataset, i.e. the data channel assignment. Permitted values are 01 and FE H (254 decimal).

Table 12 defines the assignments of the DataChannels to the signal sources for DataSet Name = 01.

A DataSetName = FE H (254 decimal) denotes an application specific channel mapping intended to accommodate for applications where the standard channel mapping of table 13 is not applicable. The manufacturer has to supply information about the data channel mapping equivalent to table 13 (value, reference value and scaling factor for each data channel), so that the secondary equipment can be correctly configured. See clause B.3 for an example.

The value of DataSetName cannot be changed during operation, i.e. the data channel assignment is fixed by design or configuration prior to shipment.

Table 12 – Data channel mapping for DatSetName = 01, general application

DataSetName	01			
	Source	Object reference	Reference value	Scaling factor (see table 5)
DataChannel#1	Current Phase A, prot.	PhsATCTR.Amps	Rated Phase Current	SCP
DataChannel#2	Current Phase B, prot.	PhsBTCTR.Amps	Rated Phase Current	SCP
DataChannel#3	Current Phase C, prot.	PhsCTCTR.Amps	Rated Phase Current	SCP
DataChannel#4	Neutral Current	NeutTCTR.Amps	Rated Neutral Current	SCM
DataChannel#5	Current Phase A, meas.	PhsA2TCTR.Amps	Rated Phase Current	SCM
DataChannel#6	Current Phase B, meas.	PhsB2TCTR.Amps	Rated Phase Current	SCM
DataChannel#7	Current Phase C, meas.	PhsC2TCTR.Amps	Rated Phase Current	SCM
DataChannel#8	Voltage Phase A	PhsATVTR.Volts	Rated Phase Voltage	SV
DataChannel#9	Voltage Phase B	PhsBTVTR.Volts	Rated Phase Voltage	SV
DataChannel#10	Voltage Phase C	PhsCTVTR.Volts	Rated Phase Voltage	SV
DataChannel#11	Neutral Voltage	NeutTVTR.Volts	Rated Phase Voltage	SV
DataChannel#12	Busbar voltage	BBTVTR.Volts	Rated Phase Voltage	SV
NOTE Object reference in IEC 61850-9-1 is based on the format <LNName>.<DataName>; LNName is <LNPrefix><LNClassName><LNInstanceID>; DataName and LNClassName are standardized; the rest is configurable. In the values provided in the table above, TCTR, and TVTRare LNClassNames; amps, volts are DataNames; the rest is an example of how the naming could be configured.				

6.2.4.1.4 Logical Device Name (LDName)

LDName= UI16,< 0..65535>

The Logical Device Name (LDName) can be used to identify the source of the data set by a unique number in the substation. LDName can be parameterized, for example, during installation.

6.2.4.1.5 Rated phase current (PhsA.Artg)

PhsA.Artg:= UI16 <0..65535>

NOTE According to the future IEC 61850-7-4, each phase can have its own rated value. To model the information contained in the universal dataset, we have selected phase A.

Gives the rated phase current in amperes (r.m.s).

NOTE The transmission of this value is optional. If it is not sent, the value zero should be transmitted instead. In this case the receiver has to be parameterized explicitly as has been done with conventional transformers. If it is transmitted no parameterization of the receiver is necessary and therefore the risk of badly configured devices is reduced and the set-up is simplified.

6.2.4.1.6 Rated neutral current (Neut.Artg)

Neut.Artg:= UI16 <0..65535>

Gives the rated neutral current in amperes (r.m.s.)

NOTE The transmission of this value is optional. If it is not sent, the value zero should be transmitted instead. In this case the receiver has to be parameterized explicitly as has been done with conventional transformers. If it is transmitted no parameterization of the receiver is necessary and therefore the risk of badly configured devices is reduced and the set-up is simplified.

6.2.4.1.7 Rated phase voltage and rated neutral voltage (PhsA.Vrtg)

PhsA.Vrtg:= UI16 <0..65535>

NOTE According to the future IEC 61850-7-4, each phase can have its own rated value. To model the information contained in the universal dataset, we have selected phase A.

Gives the rated voltage in 1/($\sqrt{3}$ *10) kV (r.m.s.)

The rated phase voltage and the rated neutral voltage are transmitted multiplied by √3 to avoid truncation errors.

Example: For an EVT with a rated voltage of U_r = 145 kV/ $\sqrt{3}$, the rated phase-voltage value in the data frame is 145 kV/ $\sqrt{3}$ * $\sqrt{3}$ *10 = 1 450.

NOTE The transmission of this value is optional. If it is not sent, the value zero should be transmitted instead. In this case the receiver has to be parameterized explicitly as it has been done with conventional transformers. If it is transmitted no parameterization of the receiver is necessary and therefore the risk of badly configured devices is reduced and the set-up is simplified.

6.2.4.1.8 Rated delay time

$\mathbf{t_{dr}}$:= UI16 <0..65535>

Gives the rated delay time in µs.

6.2.4.1.9 DataChannel#1 to DataChannel#12

DataChannel#n:=I16 <-32768...32767> (i.e. 16 bits linear 2s complement)

Each data channel DataChannel#1 to DataChannel#12 gives the measured instantaneous value of either

– phase voltage;
– phase current for protection application;
– phase current for metering application;
– neutral current; or
– neutral voltage.

The assignment of the data channels to measuring values depends on the value of DataSetName as described in 6.2.4.1.4 and clause B.3.

Scaling of phase current data for protection and metering applications

If the data channel contains a phase current, the scaling is defined by the rated output value for measuring ECTs or the rated value for protection ECTs (see table 5).

Scaling example:

Let us consider a protective ECT with a rated primary current equal to 4 000 A (r.m.s) and a rated output of SCP = 01CF H (r.m.s, RangeFlag = 0) as defined in table 5.

The analogue instantaneous current value corresponding to a sample of, for example, 2DF0 H is (2DF0/01CF) * 4 000 A = 101 598 A.

In case of an overflow, positive overflow must be indicated by the code 7FFF H, negative overflow must be indicated by 8 000 H.

Scaling of derivative phase current data for protection and metering applications

If the data channel contains the derivative of the phase current, the scaling is defined with the rated output value for measuring ECTs or the rated value for protection ECTs (see table 5) and with the rated pulsation of the primary current ($\omega = 2.\pi.f_r$).

Scaling of neutral current data

A neutral current can either be measured with a separate transducer or be calculated by summation of the three phase currents. The scaling is defined by the rated output value for measuring ECTs SCM (see table 5) and does not depend on the setting of the RangeFlag.

In case of an overflow, positive overflow must be indicated by the code 7FFF H, negative overflow must be indicated by 8 000 H. If the neutral current is calculated by adding the three phase currents, overflow must also be indicated if one of the phase currents overflows.

NOTE Rated accuracy for the neutral current can be different from the accuracy defined for phase currents.

Scaling of voltage data (phase voltage, neutral voltage or busbar voltage)

If the data channel contains the measured instantaneous voltage of phase A, B, C, the neutral voltage or the busbar voltage, the scaling is defined by the rated output value SV (see table 5).

The busbar voltage can be used to transmit one phase of the busbar for synchronization purposes.

Scaling example:

Let us consider an EVT with a rated primary voltage equal to 220kV/ $\sqrt{3}$ (r.m.s) and a rated output of SV = 2D41 H (r.m.s.) as defined in table 5.

The analogue instantaneous voltage value corresponding to a sample of, for example, 2DF0 H is (2DF0/2D41) * 220 kV/ $\sqrt{3}$ = 134 kV.

In case of an overflow, positive overflow must be indicated by the code 7FFF H, negative overflow must be indicated by 8 000 H. If the neutral voltage is calculated by adding the three phase voltages, overflow must also be indicated if one of the phase voltages does overflow.

NOTE An overflow of the digital voltage value can be reached in some cases of reclosure with trapped charges (see IEC 60044-7 clause B.4).

6.2.4.1.10 Sample counter (SmpCtr)

SmpCtr = UI16[1..16]<0..65535>

<0…65535> := sequence counter

This 16-bit counter is used to check that the contents of the frame are continuously refreshed. This counter shall be incremented each time a new frame is issued. In continuous operation, once it reaches overflow, it shall start again with the value 0.

When sync pulses are used to synchronize merging units, the counter shall be set to zero with every sync pulse. The value 0 shall be given to the data set where the sampling of the primary current coincides with the sync pulse.

6.2.4.1.11 Status words (StatusWord#1 and StatusWord#2)

StatusWord#n= BS16

An explanation of the status words StatusWord#1 and StatusWord#2 is given in figure 11 and figure 12.

If one or more data channels are not used, the corresponding status flags shall be set to invalid and the corresponding data channel shall contain 0000 H.

If a transducer has failed, the corresponding status flag shall be set to invalid and the maintenance required flag (LPHD.PHHealth) shall be set.

The maintenance flag (LPHD.PHHealth) may be set if all configured signals are valid for preventive maintenance.

When the data is invalid due to a wake-up time period, the invalid flags and the wake-up time indicator flag shall be set.

The synchronization pulse missing or not valid bit (bit4) shall be set when the following logical condition is fulfilled: [[synchronization pulse is missing or not valid] and [the internal clock of the MU has drifted by more than half of its rated limits for phase error]].

	Explanation		**Comment**
Bit 0	Maintenance required (LPHD.PHHealth)	0: ok 1: Warning or alarm (maintenance required)	
Bit 1	LLN0.Mode	0: On (normal operation) 1: Test	
Bit 2	Wake-up time indication Wake-up time data validity	0: On (normal operation), data valid 1: Wake-up time, data not valid	Shall be set during a wake-up time period
Bit 3	Merging unit synchronization method	0: Data set not to be used with interpolation schemes 1: Data set suitable for interpolation	
Bit 4	For synchronized merging units	0: Samples synchronized 1: Time sync missing/not valid	If the MU is used with interpolation schemes this bit is also set
Bit 5	For DataChannel #1)	0: Valid 1: Invalid	
Bit 6	For DataChannel #2	0: Valid 1: Invalid	
Bit 7	For DataChannel #3	0: Valid 1: Invalid	
Bit 8	For DataChannel #4	0: Valid 1: Invalid	
Bit 9	For DataChannel #5	0: Valid 1: Invalid	
Bit 10	For DataChannel #6	0: Valid 1: Invalid	
Bit 11	For DataChannel #7	0: Valid 1: Invalid	
Bit 12	Type of CT output $i(t)$ or $\mathrm{d}(i(t)/\mathrm{d}t)$	0: $i(t)$ 1: $\mathrm{d}(i(t)/\mathrm{d}t)$	Shall be set for air-core coils
Bit 13	RangeFlag	0: Scaling factor SCP = 01CF H 1: Scaling factor SCP = 00E7 H	Scaling factors SCM and SV are not affected
Bit 14	For future use		
Bit 15	For future use		

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Figure 11 – Status word #1

	Explanation		Comment
Bit 0	For DataChannel #8	0: Valid 1: Invalid	
Bit 1	For DataChannel #9	0: Valid 1: Invalid	
Bit 2	For DataChannel #10	0: Valid 1: Invalid	
Bit 3	For DataChannel #11	0: Valid 1: Invalid	
Bit 4	For DataChannel #12	0: Valid 1: Invalid	
Bit 5	For future use		
Bit 6	For future use		
Bit 7	For future use		
Bit 8	For proprietary use		
Bit 9	For proprietary use		
Bit 10	For proprietary use		
Bit 11	For proprietary use		
Bit 12	For proprietary use		
Bit 13	For proprietary use		
Bit 14	For proprietary use		
Bit 15	For proprietary use		

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Figure 12 – Status word #2

6.2.4.2 Contents of the frame

		2^7	2^6 2^5 2^4 2^3 2^2 2^1	2^0
Byte 1	Header	msb	Length of data set (= 44dec)	
Byte 2				lsb
Byte 3		msb	LNName (= 02)	lsb
Byte 4	Dataset	msb	DataSetName	lsb
Byte 5		msb	LDName	
Byte 6				lsb
Byte 7		msb	Rated phase current	
Byte 8			(PhsA.Artg)	lsb
Byte 9		msb	Rated neutral current	
Byte 10			(Neut.Artg)	lsb
Byte 11		msb	Rated phase voltage	
Byte 12			(PhsA.VRtg)	lsb
Byte 13		msb	Rated delay time	
Byte 14			(t_{dr})	lsb

Byte 1	Dataset	msb	DataChannel #1	
Byte 2				lsb
Byte 3		msb	DataChannel #2	
Byte 4				lsb
Byte 5		msb	DataChannel #3	
Byte 6				lsb
Byte 7		msb	DataChannel #4	
Byte 8				lsb
Byte 9		msb	DataChannel #5	
Byte 10				lsb
Byte 11		msb	DataChannel #6	
Byte 12				lsb
Byte 13		msb	DataChannel #7	
Byte 14				lsb
Byte 15		msb	DataChannel #8	
Byte 16				lsb

Byte 1		msb	DataChannel #9	
Byte 2				lsb
Byte 3		msb	DataChannel #10	
Byte 4				lsb
Byte 5		msb	DataChannel #11	
Byte 6				lsb
Byte 7		msb	DataChannel #12	
Byte 8				lsb
Byte 9		msb	StatusWord#1	
Byte 10				lsb
Byte 11		msb	StatusWord#2	
Byte 12				lsb
Byte 13		msb	SmpCnt	
Byte 14				lsb
Byte 15		msb	Reserved for future specifications by IEC 61850-9-1	
Byte 16			Reserved for future specifications by IEC 61850-9-1	lsb

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Figure 13 – Universal frame

NOTE In the case where some voltage or current values are not used, the corresponding field should be 0000 H and the corresponding invalid flag in the status word should be set.

6.2.5 Merging unit clock input

If specified, the clock input may be electrical or optical and should follow the following specifications:

– Time trigger: on the rising flank from low to high. For trigger levels, see below.
– Clock rate: one pulse per second.
– The MU shall make a plausibility check whether the input pulse is corrupted.

The following figure shows the shape of the pulse graphically.

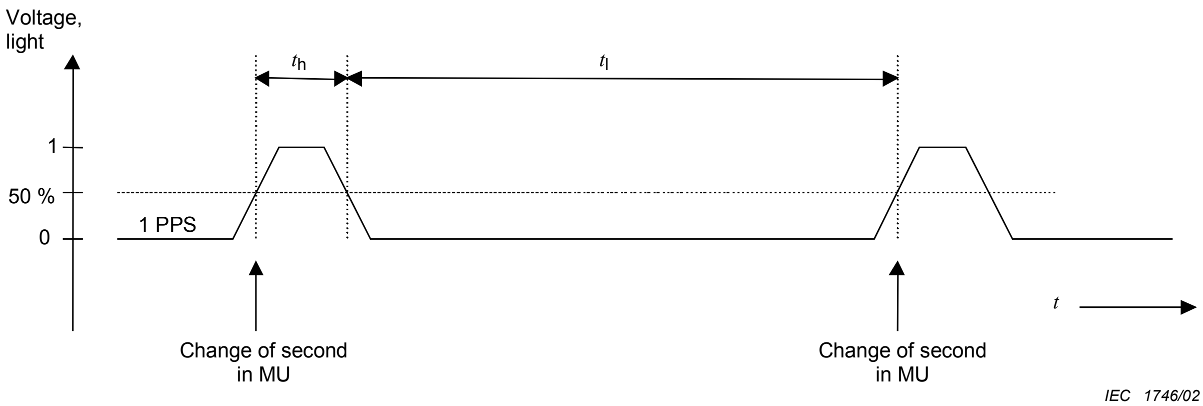


Figure 14 – Pulse shape for clock input

Further specifications

Optical input

– Trigger level: 50 % of maximum light, as in figure 14.
– Same connectors, fibres etc. as for the digital output (see table 10).
– Pulse duration t_h > 10 µs.
– Pulse gap t_l > 500 ms.

Low-voltage input (for example, for backplane solutions)

– Voltage level: 10 V or 24 V.
– Trigger level: 5 V.
– Pulse duration t_h > 30 ms.
– Pulse gap t_l > 500 ms.
– Input current 1 mA to 20 mA.

Voltage input on station battery level

– Voltage level: 60 V to 250 V.
– Trigger level: 35 V.
– Pulse duration t_h > 30 ms.
– Pulse gap t_l > 500 ms.
– Input current 1 mA to 20 mA.

NOTE 1 The pulse can be generated by a master clock or, for example, by a GPS receiver. Such a device usually has an open collector output to which the station battery can be connected. For longer distances and higher accuracies an optical input is necessary. Where there are no EMC problems, the simple low-voltage input is the most cost-effective solution.

NOTE 2 The manufacturer should declare with which sync pulse source the accuracy measurements of the transformers are made. He should also declare which requirements a sync pulse source needed to reproduce this accuracy has to fulfil (for example, maximum rise time).

6.3 Design requirements for analogue voltage output

6.3.1 Connectors

As guidance, the following designs are recommended.

Table 13 – Connectors

Connector	AC withstand voltage
Twin-BNC clamp-type plug for RG-108A	≤1,5 kV
ODU – MINI – SNAP	≤ 2 kV
Phoenix Miniconnec	≤2 kV
NOTE Phoenix Miniconnec may not be suitable for a 2 MΩ burden.	

Screw terminals may also be used.

6.3.2 Earthing of the output cable

If double-shielded cable is used, different solutions may be implemented in substations to fulfil EMC requirements

a) Inner shield grounded to one side and outer shield grounded on the other side.

b) Outer shield grounded on both sides, inner shield grounded on one side.

c) Outer shield grounded on one side and the other side grounded through a capacitance, inner shield grounded on one side.

7 Classification of tests

7.1 General

The tests specified in this standard are classified as type tests, routine tests, and special tests.

Type test: A test made on an electronic current transformer of one type to demonstrate that all electronic current transformers made to the same specification comply with the requirements not covered by routine tests. The validity of a type test which has been made on a transformer which has minor modifications or a type test made on an unmodified subassembly shall be subject to agreement between manufacturer and purchaser.

Routine test: A test to which each individual electronic current transformer is subjected.

Special test: A test other than a type test or a routine test, agreed on by manufacturer and purchaser.

7.2 Type tests

7.2.1 General type tests

The following tests are type tests; for details reference should be made to the relevant subclauses:

a) short-time current tests (see 8.1);

b) temperature-rise test (see 8.2);

c) lightning-impulse test (see 8.3.2);

d) switching-impulse test (see 8.3.3);

e) wet test for outdoor type electronic current transformers (see 8.4);
f) RIV test (see 8.5);
g) transmitted overvoltage test (see 8.6);
h) low-voltage components voltage withstand test (see 8.7)
i) EMC tests: emission (see 8.8.3);
j) EMC tests: immunity (see 8.8.4);
k) accuracy test (see 8.9);
l) additional accuracy tests for protective electronic current transformer (see 8.10);
m) verification of the protection (see 8.11);
n) tightness tests (see 8.12);
o) vibration test (see 8.13).

All the dielectric type tests should be carried out on the same electronic current transformer, unless otherwise specified.

After electronic current transformers have been subjected to the dielectric type tests of 7.2, they shall be subjected to all the routine tests of 7.3.

7.2.2 Additional type tests for digital output

a) Verification of the driver characteristics (see 8.14.2.1);
b) Verification of the receiver characteristics (see 8.14.2.2);
c) Verification of timing accuracy (see 8.14.2.3).

7.3 Routine tests

7.3.1 General routine tests

The following tests apply to each individual electronic current transformers:

a) verification of terminal markings (see 9.1);
b) power-frequency withstand test on primary terminals (see 9.2);
c) partial discharge measurement (see 9.2.2);
d) power-frequency withstand test for low-voltage components (see 9.3);
e) accuracy tests (see 9.4);
f) tightness tests (see 9.5).

The order of the tests is not standardized, but accuracy tests shall be performed after the other tests.

Repeated power-frequency tests on primary terminals should be performed at 80 % of the specified test voltage.

7.3.2 Additional routine tests for digital output

a) Fibre optic transmission (see 9.6.1);
b) Copper-wire transmission (see 9.6.2).

7.3.3 Additional routine tests for analogue output

(see 9.7).

7.4 Special tests

7.4.1 General special tests

The following tests are performed upon agreement between manufacturer and purchaser:

a) chopped lightning impulse test (see 10.1);
b) measurement of capacitance and dielectric dissipation factor (see 10.2);
c) multiple chopped impulse test on primary terminals (see IEC 60044-1 annex B);
d) mechanical tests (see 10.3);
e) accuracy test versus harmonics (see 10.4);
f) tests in accordance with the technology applied (see 10.5).

8 Type test

8.1 Short-time current tests

For the thermal short-time current I_{th} test, the electronic current transformer shall initially be at a temperature between 10 °C and 40 °C.

This test shall be made with

- the combination of auxiliary power supply voltage and secondary burden which causes the maximum internal power dissipation of the secondary converter,
- and at a current I for a time t, such that (I^2t) is not less than $(I_{th})^2$ and provided t has a value between 0,5 s and 5 s.

The dynamic test shall be made with

- the combination of auxiliary power supply voltage and secondary burden which causes the maximum internal power dissipation of the secondary converter,
- and with a primary current the peak value of which is not less than the rated dynamic current (I_{dyn}) for at least one peak.

The dynamic test may be combined with the thermal test above provided the first major peak current of that test is not less than the rated dynamic current (I_{dyn}).

The transformer shall be deemed to have passed these tests if, after cooling to ambient temperature (between 10 °C and 40 °C), it satisfies the following requirements.

a) It is not visibly damaged.
b) It withstands the dielectric tests specified in 9.2.1 but with the test voltages reduced to 90 % of those given for the primary terminals.
c) On examination, the insulation next to the surface of the conductor does not show significant deterioration (for example, carbonization).

Acceptance criteria b) and c) may not be relevant depending on the design, for example, electronic current transformer with separated insulator.

The examination c) is not required if the current density in the primary conductor, corresponding to the rated short-time thermal current, does not exceed

- 180 A/mm² where the primary conductor is of copper of conductivity not less than 97 % of the value given in IEC 60028;
- 120 A/mm² where the primary conductor is of aluminium of conductivity not less than 97 % of the value given in IEC 60121.

NOTE Experience has shown that in service the requirements for thermal rating are generally fulfilled in the case of Class A insulation provided that the current density in the primary conductor, corresponding to the rated short-time current, does not exceed the above-mentioned values.

Consequently, compliance with this requirement may take the place of the insulation examination, if agreed between manufacturer and purchaser.

8.2 Temperature-rise test

A test shall be made to prove compliance with the requirements of 6.1.2. For the purpose of this test, electronic current transformers shall be deemed to have attained a steady temperature when the rate of temperature rise does not exceed 1 K per hour.

The test-site ambient temperature shall be between 10 °C and 30 °C.

For the test, the transformers shall be mounted in a manner representative of the mounting in service.

The temperature rise may be measured by thermometers, thermocouples or other suitable device.

In the case of an electronic current transformer having more than one secondary converter, the test is to be performed on each secondary converter.

The electronic current transformer shall be deemed to have passed this test if

a) the temperature rise is in accordance with the rating values given in 5.1.6
b) after cooling to ambient temperature, it satisfies the following requirements:
   1) it is not visibly damaged,
   2) its errors do not differ from those recorded before the test by more than half the limits of error to its accuracy class.

8.3 Impulse tests on primary terminals

8.3.1 General conditions

8.3.1.1 Ambient air

Reference is made to IEC 60060-1 regarding standard reference atmospheric conditions and atmospheric factors.

For electronic current transformers where external insulation in free air is of principal concern, the correction factor K_t shall be applied, when specified.

For electronic current transformers having internal insulation only, the ambient air conditions are of no influence and the correction factor K_t shall not be applied, even when specified.

8.3.1.2 Wet test procedure

No humidity correction factor shall be applied for wet tests. The wetting procedure shall be in accordance with IEC 60060-1.

8.3.1.3 Condition of electronic current transformers

Dielectric tests shall be made on electronic current transformers completely assembled, as in service; the outside surfaces of insulating parts shall be carefully cleaned.

The electronic current transformers shall be mounted for test with minimum clearances and height as specified by the manufacturer.

Equipment tested at one distance above ground surface level will be deemed to be satisfactory if mounted at a greater distance above ground surface level in service.

For electronic current transformers using compressed gas for insulation, dielectric tests shall be performed at minimum functional density p_{me}.

The minimum functional density may be expressed as the pressure at the reference temperature of 20 °C. If, at the time of the test, the temperature differs from 20 °C, the pressure must be adjusted to correspond to the minimum functional density. The temperature and pressure of the gas during the tests shall be noted and recorded in the test report.

8.3.1.4 Records

The peak value and the waveshape of each impulse shall be recorded.

8.3.2 Lightning-impulse test

In order to comply with 6.1.1.2.3, the electronic current transformer shall be subjected to a lightning-impulse test. The test voltage shall have the appropriate value given in tables 3, 4 and 5 of IEC 60044-1 depending on the highest voltage for equipment and the specified insulation level.

The test voltage shall be applied between the line terminals of the primary current sensor connected together and earth. The frame (if any), the case (if any), and all secondary terminals (if any) shall be connected together and to earth.

Improvements in failure detection may be obtained by the recording of an additional quantity.

At the option of the manufacturer,

– the earth connection may be made through a suitable current-recording device;
– the secondary terminals (if any) may be connected together and earthed or may be connected to a suitable device for recording the appropriate output quantity during the test.

NOTE If not specified otherwise, the test shall be performed with the electronic current transformer completely assembled, including the transmission system and secondary converter.

8.3.2.1 Primary terminals having U_m < 300 kV

The test shall be performed with both positive and negative polarities. Fifteen consecutive impulses of each polarity not corrected for atmospheric conditions shall be applied. The electronic current transformer passes the test if

- no disruptive discharge occurs in the non-self-restoring internal insulation;
- no flashovers occur along the non-self-restoring external insulation;
- no more than two flashovers for each polarity occur across the self-restoring external insulation;
- no other evidence of insulation failure is detected (for example, variations in the wave shape of the recorded quantities).

NOTE The application of 15 positive and 15 negative impulses is specified for testing the external insulation. If other tests are agreed between manufacturer and purchaser to check the external insulation, the number of lightning impulses should be reduced to three of each polarity, not corrected for atmospheric conditions.

8.3.2.2 Primary terminals having $U_m \geq$ 300 kV

The tests shall be performed with both positive and negative polarities. Three consecutive impulses of each polarity, not corrected for atmospheric conditions, shall be applied.

The electronic current transformer passes the test if

- no disruptive discharge occurs;
- no other evidence of insulation failure is detected (for example, variations in the wave-shape of the recorded quantities).

8.3.3 Switching-impulse test

In order to comply with 6.1.1.1 the electronic current transformer shall be subjected to a switching-impulse test. The test voltage shall have the appropriate value given in table 4 of IEC 60044-1, depending on the highest voltage for equipment and the specified insulation level. The test voltage shall be applied between the line terminals of the primary current sensor connected together and earth. The frame (if any), the case (if any), and all secondary terminals (if any) shall be connected together and to earth.

At the option of the manufacturer the connection to earth may be made through a suitable current recording device. The secondary terminals (if any) may be connected together and earthed or may be connected to a suitable device for recording the appropriate output quantity during the test.

The test shall be performed with both positive and negative polarities. Fifteen consecutive impulses of each polarity, corrected for atmospheric conditions, shall be applied.

Electronic current transformer passes the test if

- no disruptive discharge occurs in the non-self-restoring internal insulation;
- no flashovers occur along the non-self-restoring external insulation;
- no more than two flashovers for each polarity occur across the self-restoring external insulation;
- no other evidence of insulation failure is detected (for example, variations in the wave shape of the recorded quantities).

8.4 Wet test for outdoor type electronic current transformers

In order to verify the performance of the external insulation, outdoor type transformers shall be subjected to a wet test. The wetting procedure shall be in accordance with IEC 60060-1.

8.4.1 Primary terminals having U_m < 300 kV

The test shall be performed in accordance with table 3 of IEC 60044-1 with power-frequency voltage corrected for atmospheric conditions.

8.4.2 Primary terminals having $U_m \geq$ 300 kV

The test shall be performed with switching-impulse voltage in accordance with table 4 of IEC 60044-1.

8.5 RIV tests

See IEC 60044-1.

8.6 Transmitted overvoltage test

See IEC 60044-1.

8.7 Low-voltage components voltage withstand test

8.7.1 Test conditions

The atmospheric conditions during the test shall be

- ambient air temperature: 15 °C to 35 °C;
- relative humidity: 45 % to 75 %;
- air pressure: 86 kPa to 106 kPa.

8.7.2 Application of the test voltage

The test voltage shall be applied to the connecting points of the electronic current transformer in a new and dry condition without self-heating.

Each independent circuit shall be tested at the prescribed test voltage in relation to all other circuits connected together and to earth.

a) For the test between a given circuit and all other circuits, all the connecting points of the single circuit shall be connected together;
b) For all tests, the circuits which are to be connected to earth shall be thus connected.

Unless obvious, the independent circuits are described by the manufacturer. For example, secondary converter and merging unit can be independent circuits.

The test voltages shall be applied directly to the terminals.

For devices with an insulating enclosure the exposed conductive parts shall be represented by a metal foil covering the whole enclosure except the terminals around which a suitable gap shall be left so as to avoid flashover to the terminals.

8.7.3 Power-frequency voltage withstand test

The power-frequency voltage withstand tests shall be made by applying the voltages given in 6.1.1.3.

The test voltage source shall be such that, when applying half the specified value to the device under test, the voltage drop observed is less than 10 %.

The source voltage shall be verified with an accuracy better than 5 %.

The test voltage shall be either substantially sinusoidal with a frequency between 45 Hz and 65 Hz or d.c.

The open-circuit voltage of the voltage source is initially set to not more than 50 % of the specified test voltage. It is then applied to the device under test. From this initial value the voltage shall be raised to the specified value in such a manner, that no appreciable transients occur and maintained for 1 min. It shall then be reduced smoothly to zero as rapidly as possible.

Acceptance criteria: no breakdown or flashover shall occur.

8.7.4 Impulse-voltage withstand test

The impulse-voltage withstand tests shall be made by applying the voltage given in 6.1.1.3.

A standard lightning impulse in accordance with IEC 60060 shall be used. The parameters are:

- front time: 1,2 µs ± 30 %
- time to half value: 50 µs ± 20 %
- output impedance: 500 Ω ± 10 %
- output energy: 0,5 J ± 10 %

The length of each test lead shall not exceed 2 m.

The impulse voltage shall be applied to the appropriate points accessible from the outside of the device, the other circuits and the exposed conductive parts being connected to earth.

During the test, no input or auxiliary energizing quantity shall be applied to the device.

Three positive and three negative impulses shall be applied at intervals of not less than 5 s.

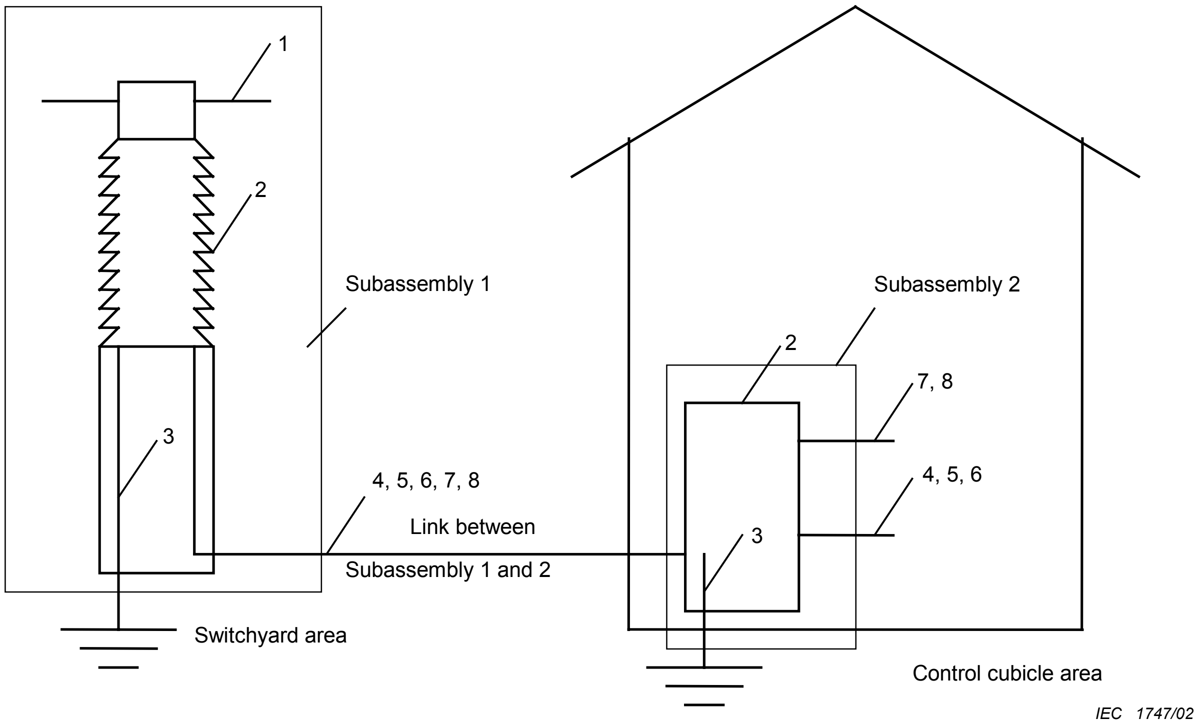
Acceptance criteria: no flashover is accepted and after the test, the ECT shall still comply with basic accuracy tests.

8.8 EMC tests

8.8.1 General

The tests shall be made to prove the compliance with 6.1.5.

In many cases an electronic transformer may be divided into a number of major sub-assemblies such as, for example, circuits located in control cubicles and circuits located in the switchgear area. EMC tests relevant for the applied technology of electronic transformer have to be carried out on each major subassembly the full electronic transformer being in operation or the missing subassemblies being simulated. An example of major subassembly division is given in figure 15.



Key
1 HV line
2 Enclosure port
3 Ground port
4 Signal port
5 Command port
6 Communication port
7 a.c. power port
8 d.c. power port

Subassembly 1: “outdoor part” in switchgear area

Subassembly 2: “indoor part” in control cubicle area

Figure 15 – Example of subassembly subjected to EMC tests

8.8.2 General conditions during EMC tests

The general conditions for EMC tests are described in IEC 61000-4-1 and CISPR 11. During the EMC tests, the length of cable between the ECT and test equipment and between subassembly 1 and 2 should be the maximum specified by the manufacturer and the arrangement of the cable shall, as far as practicable, represent in-service conditions.

8.8.3 EMC emission tests

An emission test will be performed according to the CISPR 11 testing procedure. The test limits will be those of group 1 class A. The test shall preferably be performed on the complete assembly but for ease of testing in case one of the possible subassemblies contains no electrical parts, that test can be performed on the remaining subassemblies.

8.8.4 EMC immunity tests

The test shall be performed on a port-by-port basis, guidance for the identification of ports being given in figure 15.

8.8.4.1 Harmonic and interharmonic disturbance test

The test shall be performed according to the test procedure of IEC 61000-4-13. The severity level is class 2 (full harmonic distortion 10 %). The assessment criterion is given in 6.1.5.3.

8.8.4.2 Slow voltage variation test

The test shall be performed according to the test procedure of IEC 61000-4-11 for a.c. power supply and IEC 61000-4-29 for d.c. power supply. The voltage variations used are from +10 % to −20 % of the nominal voltage of the a.c. power supply and from +20 % to −20 % of the nominal voltage of the d.c. power supply. The assessment criterion is given in 6.1.5.3.

8.8.4.3 Voltage dips and short interruption test

The test shall be performed according to the test procedure of IEC 61000-4-11 for a.c. power supply and IEC 61000-4-29 for d.c. power supply.

- The voltage dip used for the test is 30 % of the nominal voltage of the a.c. power supply during 0,1 s. The voltage interruption test is performed during 0,02 s for a.c. power supply.
- The voltage dip used for the test is 50 % of the nominal voltage of the d.c. power supply during 0,1 s.
- The voltage interruption test is performed during 0,05 s (low impedance) for d.c. power supply.
- The assessment criterion is given in 6.1.5.3.

8.8.4.4 Surge immunity test

The test shall be performed according to the test procedure of IEC 61000-4-5. The test generator to be used is the combination wave (hybrid) generator (IEC 61000-4-5, 6.1) with standard 1,2/50 μs voltage waveform (open-circuit) and 8/20 μs current waveform (short-circuit). The test level is according to installation class 4 (4 kV common mode, 2 kV differential mode). The assessment criterion is given in 6.1.5.3.

8.8.4.5 Electronic fast transient/burst test

The test shall be performed according to the test procedure of IEC 61000-4-4, the test level being class 4 (4 kV test voltage at 2,5 k Hz repetition rate on power supply port and 2 kV at 5 k Hz repetition rate on input/output signal, data and control ports – common mode). The test will be carried out using the coupling/decoupling network on the power supply port and the capacitive coupling clamp on I/O and communication ports. The assessment criterion is given in 6.1.5.3.

8.8.4.6 Oscillatory waves immunity test

The test shall be performed according to the test procedure of IEC 61000-4-12. The test generator to be used is the damped oscillatory wave generator (IEC 61000-4-12, 6.1.2). The test voltage will be 2,5 kV common mode and 1 kV differential mode both for power supply and control/signal lines (as in IEC 60255-22-1). Test frequency will be 1 M Hz at 400/s repetition rate (as in IEC 60255-22-1). The assessment criterion is given in 6.1.5.3.

8.8.4.7 Electrostatic discharge test

The test shall be performed according to the test procedure of IEC 61000-4-2. The test level is class 2 (4 kV test voltage) which gives protection in antistatic environments (like concrete) for relative humidity as low as 10 % (see also IEC 61000-4-2, clause A.4). The assessment criterion is given in 6.1.5.3.

8.8.4.8 Power-frequency magnetic field immunity test

The test shall be performed according to the test procedure of IEC 61000-4-8. Test level is 5 (100 A/m steady state and 61 000 A/m × 1″). The assessment criterion is given in 6.1.5.3.

8.8.4.9 Pulse magnetic field immunity test

The test shall be performed according to the test procedure of IEC 61000-4-9. Test level is 5 (61 000 A/m peak). The assessment criterion is given in 6.1.5.3.

8.8.4.10 Damped oscillatory magnetic field immunity test

The test shall be performed according to the test procedure of IEC 61000-4-10. Test level is class 5 (100 A/m test field). The assessment criterion is given in 6.1.5.3.

8.8.4.11 Radiated, radiofrequency, electromagnetic field immunity test

The test shall be performed according to the test procedure of IEC 61000-4-3. Test level is class 3 (10 V/m field strength). The assessment criterion is given in 6.1.5.3.

8.9 Accuracy test

8.9.1 General

The following accuracy tests are applied to measuring electronic current transformer and to protective electronic current transformer. Test circuits are given in annex B for digital output and annex C for analogue output.

8.9.2 Basic accuracy tests

8.9.2.1 Basic accuracy tests for measuring electronic current transformer

To prove compliance with 12.2, tests shall be made at each value of current given in tables 19, 20 and 21 at rated frequency, at rated burden (if relevant), and at ambient temperature, unless otherwise specified. Current transformers having rated primary current factor greater than 1,2 shall be tested at rated primary extended current instead of 1,2 times the rated primary current.

NOTE The test can be carried out using a pure delay time device inserted between the reference transformer and the accuracy measurement system.

8.9.2.2 Basic accuracy test for protective electronic current transformer

To prove compliance with 13.1.3, the test shall be made at rated primary current (see table 20), at rated frequency, at rated burden (if relevant) and at ambient temperature.

NOTE The test can be carried out using a pure delay time device inserted between the reference transformer and the accuracy measurement system.

8.9.3 Temperature cycle accuracy test

In addition to the basic accuracy tests made in accordance with 8.9.2, the temperature cycle accuracy test shall be performed in the following conditions:

– at rated frequency;
– at rated current or rated primary extended current applied continuously;
– at rated burden (if relevant);
– with indoor and outdoor components exposed to their specific maximum and minimum ambient air temperature. A cycle test in accordance with figure 16 shall be performed.

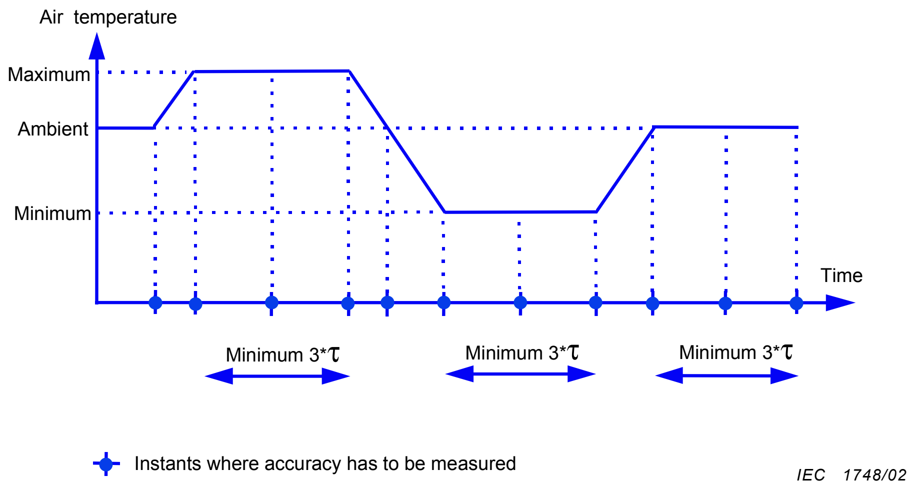


Figure 16 – Temperature cycle accuracy test

Minimum temperature variation rate is 5 K/h. It can be higher only if allowed by the manufacturer.

The thermal time constant τ shall be declared by the manufacturer.

NOTE Time needed to stabilize the temperature of the electronic current transformer depends mainly on the size and construction of the transformer.

For electronic current transformers, partially indoor, partially outdoor, the tests shall be made for indoor and outdoor parts, each one at both extremes of relevant temperature range, respecting the following rules:

– ambient air temperature for both parts;
– maximum temperature for indoor part when maximum temperature for outdoor part;
– minimum temperature for indoor part when minimum temperature for outdoor part.

In normal service conditions the measured error of every measuring point should be within the limits of the relevant accuracy class.

8.9.4 Test for accuracy versus frequency

In addition to the basic accuracy tests made in accordance with 8.9.2, tests for accuracy shall be made at the two extremes of standard reference range of frequency given in 5.1.5, at rated current, at rated burden (if relevant) and at constant ambient temperature.

The error shall be within the limits of the relevant accuracy class.

NOTE Measurement with different frequencies are performed with a test circuit. For the tests, accuracy measurement system calibrated at rated frequency may be acceptable.

8.9.5 Test for accuracy in relation to replacement of components

To prove compliance with 6.1.9 the following test shall be performed. The ability of the electronic current transformer to fulfil its accuracy class when some of its components are replaced shall be proven by means of an accuracy test at room temperature, rated frequency, rated current and rated burden (if relevant).

8.9.6 Test for signal-to-noise ratio

To prove compliance with 6.1.6 a test for signal-to-noise ratio shall be performed. The test procedure shall be agreed upon between manufacturer and user. See D.2.3 for guidance.

8.10 Additional accuracy tests for protective electronic current transformers

8.10.1 Test for composite error

Compliance with the limits of composite error given in table 20 shall be demonstrated by a direct test in which a substantially sinusoidal current equal to the rated accuracy limit primary current is passed through the primary terminals with rated burden (if relevant).

The test may be carried out on an ECT similar to the one being supplied, except that reduced insulation may be used provided that the same geometrical arrangement is retained.

NOTE Where very high primary currents and a single-bar primary conductor of ECT are concerned, the distance between the return primary conductor and the ECT should be taken into account from the point of view of reproducing service conditions.

8.10.2 Test for transient performance

Compliance with the limits of instantaneous error up to t' and/or t'' and at accuracy limit condition given in table 20 shall be demonstrated by a direct test in which a transient current defined in 3.3.11 is passed through the primary terminals with rated burden (if relevant), rated primary short-circuit current, rated primary time constant and rated duty cycle.

NOTE Where very high primary currents and a single-bar primary conductor of ECT are concerned, the distance between the return primary conductor and the ECT should be taken into account from the point of view of reproducing service conditions.

8.11 Verification of the protection

8.11.1 Verification of the IP coding

In accordance with the requirements specified in 6.1.13.1 and 6.1.13.2, tests shall be performed in accordance with IEC 60529 on the enclosures of all parts of the ECT fully assembled as under service conditions.

8.11.2 Mechanical impact test

In accordance with the requirements specified in 6.1.13.3, enclosures for indoor installation shall be subjected to an impact test. Three blows are applied to points of the enclosure that are likely to be the weakest points. Devices such as connectors, displays, etc. are excepted.

The use of a spring-operated impact test apparatus as defined in IEC 60068-2-75 is recommended.

After the test, the enclosure shall show no breaks and the deformation of the enclosure shall not affect the normal function of the electronic current transformer, and shall not reduce the specified degree of protection. Superficial damage, such as removal of paint, breaking of cooling ribs or similar parts, or depression of small dimension can be ignored.

8.12 Tightness tests

The purpose of tightness tests is to demonstrate that the leakage rate F_{rel} does not exceed its permissible value specified in 6.1.11.

For gas-filled electronic current transformer, in general, only cumulative leakage measurements allow calculation of leakage rates. For the application of an adequate test method, reference is made to IEC 60694, 6.8 and to IEC 60068-2-17.

For oil-filed electronic current transformer, the tightness test shall be a type test on the electromagnetic unit assembled as for normal service, filled with the liquid specified. A minimum pressure of $(0{,}5 \pm 0{,}1) \times 10^5$ *P*a above the maximum operating pressure shall be maintained during 8 h inside the e.m.u. The e.m.u. shall be considered to have successfully passed the test if there is no evidence of leakage.

8.13 Vibration tests

8.13.1 Vibrations test for secondary parts

The secondary converter, the merging unit and secondary power supply are generally comparable to electrical secondary equipment in the substation and shall be tested in accordance with IEC 60068-2-6 with the secondary parts operating in the normal service condition.

8.13.2 Vibration test for primary parts

The test arrangement shall, as far as reasonably practicable, represent the worst-case service condition in respect of vibration. Vibration levels will vary depending on connection arrangements, insulation type, and for circuit breakers, the actuation principle (spring mechanisms are considered to generate higher vibration levels).

8.13.3 Vibration test for primary parts during short-time current

This test is performed to determine that the ECT operates correctly in the presence of vibration resulting from busbar vibration caused by short-time current electromagnetic forces.

This test can be carried out in conjunction with short-time current test or composite error test. 5 ms after the last opening of the circuit-breaker, the r.m.s. value of the secondary output signal of the ECT at rated frequency calculated over one period, which should theoretically be “0”, shall not exceed 3 % of the rated secondary output. To represent the worst-case condition with respect to vibration, the ECT should be connected via a rigid connection to the circuit-breaker.

8.13.4 Vibration tests for primary parts mechanically coupled to a circuit- breaker

8.13.4.1 General

These tests shall also apply to GIS switchgear, medium voltage switchgear and dead tank circuit-breaker mounted ECTs.

8.13.4.2 During operation

This test is performed to determine that the ECT operates correctly in the presence of vibration resulting from circuit-breaker operation.

The circuit-breaker shall be operated through one duty cycle (open-close-open) without current. 5 ms after the last opening of the circuit-breaker, the r.m.s. value of the secondary output signal of the ECT at rated frequency calculated over one period, which should theoretically be “0”, shall not exceed 3 % of the rated secondary output. To represent the worst-case condition in respect of vibration, the circuit-breaker should be connected via a flexible conductor.

8.13.4.3 Vibration endurance test

The circuit-breaker shall be operated without primary current 3 000 times as described in IEC 60056. ECT accuracy at rated current shall be measured before and after the test. The ECT error following the test must not differ from that recorded before the test by more than half the limit of error appropriate to its accuracy class.

NOTE Vibration levels generated by circuit-breakers have been found to be principally dependant on the actuation principle. A circuit-breaker having a spring mechanism will generally produce higher levels of vibration, thus an ECT test on such a circuit-breaker may be considered valid for other circuit-breakers, subject to agreement between manufacturer and purchaser.

8.14 Additional type test for digital output

8.14.1 General

For these tests, the ECT shall be used under normal service conditions, at its rated characteristics (auxiliary power supply, and recommended fibre optic/cable type and length).

8.14.2 Fibre optic transmission

8.14.2.1 Verification of optical driver characteristics

a) Rise and fall time.

b) Characteristics of optical pulse.

8.14.2.2 Verification of optical receiver characteristics

a) Rise and fall time.

b) Pulse width distortion.

8.14.2.3 Verification of timing accuracy

a) Clock jitter

The content of the test signal for this test shall be a Manchester-encoded pseudo-random sequence with a minimum repetition period of 511 bits. Jitter shall be measured at zero-crossing point.

NOTE It is possible to combine jitter measurement and rise and fall time measurement

8.14.3 Copper-wire transmission

8.14.3.1 Verification of line-driver characteristics

a) Output impedance.

b) Signal amplitude.

c) Rise and fall time.

8.14.3.2 Verification of line-receiver characteristics

a) Receiver input impedance.

b) Maximum correctly detectable input signals.

c) Minimum correctly detectable input signals.

8.14.3.3 Verification of timing accuracy

a) Clock jitter.

The jitter shall be measured at the output of the recommended cable for the transmission line, at specified length, terminated by its rated termination impedance (in order to measure also the effect of the transmission medium, of impedance mismatches, connectors, etc.). If this is not possible, it is acceptable to use a model of the transmission line.

The content of the test signal for this test shall be a Manchester-encoded pseudo-random sequence with a minimum repetition period of 511 bits. Jitter shall be measured at zero-crossing point.

NOTE It is possible to combine jitter measurement and rise and fall time measurement.

9 Routine tests

9.1 Verification of terminal markings

It shall be verified that the terminal markings are correct (see table 15).

9.2 Power-frequency withstand tests on primary terminals and partial discharge measurement

9.2.1 Power-frequency test

See 8.2.1 of IEC 60044-1.

When the insulation is only provided by solid insulators and air at ambient pressure, the power-frequency voltage withstand test may be omitted if the dimensions between the conductive parts and the frame are checked by dimensional measurements.

Bases for the checking of dimensions are the dimensional (outline) drawings, which are part of the type test report (or are referred to in it). Therefore, in these drawings, all information necessary for dimensional checking including the permissible tolerances shall be given.

9.2.2 Partial discharge measurement

See 8.2.2 of IEC 60044-1.

If not relevant for a specific design, this test can be omitted.

9.3 Power-frequency voltage withstand test for low-voltage components

For routine tests the same test set-up as for the type test is used (see 8.7.3). The duration of the test can either be 1 min as described or 1 s at 1,1 times the specified test voltage level. The choice shall be at the manufacturer’s discretion.

9.4 Accuracy tests

The routine test is, in principle, the same as the type test in 8.9.2. However, routine tests at a reduced number of currents are permissible if type tests on a similar transformer have demonstrated that such a reduced number of tests is sufficient to prove compliance with specified accuracy class.

9.5 Tightness tests

Routine tests shall be performed at normal ambient temperature with the electronic current transformer filled at the pressure corresponding to the manufacturer's test practice. For gas-filled electronic current transformer sniffing may be used. For oil-filled electronic current transformer the tightness test of 8.12 should be applied if relevant.

9.6 Additional routine tests for digital output

9.6.1 Fibre optic transmission

a) Measurement of transmission power according to table 10.

9.6.2 Copper-wire transmission

a) Measurement of signal amplitude at output of line driver.

9.7 Additional routine tests for analogue output

a) Measurement of secondary direct voltage offset (Usdc0).
b) If applicable (ECT powered by line current), measurement of the minimum primary current needed to ensure nominal performance of the ECT.

10 Special tests

10.1 Chopped lightning-impulse test on primary terminals

See clause 9 of IEC 60044-1.

10.2 Measurement of capacitance and dielectric dissipation factor

See clause 9 of IEC 60044-1.

10.3 Mechanical tests

The tests are carried out to demonstrate that an electronic current transformer is capable of complying with the requirements specified in table 9.

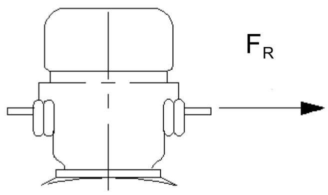
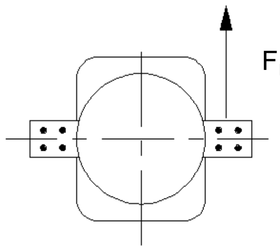
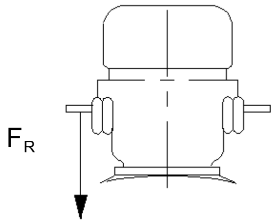
The electronic current transformer shall be assembled with all relevant parts subject to mechanical stress, installed in a vertical position with the frame rigidly fixed.

Liquid-immersed electronic current transformer shall be filled with the specified insulation medium and submitted to the operating pressure.

The test loads shall be applied for 60 s for each of the conditions indicated in table 14.

The electronic current transformer shall be considered to have passed the test if there is no evidence of damage (deformation, rupture or leakage).

Table 14 – Modalities of application of test loads to be applied to the primary terminals

Horizontal to each terminal	 
Vertical to each terminal	
NOTE The test load shall be applied to the centre of the terminal.	

10.4 Tests for accuracy versus harmonics

The tests are carried out to demonstrate that an electronic current transformer complies with the accuracy requirement on harmonics specified in 12.3 and 13.2.

In an ideal case, tests on harmonics should be made with the rated primary current at the rated frequency plus a percentage of the rated primary at each considered harmonic frequency. Such a primary current should provide a realistic image of the dynamic requirements on the transformer and will yield a good image of some non-linear phenomena which can happen in the transformer (intermodulation, for example).

However, it can be difficult to achieve a test circuit which generates such primary current. For practical considerations, it is accepted that the accuracy tests be made with only one single harmonic frequency applied at the primary side for each measurement.

The test circuit shall be defined by agreement between user and manufacturer.

NOTE 1 The test circuit could be adapted from the one defined in clause D.5.

NOTE 2 The reference CT could be replaced by a coaxial shunt commonly used for short-circuit tests.

NOTE 3 The primary current could be supplied by a power amplifier.

NOTE 4 Tests which apply to quality metering could be more difficult to achieve.

10.5 Tests in accordance with the technology applied

Special tests in accordance with the technology applied can be defined by an agreement between manufacturer and purchaser, for example, artificial pollution tests or artificial ageing tests.

11 Marking

11.1 Terminal marking – General rules

The terminal markings shall identify

a) the primary and secondary terminals;

b) for analogue output, the relative polarities of secondary outputs.

Additionally, all cables, including their terminations, shall be clearly marked to allow identification. The fibres shall be coded or coloured for identification at both ends in accordance with IEC 60304.

11.1.1 Method of marking

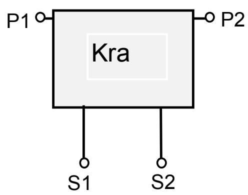
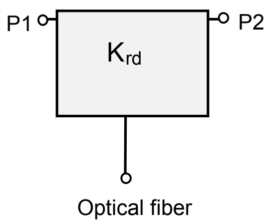
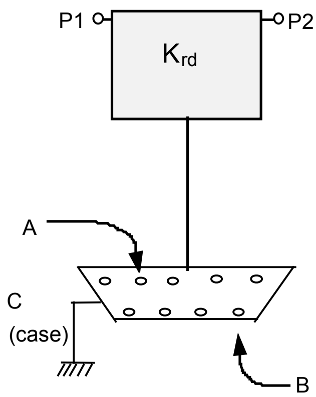
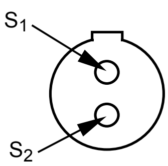
The terminals shall be marked clearly and indelibly, either on their surface or in their immediate vicinity.

The marking shall consist of letters followed, or preceded where necessary, by numbers. The letters shall be in block capitals.

11.1.2 Markings to be used

The markings of electronic current transformer terminals shall be as indicated in table 15.

Table 15 – Markings of terminals

Primary terminals Secondary terminals			
ODU-MINI-SNAP Secondary terminals			
	ANALOGUE OUTPUT	DIGITAL OUTPUT, OPTICAL	DIGITAL OUTPUT, COPPER WIRES

Pin-out of the electrical connector for the digital output:

PIN n°	SIGNAL
1	
2	DATA A
3	
4	
5	
6	
7	
8	
9	DATA B

All earthing terminals shall be marked with the earth symbol, as indicated by symbol number 5019 of IEC 60417.

Any fibre optic terminal boxes shall be clearly labelled 'Fibre optic terminal box'.

Optical cables shall be sufficiently clearly marked with the words 'optical cable' to distinguish it from electrical cables.

11.1.3 Indication of relative polarities

For analogue output, all the terminals marked P1, S1 shall have the same polarity at the same instant taking into account the effect of delay time (if any).

For digital output, the terminal marked P1 shall have the positive polarity (negative polarity) when its corresponding value in the frame has its MSB equal to 0 (equal to 1).

11.2 Rating plate markings

All electronic current transformers shall carry at least the following markings:

a) the manufacturer's name or other mark by which he may be readily identified;

b) a serial number or a type designation, preferably both;

c) the rated primary current and rated secondary output;

d) the rated frequency (for example, 50 Hz);

e) the accuracy class;

NOTE Where appropriate, the category of secondary output should be marked (for example, 1S, 2 KΩ, class 0,5; 2S, 20 kΩ, class 1).

f) the highest voltage for equipment (for example, 1,2 kV or 145 kV);

g) the rated insulation level (for example, 6/–kV* or 275/650 kV).

NOTE The two items f) and g) may be combined into one marking (for example, 1,2/6/–kV*or 145/275/650 kV).

All information shall be marked in an indelible manner on the electronic current transformer or on a rating plate securely attached to the transformer.

In addition, the following information shall be marked whenever space is available:

h) the rated short-time thermal current (I_{th}) and the rated dynamic current if it differs from 2,5 times the rated short-time thermal current (for example, 13 kA or 13/40 kA);

* A dash indicates the absence of an impulse voltage level.

i) the class of insulation, if different from class A;

NOTE If several classes of insulating material are used, the one which limits the temperature rise of the electronic current transformer should be indicated.

h) on transformers with two secondary converters, the use of each converter and its corresponding terminals.

The rating plate of all electronic current transformers shall, where practicable, be readable from ground level and carry the markings given in table 16.

Table 16 – Rating plate marking

Common rating plate markings							
Rating	**Abbre-viation**	**Measuring ECT**	**Protective ECT**	**Analogue output**	**Digital output**	**Clause or subclause**	**Note**
Designation: Electrical current transformer	ECT	x	x	x	x		
Manufacturer's name or abbreviation		x	x	x	x		
Type designation		x	x	x	x		
Serial number with year of manufacture		x	x	x	x		
Reference to IEC 60044-8		x	x	x	x		
Highest voltage for equipment	U_m	x	x	x	x	3.1.31, 6.1.1	1
Rated insulation level		x	x	x	x	3.1.32, 6.1.1	
Rated frequency	f_r	x	x	x	x	3.1.18	
Rated primary current	I_{pr}	x	x	x	x	3.1.20, 5.1.1	
Rated short-time thermal current	I_{th}	x	x	x	x	3.1.41, 5.1.4.1.2	
Rated dynamic current	I_{dyn}	x	x	x	x	3.1.42, 5.1.4.1.3	
Rated extended primary current factor	K_{pcr}					3.2.3, 5.1.2	
Rated symmetrical short-circuit current factor for transient conditions	K_{ssc}		x	x	x	3.3.6, 5.1.4.2.1	
Rated primary time constant	τ_{pr}		x	x	x	3.3.7, 5.1.4.2.3	
Rated phase offset	φ_{0r}	x	x	x	x	3.1.28, 5.2	
Rated duty cycle			x	x	x	3.3.9	
Rated wake-up time		x	x	x	x	3.1.44, 5.1.11	
Weight		x	x	x	x		
NOTE For part replacement, refer to the operation manual.							

Rating plate markings for each secondary converter							
Rating	Abbreviation	Measuring ECT	Protective ECT	Analogue output	Digital output	Clause or subclause	Note
Rated secondary output		x	x	x		3.1.22, 5.4.2	
Terminal markings		x	x	x		11.1	
Rated burden	R_{br}			x		3.5.3, 5.4.3	
Accuracy class		x	x	x	x	12, 13	3
Rated delay time	t_{dr}	x	x	x	x	3.1.27, 5.3.2, 5.4.1	

Rating plate markings for auxiliary power supply							
Rating	Abbreviation	Measur-ing ECT	Protective ECT	Analogue output	Digital output	Clause or subclause	Note
Rated auxiliary power supply voltages	U_{ar}	x	x	x	x	3.1.11, 5.1.7	4
Rated auxiliary power supply frequency		x	x	x	x	5.1.8	
Rated supply current (nominal conditions)	I_{ar}	x	x	x	x	3.1.12	
Maximum supply current (overload conditions)	$I_{a\ max}$	x	x	x	x	3.1.13	
x = applicable							

Rating plate markings for the merging unit							
Rating	Abbreviation	Measuring ECT	Protective ECT	Analogue output	Digital output	Clause or subclause	Note
Type of interface (optical/electrical)		x	x		x		
Rated delay time	t_{dr}	x	x		x	3.1.27, 5.3.2, 5.4.1	
Data rate	$1/T_s$	x	x		x	3.4.5, 5.3.3	
Clock input (yes:no)		x	x		x	3.4.3, 6.2.5	
Intended to be used with interpolation schemes (yes/no)		x	x		x	Annex B	
Type of connector		x	x		x	6.2.2.1, 6.2.2.5	
Type of fibre		x	x		x	6.2.2.1	
x = applicable							

NOTE 1 The highest voltage for equipment and rated insulation level may be combined to form one marking (for example, 145/275/650 kV).

NOTE 2 See relevant sub-part.

NOTE 3 The rated burden and the corresponding accuracy class shall be combined to form one marking (for example, 20 kΩ, class 1).

NOTE 4 The nature of auxiliary power supply and rated voltage shall be combined to form one marking (for example, 230 V a.c.).

12 Additional requirements for measuring electronic current transformers

12.1 Accuracy class designation

For measuring current transformers, the accuracy class is designated by the highest permissible percentage current error at rated current prescribed for the accuracy class concerned.

12.1.1 Standard accuracy classes

The standard accuracy classes for measuring current transformers are:

0,1 – 0,2 – 0,5 – 1 – 3 – 5.

12.2 Limits of current error and phase error at rated frequency

For classes 0,1 – 0,2 – 0,5 and 1, the current error and phase error at rated frequency shall not exceed the values given in table 17.

Table 17 – Limits of error

Accuracy class	± percentage current (ratio) error at percentage of rated current shown below				± phase error at percentage of rated current shown below							
					Minutes				Centiradians			
	5	20	100	120	5	20	100	120	5	20	100	120
0,1	0,4	0,2	0,1	0,1	15	8	5	5	0,45	0,24	0,15	0,15
0,2	0,75	0,35	0,2	0,2	30	15	10	10	0,9	0,45	0,3	0,3
0,5	1,5	0,75	0,5	0,5	90	45	30	30	2,7	1,35	0,9	0,9
1,0	3,0	1,5	1,0	1,0	180	90	60	60	5,4	2,7	1,8	1,8
NOTE The limit of current error and phase error prescribed for 120 % of rated primary current should be retained up to the rated extended primary current.												

For classes 0,2 S and 0,5 S, the current error and phase error of current transformers for special applications (in particular, in connection with special electricity meters which measure correctly at a current between 1 % and 120 % of the rated current) at rated frequency shall not exceed the values given in table 18.

Table 18 – Limits of error for current transformers for special application

Accuracy class	± percentage current (ratio) error at percentage of rated current shown below					± phase error at percentage of rated current shown below									
						Minutes					Centiradians				
	1	5	20	100	120	1	5	20	100	120	1	5	20	100	120
0,2 S	0,75	0,35	0,2	0,2	0,2	30	15	10	10	10	0,9	0,45	0,3	0,3	0,3
0,5 S	1,5	0,75	0,5	0,5	0,5	90	45	30	30	30	2,7	1,35	0,9	0,9	0,9
NOTE The limit of current error and phase error prescribed for 120 % of rated primary current should be retained up to the rated extended primary current.															

For class 3 and class 5, the current error at rated frequency shall not exceed the values given in table 19.

Table 19 – Limits of error

Class	± percentage current (ratio) error at percentage of rated current shown below	
	50	120
3	3	3
5	5	5

NOTE The limit of current error prescribed for 120 % of rated primary current shall be retained up to the rated primary extended current.

Limits of phase error are not specified for class 3 and class 5.

More information and an explanatory diagram on the limits of accuracy and protection classes are available in annex E.

For analogue output, the secondary burden used for test purposes shall be chosen as specified in the relevant clauses.

12.3 Accuracy requirements on harmonics

Accuracy requirements on harmonics are given in annex D.

13 Additional requirements for protective electronic current transformers

13.1 Accuracy classes

13.1.1 Accuracy class designation

For protective electronic current transformers, the accuracy class is designed by the highest permissible percentage composite error at the rated accuracy limit primary current prescribed for the accuracy class concerned, followed by the letter "P" (meaning protection) or by the letters "TPE" (meaning transient protection electronic classes – see annex A for more explanations).

13.1.2 Standard accuracy classes

The standard accuracy classes for protective current transformers are:

5 P, 10 P, and 5TPE.

13.1.3 Limits of error

At rated frequency, the current error, phase error and composite error and, during application of specified duty cycle if transient performance is specified, the maximum peak instantaneous error, shall not exceed the values given in table 20. The phase error indicated in the tables of limits of errors are the values remaining after the compensation of the rated delay time.

Table 20 – Limits of error

Accuracy class	Current error at rated primary current %	Phase error at rated primary current		Composite error at rated accuracy limit Primary current %	At accuracy limit condition Maximum peak instantaneous error %
		Minutes	Centiradians		
5TPE	± 1	± 60	± 1,8	5	10
5 P	± 1	± 60	± 1,8	5	-
10 P	± 3	-	-	10	-

NOTE 1 Information on transient conditions related to class TPE and classes (PR and PX) defined in IEC 60044-1 and other classes (TPS, TPX, TPY, TPZ) defined in IEC 60044-6 are given in annex A.

For analogue output electronic current transformers, the secondary burden used for test purposes shall be chosen as specified in the relevant clauses.

13.2 Accuracy requirements on harmonics

Accuracy requirements on harmonics are given in annex D.

14 Information to be given with enquiries, tenders and orders

14.1 Designation

When specifying an electronic current transformer for an enquiry or an order, the following items in table 21 are necessary to determine its performances.

Table 21 – Designation of an electronic current transformer

Rating	Abbreviation	Definition	Clause or sub-clause
Rated mechanical strength			6.1.8
Highest voltage for equipment	U_m	3.1.31	6.1.1.1
Rated insulation level		3.1.32	6.1.1.1
Service conditions			4
Rated frequency	f_r	3.1.18	5.1.5
Rated primary current	I_{pr}	3.1.20	5.1.1
Rated primary short-circuit current for transient response	I_{psc}	3.3.5	5.1.4.2.2
Rated extended primary current factor	K_{pcr}	3.2.3	5.1.2
Rated symmetrical short-circuit current factor for transient response	K_{ssc}	3.3.6	5.1.4.2.1
Specified primary time constant for transient response	τ_{pr}	3.3.7	5.1.4.2.3
Type of output (analogue voltage or digital)			
Type of merging unit sync method (interpolation or sync pulse, for digital output)			Annex B
Electrical or optical interface at the merging unit (for digital output)			6.2.2
Rated secondary output (for analogue output)	U_{sr}	3.1.22	5.4.2
Rated secondary burden (for analogue output)	R_{br}	3.5.3	5.4.3
Accuracy limit factor	K_{alf}	3.3.3	5.1.4.1.1
Accuracy class			12, 13
Rated auxiliary power supply voltage	U_{ar}	3.1.11	5.1.7
Rated phase offset	φ_{0r}	3.1.28	5.2
Rated delay time	t_{dr}	3.1.27	5.3.2, 5.4.1
Rated wake-up time		3.1.44	5.1.11
Maximum power consumption of the ECT			
Application (for example, free-standing, GIS, suspended on busbar, breaker-mounted)			

14.2 Dependability

The manufacturer shall provide a reliability and dependability credibility file (see 6.1.9).

15 Rules for transport, storage and installation

It is essential that the transport, storage and installation of electronic current transformers, as well as their operation and maintenance in service, be performed in accordance with instructions given by the manufacturer.

Consequently, the manufacturer should provide instructions for the transport, storage, installation, operation and maintenance of electronic current transformers. The instructions for the transport and storage should be given at a convenient time before delivery, and the instructions for the installation, operation and maintenance should be given by the time of delivery at the latest.

It is impossible, here, to cover in detail the complete rules for the installation, operation and maintenance of each one of the different types of apparatus manufactured, but the following information is given with regard to the most important points to be considered for the instructions provided by the manufacturer.

15.1 Conditions during transport, storage and installation

A special agreement should be made between manufacturer and user if the services conditions of temperature and humidity in that 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. Vibration during transport shall be considered. Appropriate instructions should be given.

15.2 Installation

For each type of electronic current transformer, the instructions provided by the manufacturer should at least include the items listed below.

15.3 Unpacking and lifting

Required information for unpacking and lifting safely, including details of any special lifting and positioning devices which are necessary, should be given.

15.4 Assembly

When the electronic current transformer is not fully assembled for transport, all transport units should be clearly marked. Drawings showing assembly of these parts should be provided with the electronic current transformer.

15.4.1 Mounting

Instructions for mounting of electronic current transformers, operating devices and auxiliary equipment should include sufficient details of locations and foundations to enable site preparation to be completed.

These constructions should also indicate

– the total mass of the apparatus inclusive insulating fluids;

– the mass of insulating fluids;

– the mass of the heaviest part of the apparatus to be lifted separately if it exceeds 100 kg;

– the centre of gravity.

15.4.2 Connections

Instructions should include information on

a) connection of conductors, comprising the necessary advice to prevent overheating and unnecessary strain on the electronic current transformer 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;

e) type of cable to be connected at the secondary terminals: the manufacturer shall indicate a recommended cable (including complete reference and the references of at least one supplier) and the maximum recommended length, for this cable, between the secondary terminals and the secondary equipment.

15.4.3 Final installation inspection

Instruction should be provided for inspection and tests which should be made after the electronic current transformer 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.

NOTE When optical system used, it is important to verify its integrity and to perform functional tests during final inspection to ensure that no physical damage has occurred to the fibre during installation.

15.5 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 all operation features provided, so that the user has an adequate understanding of the main principles involved.
– The minimum wake-up current.
– A description of the safety features of the equipment and the operation.
– As relevant, a description of the action to be taken to manipulate the equipment for maintenance and testing.

15.6 Maintenance

15.6.1 General

The effectiveness of maintenance depends mainly on the way instructions are prepared by the manufacturer and implemented by the user.

15.6.2 Recommendation for the manufacturer

The manufacturer should issue a maintenance manual including the following information.

a) Schedule maintenance frequency and active time.
b) Detailed description of the maintenance work:
   – recommended place for the maintenance work (indoor, outdoor, in factory, on site, electronic current transformer);
   – procedures for inspection, diagnostic tests, examination, overhaul, function check-out (limits of values and tolerances for example, opto-electrical component operating efficiency);
   – reference to drawings;
   – reference to part numbers;
   – use of special equipment or tools (cleaning and degreasing agents);
   – precautions to be observed (for example, cleanliness).

c) Comprehensive drawings of the details of the electronic current transformer important for maintenance, with clear identification (part number and description) of assemblies, subassemblies and significant parts.

NOTE Expended detail drawing which indicate the relative position of components in assemblies and sub-assemblies are a recommended illustration method.

d) List of recommended spare parts (description, reference number quantities) and advice for storage.

e) Estimate of active scheduled maintenance time.

f) How to proceed with the equipment at the end of its operating life, taking into consideration environmental requirements.

The manufacturer should inform the users of a particular type of electronic current transformer and about corrective actions required by possible systematic defects and failures.

Availability of spares: The manufacturer should be responsible for ensuring the continued availability of recommended spare parts required for maintenance for a period not less than 10 years from the date of the final manufacture of the electronic current transformer.

15.6.3 Recommendations for the user

If the user wishes to do his own maintenance, he should ensure that his staff have sufficient qualification as well as a detailed knowledge of the electronic current transformer.

The user should record the following information:

– the serial number and the type of the electronic current transformer;
– the date when the electronic current transformer is put in service;
– the results of all measurements and tests including diagnostic tests carried out during the life of the electronic current transformer;
– dates and extent of the maintenance work carried out;
– the history of service, records of the electronic current transformer measurement during and following a special operating condition (for example, fault and post-fault operating state);
– references to any failure report.

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.

15.6.4 Failure report

The purpose of the failure report is to standardize the recording of the electronic current transformer 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 the following whenever such data is available:

a) identification of the electronic current transformer which failed:
   - substation name;
   - identification of the electronic current transformer (manufacturer, type, serial number, ratings);
   - electronic current transformer family (oil or SF6 insulation, self-supported or busbar supported, whether mechanically coupled to a circuit-breaker or not);
   - electronic current transformer technology used (air-core coil, iron-core coil, optical)
   - location (indoors, outdoors);
   - enclosure.
b) history of the electronic current transformer:
   - date of commissioning of the equipment;
   - date of failure/defect;
   - date of last maintenance;
   - details of any changes made to the equipment since manufacture;
   - condition of the electronic current transformer 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;
   - other components.
d) stresses presumed contributing to the failure/defect
   - environmental conditions (temperature, wind, 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, electronic, tightness, if applicable);
   - cause (design, manufacture, inadequate instructions, incorrect mounting, incorrect maintenance, stresses beyond those specified, etc.).
g) consequences of the failures or defect
   - electronic current transformer down-time;
   - time consumption for repair;
   - labour cost;
   - spare parts cost.

A failure report may include the following information:

- drawings, sketches;
- photographs of defective components;
- single-line station diagram;
- records or plots;
- references to maintenance manual.

16 Safety

A high-voltage electronic current transformer can be safe only when it is installed in accordance with the relevant installation rules and used and maintained in accordance with the manufacturer's instructions (see clause 15).

A high-voltage electronic current transformer is normally only accessible to instructed persons. It shall be operated and maintained by skilled persons. When unrestricted access is available to a distributed electronic current transformer, additional safety features may be required.

The following specifications of this standard provide personal safety measures for electronic current transformers against various hazards.

16.1 Electrical aspects

- isolating distance (see 6.1.1);
- earthing (indirect contact) (see 6.1.12);
- separation of HV and LV circuits (see 6.1.13);
- IP coding (direct contact) (see 6.1.13);

16.2 Mechanical aspects

- pressurized components (see 6.1.11);
- mechanical impact protection (see 6.1.13.3);

16.3 Thermal aspects

- flammability (see 6.1.14);

Annex A
(informative)

Transient performances of ECTs

A.1 Introduction

Any current transformer (magnetic or electronic) reproduces the a.c. component and the transient d.c. component with different instantaneous errors. The instantaneous error of the a.c. component affects the operation of protection relays. The instantaneous error of the transient d.c. component is usually not relevant for protection algorithms. Nevertheless, it is visible in transient fault recorder plots. Non-linearity of the (E)CT may distort the reproduced a.c. component. Consequently, the instantaneous error of the a.c. component may depend on the input amplitude and the magnitude of the transient d.c. component.

A detailed analysis of transient performances required for certain applications is given in IEC 60044-6. However, this standard applies only for the conventional technology, which is based on magnetic materials. Many ECTs, based on different technologies like Faraday sensors or Rogowski coils, are not subjected to the limitation of conventional CTs, and provide to the user more flexibility with regards to primary d.c. components. The aim of this annex is to illustrate the benefit that users can get using ECTs when transient performances are required.

A.2 Short-circuit current in a network

To determine the short-circuit current in a network, an equivalent electrical circuit could be the electrical circuit describe in figure A.1.

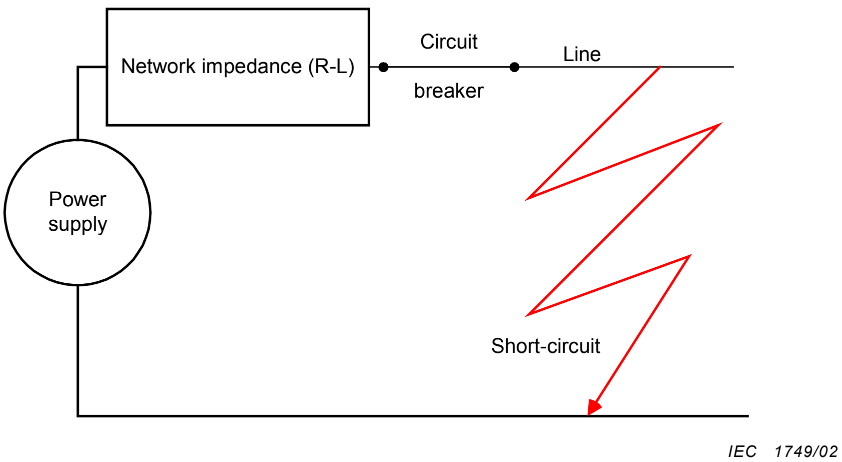


Figure A.1 – Equivalent electrical circuit of the network

An approximate expression for the instantaneous value of a short-circuit current having a symmetrical component I_{psc} may be written:

$$i(t) = \sqrt{2} \cdot I_{psc} \cdot \left[e^{-t/\tau_p} \cdot \cos(\theta) - \cos(\omega \cdot t + \theta) \right]$$

where τ_p is the primary time constant (expressed by the ratio L/R of the electrical components of the circuit described in figure A.1).

The second part of the expressions describes the time evolution of the primary current for steady-state condition.

The first part describes the transient component which is added to the steady-state current to fulfil continuity equations related to reactive components of the network. Such part exists only when the phase displacement between primary voltage and current are not the same before and after the primary fault. If the phase displacement remains unchanged, θ = 90° and the transient component collapses.

To eliminate such short circuit, the circuit-breaker is open. As many short circuits are the result of atmospheric over-voltages on the line insulator, automatic cycles are apply to the circuit-breaker to eliminate these faults in a short time and continue to supply the network. In case of real fault, the short circuit appears a second time when the circuit-breaker closes. To determine the behaviour of a current transformer during transient phenomena, a combination of two short-circuit currents is necessary (as described in 3.3.9).

However, the short-circuit current generally results in a network of an addition of different exponential currents (figure A.2) and describing the short-circuit current by this formula is only an approximation. On the other hand, the symmetrical amplitude I_{psc} and the primary time constant change with the location of the fault, and also with the network configuration when the fault occurs. Due to the presence of power transformers in the substation, the primary time constant could be very high (for example, 200 ms) if the short circuit is located near the substation, but could be lower if the fault occurs some kilometres farther due to the resistive part of the line (for example, 60 ms). I_{psc} depends also on the situation of the fault.

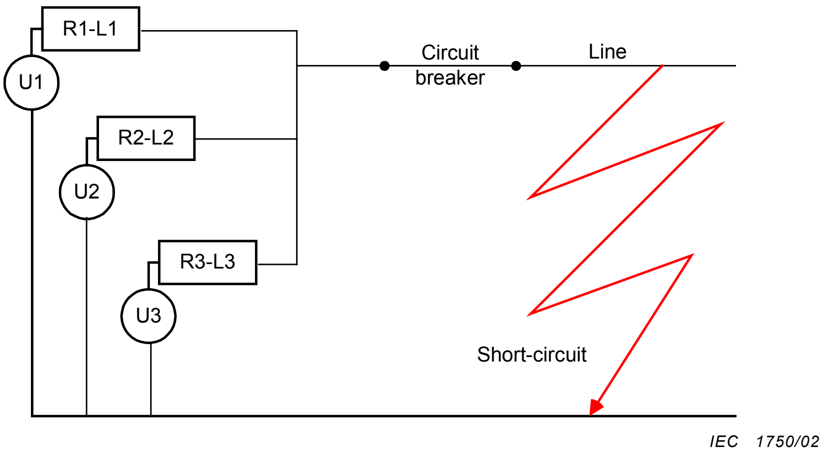


Figure A.2 – More complex equivalent electrical circuit during short circuit

The determination of these parameters is difficult and several hypotheses are to be taken into account to determine the specification of the current transformer. This is also due to the behaviour of the current transformers which are affected by the characteristics of primary short and by the secondary circuit as explained in the following clause.

A.3 Equivalent circuit of a current transformer during short circuit

To analyse the behaviour of magnetic CTs during short-circuit current, the following equivalent circuit described in figure A.3 is useful.

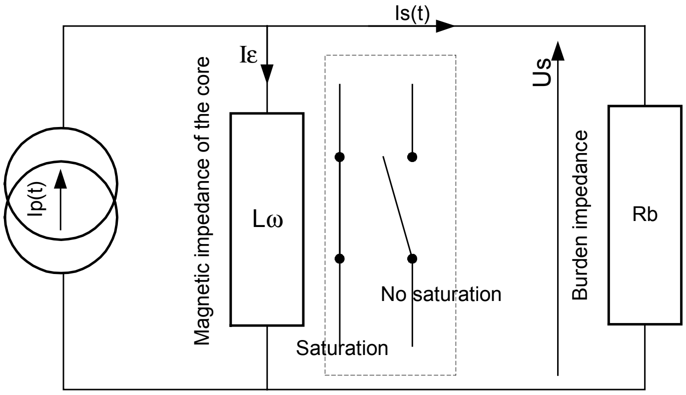


Figure A.3 – Equivalent electrical circuit of magnetic current transformer during short circuit

The primary current is represented by a current source. The secondary circuit is represented by the burden impedance (including the impedance of the wires). The CT is only represented by the $L\omega$ reactance which is the magnetic impedance of the CT core.

The difficulties are related to the non-linearity of this impedance when saturation of the core occurs. To simplify this impedance could be considered as an open circuit when the core is not saturated; in this case, the error represented by the current in this impedance is very small (quite null). When saturation occurs, this impedance could be represented by a short circuit, all the primary current is flowing through this impedance, the error is very high. The current in the secondary circuit reaches zero.

Saturation occurs when the magnetic flux reaches the knee point of the saturation curve (see figure A.4). The flux is the result of the integration of the voltage Us (see figure A.3).

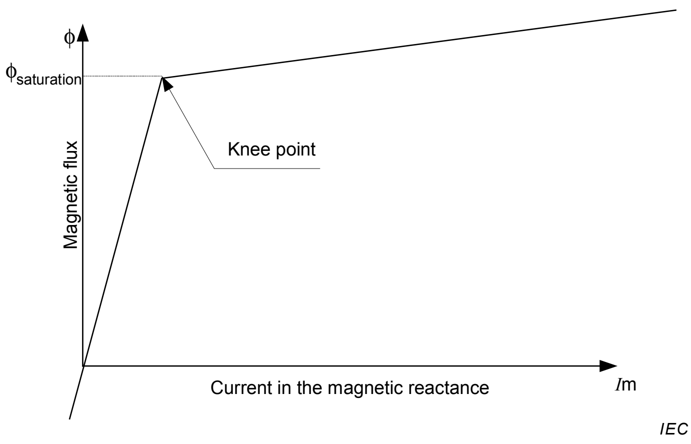


Figure A.4 – Magnetic reactance of the a CT without remanence

In steady-state conditions, the saturation of the core is directly linked by the amplitude of Us. This voltage depends on the current and the burden which are the main parameters to be checked to avoid saturation of the core.

During transient conditions, the flux is the result of the global evolution of Us which contains in this case a sinusoidal part and a d.c. part coming from the primary short-circuit current. The higher the primary time constant, the more quickly the knee point is reached. To avoid saturation during transient due to the d.c. component, an important increase in the size of the core is needed.

When the short-circuit current disappears, the magnetic core is not able to return immediately in initial conditions. A transient exponential current is flowing through the secondary circuit. The time constant of this current is the secondary time constant (τ_2 = L/Rb). Due to the high value of the reactance of the core, this time constant could also be very high compared to the primary time constant (for example, τ_2 could reach 2, 3,… 5 s depending on the size of the core). If a new short circuit appears before the flux goes down, the possible increase before saturation is reduced.

Another problem could also appear when the short-circuit current disappears. If the core is built without an air gap, a remanence flux could be obtained. This is again a very important aspect if a new short-circuit current is applied to the CT. The possible increase of the flux before saturation is drastically reduced. (In some cases, the remanent flux could reach 80 % of the saturation flux.)

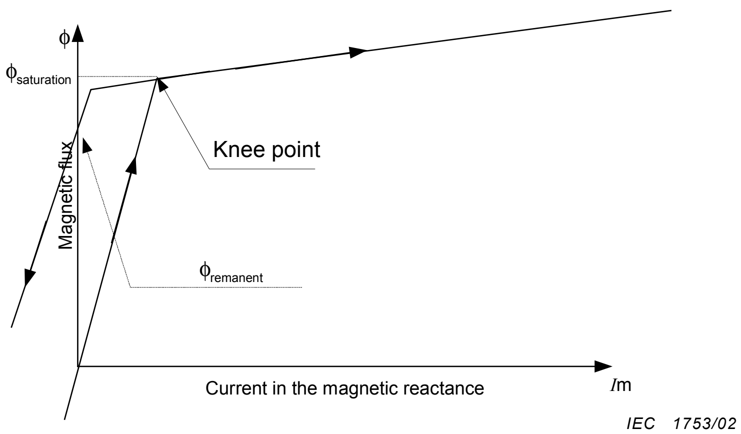


Figure A.5 – Magnetic reactance of the CT with remanence

A.4 Accuracy classes for magnetic current transformers

A.4.1 General

The technological limitations of magnetic CTs could be solved by a good design of the core. However, the design is related to a particular specification and new designs have to be made for different applications. For this reason, different protective classes are given in the relevant standards for CTs. The following clauses give a quick explanation of the protective classes described in IEC 60044-1 and IEC 60044-6. The protective classes in IEC 60044-1 are based on steady-state tests. In IEC 60044-6 they are based on transient tests.

A.4.2 Accuracy classes in steady-state conditions

A.4.2.1 Classical Class P of IEC 60044-1

When the short-circuit current is not very high compared to the rated current, the time to eliminate the fault is not critical. Classical electromechanical relays can be used (now modern electronic analogue or digital relays are also used). In addition, in this type of electrical circuit, the primary time constant being in general very small the transient current could be neglected. For this kind of application the classical class P is used. The aim is to avoid saturation in steady-state conditions, only the value of the short-circuit current and the burden are to be taken into account.

A.4.2.2 New Class PR and PX of IEC 60044-1

When the short-circuit current is high, the consequences are dangerous and elimination in a short time is required. This problem was solved during seventies with the definition of transient performance classes (see A.4.3). The verification of these classes are costly and the total behaviour of the CTs are not always needed. For instance, in some cases, it is enough to determine the condition to avoid saturation with the calculation of the voltage Us for the knee point (see figures A.3 and A.4).This is the aim of the new class PX based on long experience of the BS practices.

The class PR is relevant for differential relays. In this case, the elimination of the short-circuit current has to be as quick as possible. The reaction time of the protective relay is very small (for example, 5 ms). Even with a d.c. component, the increase in the flux is too small to reach saturation of the core during this short time. Later saturation can occur without incidence. The only condition is to avoid a remanent flux to be sure that every CT connected to the differential protective relays are in the same initial conditions.

A.4.3 Transient accuracy classes of IEC 60044-6

The IEC 60044-6 standard defines special classes like TPS, TPX, TPY, TPZ, and provides a detailed analysis of transient performances required for certain applications These classes complete the set of protection classes P, PR and PX defined in IEC 60044-1.

The explanation of the differences between these four classes is not the aim of this annex and for more explanations the reader can consult IEC 60044-6.

The classes TPZ and TPY are very often used for modern distance protective relays. The aim for the class TPZ is to avoid saturation of the core due to the d.c. component. For that a large air gap is include in the core. The effect is to change the characteristics of the magnetic impedance as shown in figure A.6.

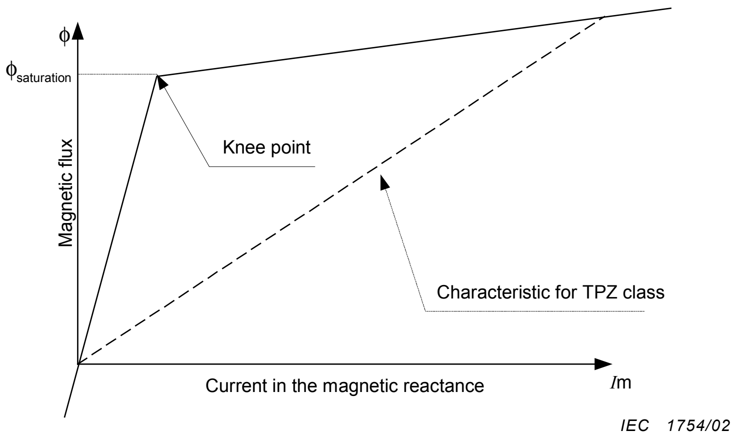


Figure A.6 – Example of magnetic reactance of the a CT for a TPZ class

The result is to eliminate the remanence apparition and to avoid the effect of the d.c. component. The secondary output does not transmit a correct view of the d.c. component, and the phase error is bigger as a classical protective class. For this TPZ class the error is based on the power-frequency component only.

If the phase error has to be reduced, TPY class should be used. For this class, the size of the magnetic core is increased to avoid saturation even if a d.c. component exists. The difficulty comes from the big influence on the magnetic flux (which demands that the size of the core be increased). The increasing factor is given by $k = (1 + \tau_{pr}\omega)$ (for example, for a primary time constant equal to 100 ms, the factor k is higher than 30 for a power frequency of 50 Hz).

The effect is to change the characteristics of the magnetic impedance as shown in figure A.7.

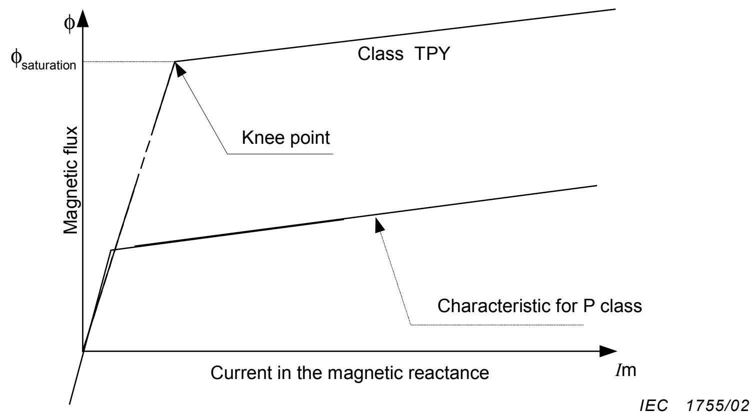


Figure A.7 – Example of the magnetic reactance of a CT for a TPY class

Due to the size of the core the saturation flux is very high and the air gap in the core avoids remanence flux. The error is given by a transient error which includes the d.c. component and the power-frequency component. This definition of error is taken in this standard for the electronic current transformer.

A.5 Class TPE

Class TPE is defined by a maximum peak instantaneous error of 10 % at the accuracy limit condition, the rated primary time constant and the rated duty cycle. The peak instantaneous error assesses the error of the transient d.c. component and the a.c. component at once. The definition is equivalent to the definition of class TPY for conventional CTs. A class TPE ECT thus meets the usual requirements for protection applications and fault transient recording.

(E)CTs for a.c. applications usually have a high pass characteristic below rated frequency. Class TPE implicitly defines the maximum lower cut-off frequency (or secondary time constant) of an ECT. For example, a rated primary time constant of τ_{pr} = 120 ms implies a lower cut-off frequency of maximum 0,15 Hz for a first-order system to yield an instantaneous error of the transient d.c. component below 10 %. A higher primary time constant requires a lower cut-off frequency to obtain the same peak instantaneous error of the transient d.c. component.

If an ECT is

– applied in a network with a higher primary time constant than the rated time constant or (equivalent)
– has a higher cut-off frequency (lower secondary time constant) than required by class TPE requirements

the instantaneous error of the transient d.c. component increases. If the design is sufficiently linear, the instantaneous a.c. error remains low or even within the specified limits of the ECT. The transient behaviour is similar to a conventional class TPZ CT. As protection algorithms usually depend only on the instantaneous a.c. error, the design can be applied without restriction. Nevertheless, interpreting transient fault recorder data requires the knowledge of the secondary time constant of the ECT. If the design is significantly non-linear, the instantaneous a.c. error will increase and may exceed an acceptable limit. The manufacturer should therefore specify the instantaneous a.c. error for this application.

A.6 Comparison of class TPE to conventional transient performance classes

Above a certain level of signals, almost every system becomes non-linear. However, two cases should be considered, according to the frequency response.

– Case one: Systems without d.c. rejection.

  This is typically the case for conventional technology using magnetic materials. Any d.c. component on the primary induces a d.c. offset on the magnetic induction which reduces the linear zone available for the a.c. component. Moreover, due to the hysteresis of the material, and if no countermeasure is applied (for example, air gaps), the material memorises the former history of the magnetic induction. Therefore, the behaviour of the CT submitted to transient conditions depends on the history and can result in saturation, as the effects of applied primary current are added to those coming from the pass. For that reason, conventional CTs with transient performances should be tested according to relevant duty cycle.

– Case two: System with d.c. rejection

  The frequency response of such systems is limited in the low frequency side: they are unable to transmit any d.c. components. This is typically the case for any system having a transfer function on the following form:

$$H(f) = H_0 . \frac{j . \dfrac{f}{f_{\mathrm{low}}}}{1 + j . \dfrac{f}{f_{\mathrm{low}}}}$$

  where f_{low} is the low cut-off frequency and f the frequency of the network.

  When submitted to the primary current expressed in clause A.2, and when properly adjusted, these systems can transmit the a.c. component with low errors while removing part or all of the d.c. component.

Therefore the primary time constant can vary up to very large values without affecting the accuracy of the a.c. component measurement.

Example

Assume a rated primary time constant of 60 ms, which can be associated with an equivalent frequency of 2,67 Hz, and an ECT designed with a low cut-off frequency of 0,5 Hz. Transient errors of the ECT comply with accuracy class 5TPE (see 13.1.3), for both a.c. and d.c. components. If, for any reason, a primary fault appears with a larger time constant, 200 ms, for example, which can be associated with an equivalent frequency of 0,8 Hz, the error will be higher but the a.c. error will be the same. The protective relay is able to work correctly.

Due to the great difficulties in determining the rated value of the primary time constant and the amplitude of the short-circuit current (I_{psc}) for a given network and the high sensibility of magnetic CTs to the primary time constant, this is a major advantage of the TPE class.

Another advantage is also given by the relative independence of the accuracy versus the burden in the secondary circuit for analogue output. In the case of digital output, there is non-correlation of the output on accuracy.

Annex B
(informative)

Technical information for electronic current transformers with digital output

B.1 Scope

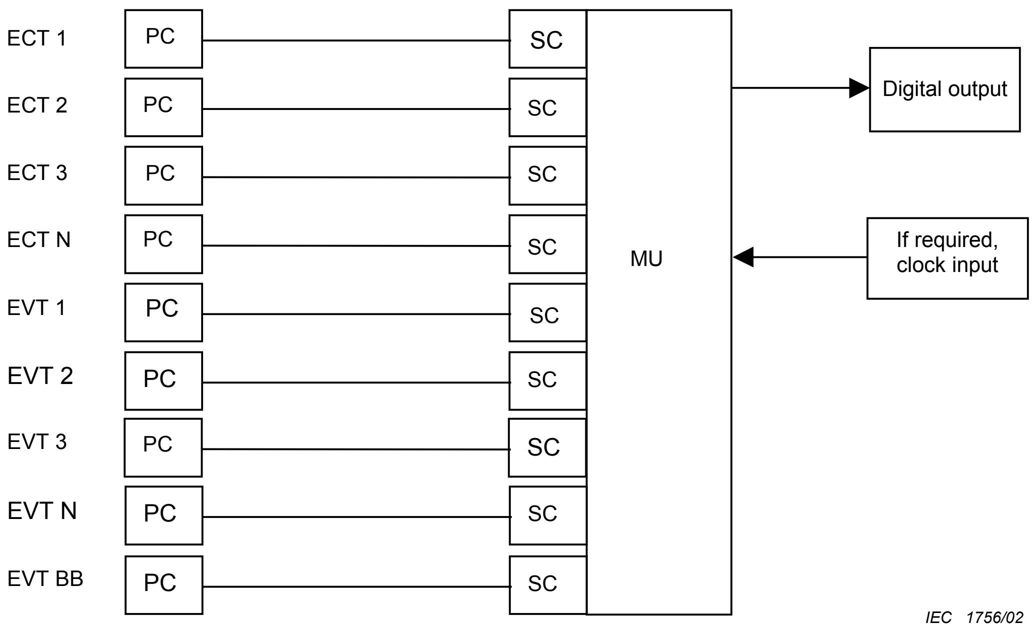
This annex applies to newly manufactured electronic current transformers with digital output for use with electrical measuring instruments and electrical protective devices.

Electronic current transformers use current sensors (current transformers, Hall effect sensors, air-core coils (Rogowski) for example) and/or optical arrangements and provide a digital output.

This annex gives the information required to deal with interpolation and sync mechanisms, error measurement and calculation, etc.

B.2 Operation principle of the digital output.

To use efficiently the advantages for electrical current and voltage transformers, the signals must be treated in a uniform way. Instantaneous values of current and voltage, taken from the same instance with a time uncertainty of less than a few microseconds, must be transmitted to the measuring and protection equipment. A recommended way to do this is to combine the currents and voltages from one bay, i.e. the currents and voltages in the three phases and transmit them in one protocol. The physical unit doing this combination of currents and voltages is called the merging unit (MU). The structure of the measuring system is given in figure B.1.



Key

– PC – Primary Converter
– SC – Secondary Converter
– MU – Merging Unit

Figure B.1 – Combination of ECTs and EVTs to form the digital output

How the transformers connected to one merging unit are synchronized is manufacturer specific and not defined in this standard.

B.3 Other assignment of the data channels

Some applications require different data channel assignments from the one given in table 12 of 6.2.4.1.3 (DataSetName = 01). For example, a line protection relay for a 1½ breaker arrangement with combined voltage and current transducers on either side of the breakers requires at least two sets of currents (protection resolution) and one set of voltages.

DataSetName = FE H (254 decimal) allows the manufacturer to freely assign data channels to sources to meet specific applications. In this case, the manufacturer specifies the data channel assignment as shown in the example in table B.1. The following items are necessary for correct configuration of the data sink for each data channel:

Value: Textual description of the signal

Reference value: The applicable reference value for this channel, possible values are rated phase current, rated neutral current, rated phase voltage

Scaling factor: The scaling factor of this data channel as defined in table 5. Possible values are SCP, SCM and SV

The data channel assignment must not change during normal operation.

Table B.1 – Sample application specific assignment of the data channels with DataSetName = FE H. Application for line protection and synchronization of 1½-beaker arrangements with combined ECTs/EVTs on both sides of the breakers

DataSetName	FE H			
	Value	**Source**	**Reference value**	**Scaling factor**
DataChannel#1	Current Phase A, prot.	DS 1	Rated Phase Current	SCP
DataChannel#2	Current Phase B, prot.	DS 1	Rated Phase Current	SCP
DataChannel#3	Current Phase C, prot.	DS 1	Rated Phase Current	SCP
DataChannel#4	Voltage Phase A	Line A	Rated Phase Voltage	SV
DataChannel#5	Voltage Phase B	Line A	Rated Phase Voltage	SV
DataChannel#6	Voltage Phase C	Line A	Rated Phase Voltage	SV
DataChannel#7	Current Phase A, prot.	DS 2	Rated Phase Current	SCP
DataChannel#8	Current Phase B, prot.	DS 2	Rated Phase Current	SCP
DataChannel#9	Current Phase C, prot.	DS 2	Rated Phase Current	SCP
DataChannel#10	Voltage Phase A	Bus Bar 1	Rated Phase Voltage	SV
DataChannel#11	Voltage Phase A	Bus Bar 2	Rated Phase Voltage	SV
DataChannel#12	Voltage Phase A	Line 2	Rated Phase Voltage	SV

B.4 Mathematical description of the digital output

Compared to an analogue output the digital output is not a function of time (t) but a sequence of values and therefore a function of a counter n, which is an integer number.

The time at which the primary currents and voltages of the n^{th} data set have been sampled is called t_n. Since equidistant sampling is used, the distance in time T_s between two samples is constant and equal to the reciprocal of the data rate: $t_{n+1} - t_n = T_s$

With the help of these definitions the digital output can be described as follows:

$$i_s(n) = I_{ssc}\sqrt{2}\,.\sin(2\pi.f.t_n + \varphi_s) + I_{sdc}(n) + i_{sres}(n);$$

where

- i_s is a digital number at the merging unit output representing the actual instantaneous value of the primary current;
- I_{ssc} is the r.m.s. value of the symmetrical component of a certain merging unit output;
- I_{sdc} is the secondary direct output including the exponential component;
- i_{sres} is the secondary residual output including harmonic and subharmonic components;
- n is the data set counter;
- t_n is the time at which primary currents and voltages of the n^{th} data set have been sampled;
- f is the frequency;
- φ_s is the secondary phase displacement.

B.5 Time synchronization of the merging units

Many protections require signals from different bays with synchronized current and voltage information. It is therefore necessary to be able to synchronize current and voltage information from different protocols. There are two means to do this synchronization, interpolation of the values from several protocols or to use a station-wide clock for synchronization of the different protocols.

In the case of interpolation, the different known time delays in the different protocols are used to calculate the samples at a decided instance using interpolation between the samples from the different protocols. See figure B.2.

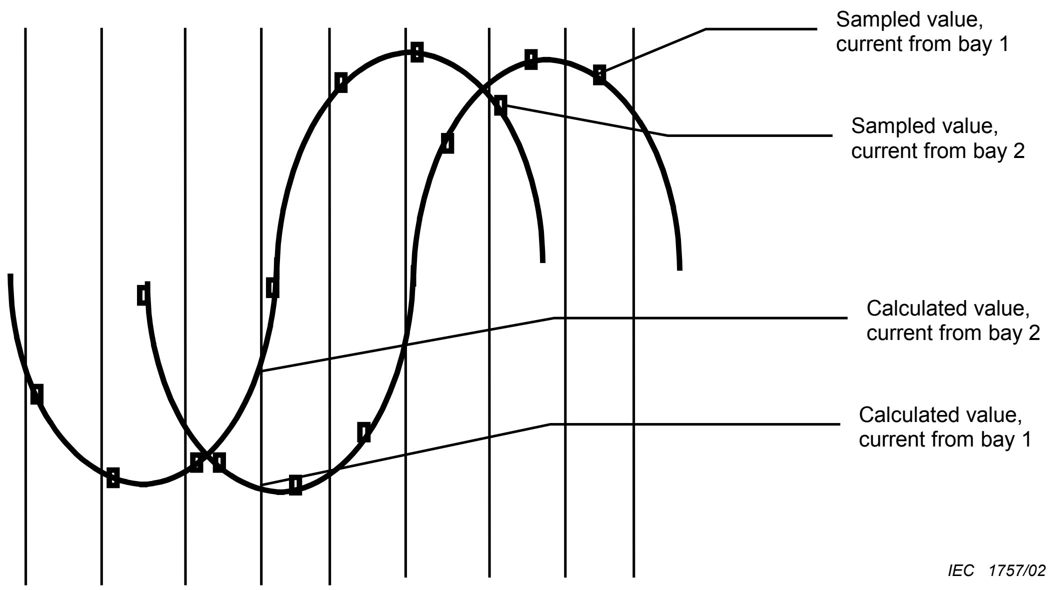


Figure B.2 – Synchronized samples of current from bay 1 and bay 2 calculated from non-synchronized samples from bay 1 and bay 2 respectively

In the case of synchronization using a common clock pulse, each merging unit must have a clock input and means to give out the protocol with samples taken at a time instance given by the signal at the clock input. See figure B.3.

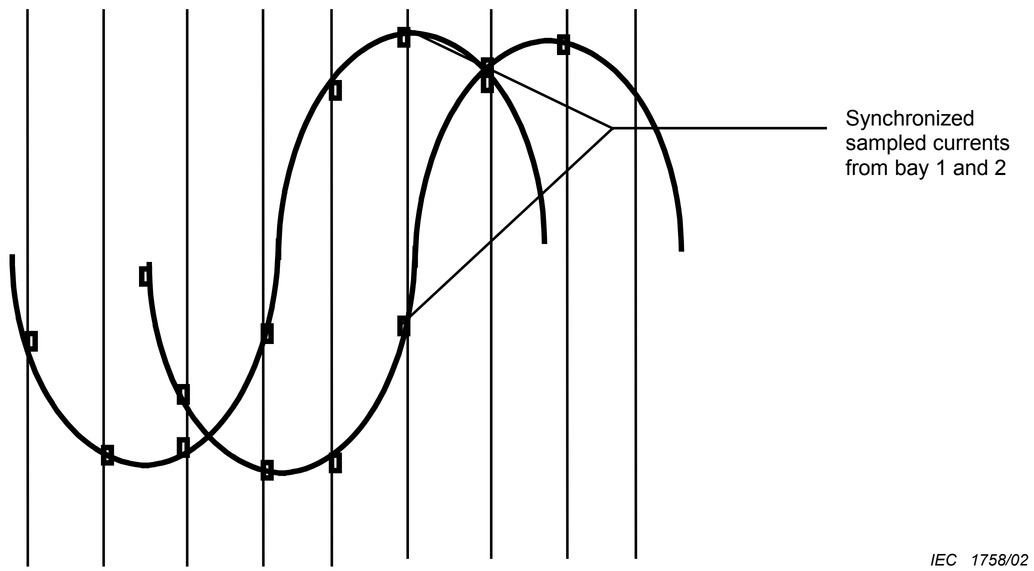


Figure B.3 – Samples from current in bay 1 and 2 sampled synchronized by a common clock

B.6 Error measurement

B.6.1 Definition of the phase error for the digital interface

In figure B.4 a certain primary current measured by an ECT is marked. After a certain period of time the measured current value is transmitted digitally coded via the digital interface. Of course, the transmitted value is generally not exactly the same as the actual primary current to be measured due to the amplitude error of the transformer.

The period of time up till the beginning of the transmission is the phase displacement. It consists of two components: a constant rated value equal to $\varphi_{0r} - 2\pi \times f \times t_{dr}$ and possibly a variable part.

It is very important that the phase displacement keeps exactly to its rated value defined by φ_{0r} and t_{dr}, if the data of two merging units are joined using an interpolation method. In this case any deviations of the phase displacement from $\varphi_{0r} - 2\pi \times f \times t_{dr}$ will result in a phase error when the data of several merging units is joined.

It has to be pointed out that the time where the primary current is sampled is, in general, not the same time where the A/D converter in the transformer samples, since there are usually analogue components (filters, phase shift of the air-core coil, etc.) that cause a phase shift or delay before the primary current information reaches the A/D converter. Such delays and phase shifts are included either in the rated delay time or in the rated phase offset.

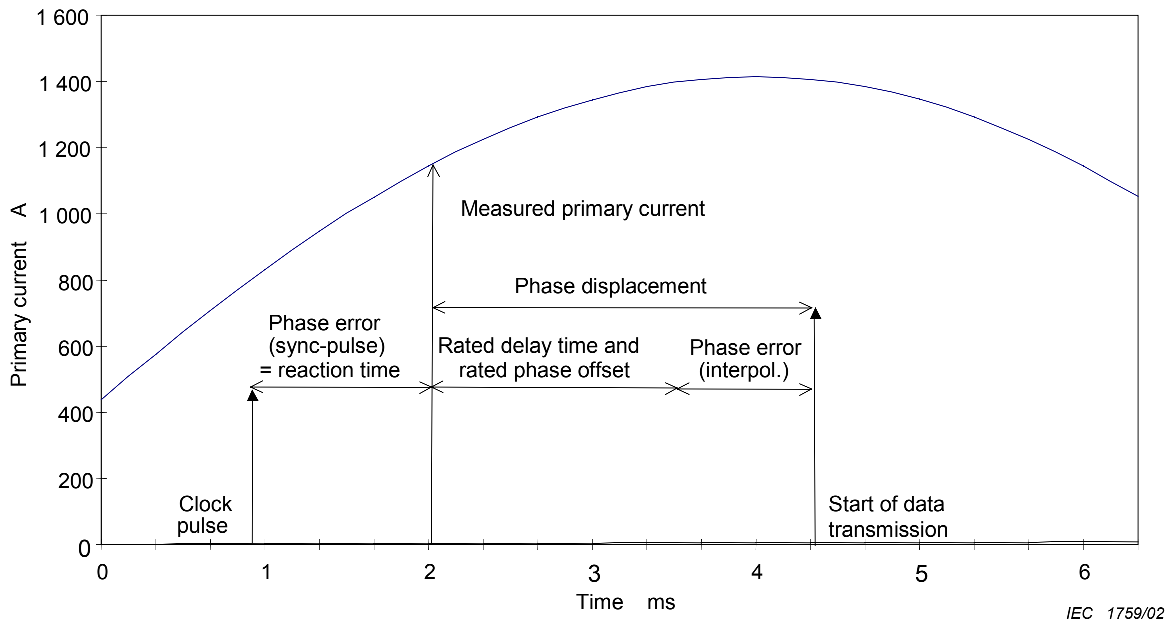


Figure B.4 – Phase error definition for the digital interface

In the case where several merging units are to be synchronized with a common clock pulse another time becomes important: the period of time between a clock pulse and a current or voltage measurement. This time is supposed to be zero. Any deviation from zero causes a phase error. This period of time is also called “reaction time”.

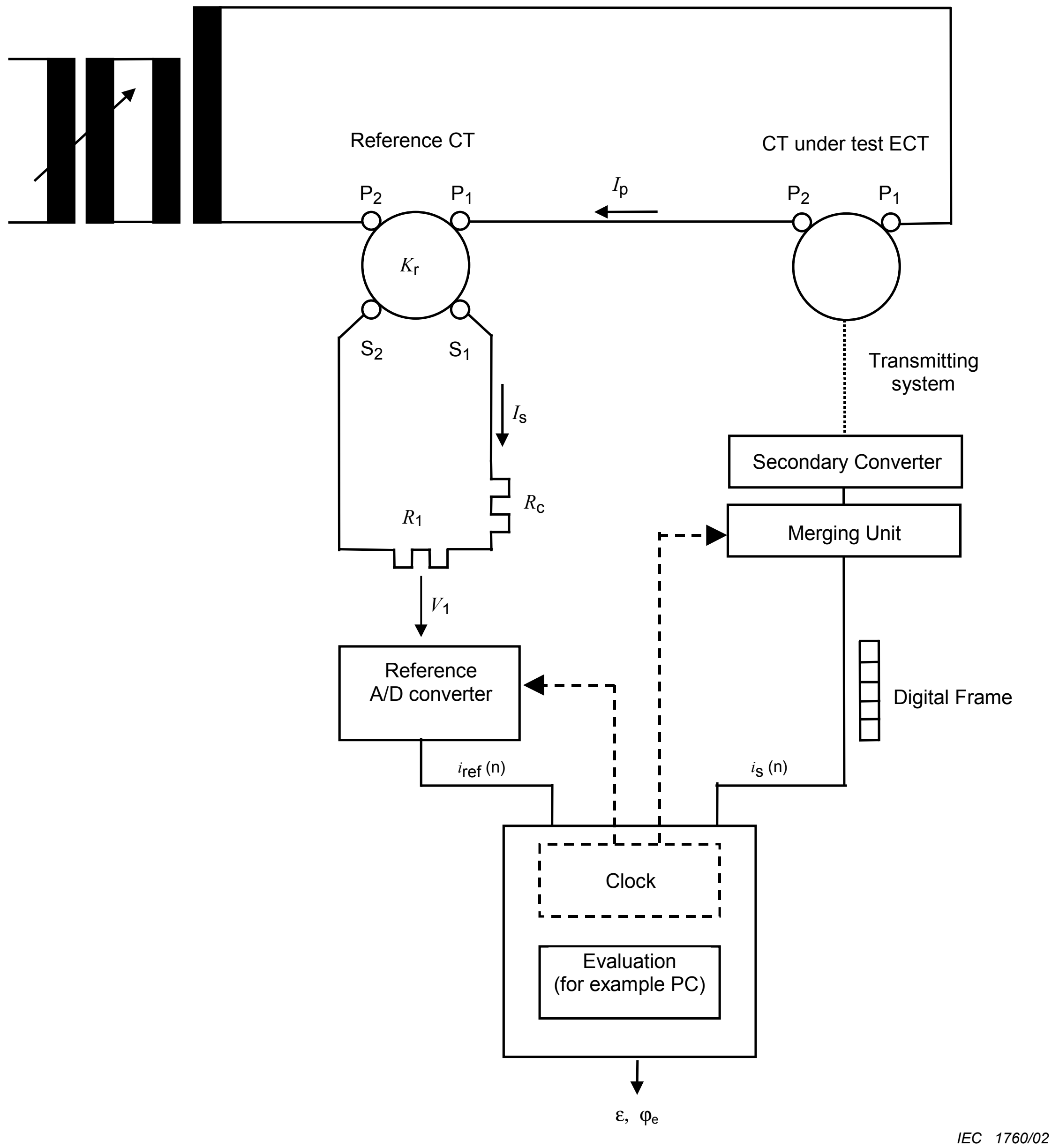
The clock pulse is not transmitted for every measurement but every second. It is used to synchronize the internal clock of the merging unit with a certain master clock. The duration of the reaction time can be made zero since the clock pulses are well-defined periodic signals.

By doing so, it can be ensured that none of the measurements between two clock pulses exceed the transformer's specified phase error if only those made at the same time with the clock pulses do not.

A merging unit can be designed to use either of these principles (interpolation or clock) or both.

B.6.2 Test set-up and procedure

Figure B.5 shows an accuracy test set-up for the merging unit and a transformer connected to it.



Key

K_r Rated transformation ratio of Reference CT

V_1 Voltage at the input of the Reference A/D converter

R_1 Burden used to adjust the voltage at the input of the Reference A/D converter

$R_1 + R_c$ Rated secondary burden of Reference CT

R_1 is required to be a high accuracy burden.

Figure B.5 – Test set-up

If the error of the reference system is negligible compared to the tested accuracy class, the digitised output of the reference i_{ref} times its rated transformation ratio K_r can be taken to be equal to i_p and used directly in the error calculations, made by the evaluation unit in figure B.5 and described in the next paragraph.

In the case of a merging unit intended to be used with an interpolation scheme, the evaluation unit (for example, a PC) first has to take means to get time-coherent data sets from the reference and the transformers under test. To do so the evaluation unit uses the rated delay time and the rated phase offset of the transformer under test and of the reference system, which has to be known very precisely.

If t_{nre} is the time the beginning of the n^{th} data set is received from the transformer under test, then t_n, the time the data set has been sampled is calculated as follows:

$$t_n = t_{nre} - t_{dr} + \varphi_{0r} / (2\pi f)$$

The appropriate primary current value $i_p(t_n)$ or $i_{ref}(t_n)$ then can be calculated using the reference data i_{ref} and an interpolation algorithm. Another possibility is to use the incoming data sets from the transformer under test to trigger the sampling of the reference CT in a way that both samples of the primary current are taken at the same time.

Once a time-coherent set of current data from the reference transformer and the transformer under test has been obtained, the error calculation can be made according to the mathematical methods described in the next paragraph.

For a merging unit that is synchronized using clock pluses the procedure is different. Since the transformer under test and the reference transformer are supplied with the same clock pulses, their samples are supposed to be time-coherent already. i_s(n) coming from the transformer under test and $i_{ref}(n)$ coming from the reference transformer can be compared directly. In the equations in the following paragraph $i_p(t_n)$ can be directly replaced by $K_{rd\ ref}\ i_{ref}(n)$. Of course when clock pulses are used for synchronization, it has to be ensured that the clock pulses are accurate enough.

Once a transformer with digital output has proved to be accurate enough, it can of course act as a reference itself. After calibration with an independent external reference using one of the methods above, the calibrated transformer can replace the reference system in Figure B.5, so that two MUs are connected to the evaluation unit, one with the transformer under test, one with the reference transformer. If both transformers use the same MU technology the set-up can be simplified by connecting both to the same MU.

B.6.3 Mathematical evaluation for the error calculation

B.6.3.1 Amplitude and phase error

B.6.3.1.1 Error calculation using a digital bridge

One way to calculate the errors is to perform digital calculations equivalent to the functionality of a conventional transformer bridge.

In this case for sinusoidal current and $t_n \geq t_{dr} - \varphi_{0r}/(2\pi f)$ the phase and amplitude error are calculated from the instantaneous values with the help of the following equation:

$$\varepsilon'(\varphi_{ad}) = \frac{100}{I_p}\sqrt{\frac{T_s}{k\,T}\sum_{n=1}^{k\,T/T_s}\left(K_{rd}\, i_s(n) - i_p(t_n + \frac{\varphi_{ad}}{2\pi\, f})\right)^2}$$

where

K_{rd} is the rated transformation ratio;

I_p is the r.m.s. value of the primary current;

i_p is the primary current;

i_s is the secondary digital output (at the merging unit output);

T is the duration of one power cycle;

n is the data set counter;

t_n, is the time where primary currents and voltages of the n^{th} data set have been sampled;

k is the number of summation periods;

T_s is the distance in time between two samples of the primary current;

φ_{ad} is an adjustable phase shift.

To calculate the amplitude error ε (in %) and the phase error φ_e the adjustable phase shift φ_{ad} is chosen so that $\varepsilon'(\varphi_{ad})$ becomes minimal. In this case is $\varphi_e = \varphi_{ad}$ and $\varepsilon = \varepsilon'$.

The phase shift φ_{ad} can be introduced digitally using an interpolation algorithm.

Digital bandpass filtering of $K_{rd}\, i_s - i_p$ around the frequency under test and a large number of summation periods *k* can be used to ensure a stable result of the above calculation.

B.6.3.1.2 Error calculation using Fourier transforms

Both $i_p(t_n)$ and $i_s(n)$ are periodical signals. The (discrete) Fourier transform of these signals after digitization are given by the formula:

$$I_p(f) = \sum_{n=0}^{k\,T/T_s - 1} i_p(t_n).e^{-j.2.\pi.f.t_n}$$

$$I_s(f) = \sum_{n=0}^{k\,T/T_s - 1} i_s(n).e^{-j.2.\pi.f.t_n}$$

where

i_p is the primary current;

i_s is the secondary digital output (at the merging unit output);

n is the data set counter;

t_n, is the time where primary currents and voltages of the n^{th} data set have been sampled;

k is the number of summation periods;

T_s is the distance in time between two samples of the primary current;

For harmonic h, the application of the above equations with $f = f_h = h.f_r$ gives two complex coefficients:

$$I_p(f_h) = \left|I_p(f_h)\right|.e^{-j.\varphi_{p,h}}$$

$$I_s(f_h) = \left|I_s(f_h)\right|.e^{-j.\varphi_{s,h}}$$

For sinusoidal current and $t_n \geq t_{dr} - \varphi_{0r}/(2\pi f)$ the phase and amplitude error at rated frequency are calculated from the Fourier transform coefficients for h = 1.

Amplitude error: $\varepsilon(\%) = 100.\dfrac{K_{rd}.\left|I_s(f_1)\right| - \left|I_p(f_1)\right|}{\left|I_p(f_1)\right|}$

where K_{rd} is the rated transformation ratio

phase error: $\varphi_e(\text{rad}) = \varphi_{s,1} - \varphi_{p,1}$

B.6.3.1.3 Error calculation using digital synchronous detection algorithm

An other possibility to calculate the gain and phase errors is to perform digital calculations based on synchronous detection principles (commonly used in lock-in amplifier) as used for analogue output (see clause C.4).

B.6.3.2 Composite error

To calculate the composite error ε_c the analogue function is replaced by an equivalent digital calculation (for $t_n \geq t_{dr} - \varphi_{0r}/(2\pi f)$):

$$\varepsilon_c = \frac{100}{I_p}\sqrt{\frac{T_s}{kT}\sum_{n=1}^{kT/T_s}\left(K_{rd}\cdot i_s(n) - i_p(t_n)\right)^2}$$

where

K_{rd} is the rated transformation ratio;

I_p is the r.m.s. value of the primary current;

i_p is the primary current;

i_s is the secondary digital output (at the merging unit output);

T is the duration of one cycle;

n is the data set counter;

t_n, is the time where primary currents and the n^{th} data set have been sampled;

k is the number of summation periods;

T_s is the distance in time between two samples of the primary current.

A large number of summation periods k can be used to ensure a stable result of the above calculation. Bandpass filtering is not allowed.

NOTE For stand-alone air-core coils, secondary output is measured at the output of an integrator (see definition of K_{ra} K_{rd} and annex C). The integrator can be realized digitally in the evaluation unit. Since the integrator may influence the delay time, it is allowed in this test set-up that the delay time differs from the rated delay time of the transformer under test.

B.6.3.3 Instantaneous error

The instantaneous error current is defined for $t_n \geq t_{dr} - \varphi_{0r}/(2\pi f)$ and is calculated by the following expression:

$$i_\varepsilon(n) = K_{rd}.i_s(n) - i_p(t_n)$$

where

K_{rd} is the rated transformation ratio;

i_p is the primary current;

i_s is the secondary digital output (at the merging unit output);

n is the data set counter;

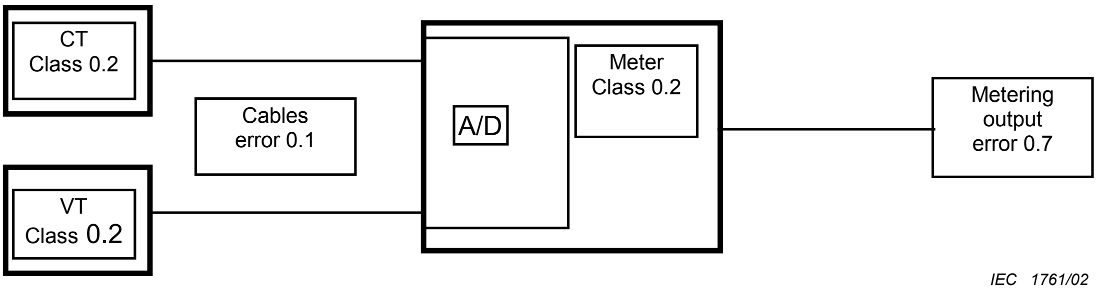
t_n, is the time at which primary currents and voltages of the n^{th} data set have been sampled.

NOTE For stand-alone air-core coils, secondary output is measured at the output of an integrator (see definition of K_{ra} or K_{rd} and annex C). The integrator can be realized digitally in the evaluation unit. Since the integrator may influence the delay time, it is allowed in this test set-up that the delay time differs from the rated delay time of the transformer under test.

B.7 Comparison of total system accuracy using analogue and digital output CT/VT

When comparing systems built of components having the same accuracy class, the total system accuracy is not the same for systems based on ECTs and EVTs with digital output as for systems based on components with analogue outputs. See figure B.6. When using ECTs and EVTs with digital output, the error contribution from the purely digital signal transmission is eliminated. The meter is in this case a pure calculation from the digital values and thereby not adding any errors provided the precision in the calculation is properly chosen. All possibilities of temperature or long-term drift in the meter is also eliminated.

Conventional metering system



Metering system with ECT and EVT with digital output

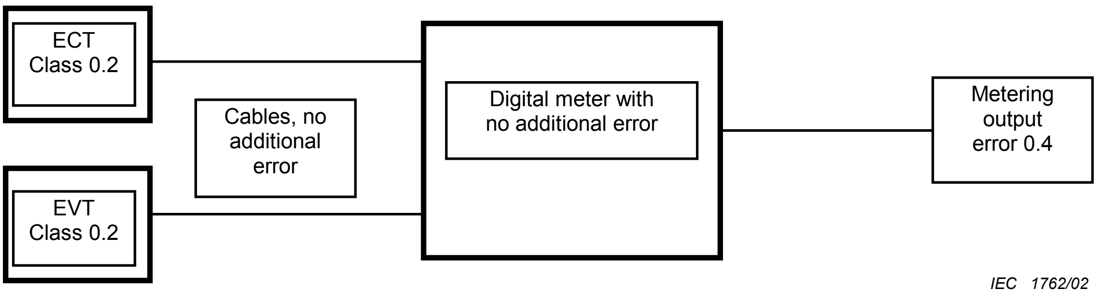


Figure B.6 – Comparison of errors in conventional metering systems and systems based on ECTs and EVTs with digital output

Annex C
(informative)

Technical information for electronic current transformers with analogue output

C.1 Scope

This annex applies to newly manufactured electronic current transformer with analogue voltage output for use with electrical measuring instruments and electrical protective devices.

Electronic current transformers use current sensors (current transformers, Hall effect sensors, air-core coils (Rogowski) for example) and/or optical arrangements and provide an analogue voltage output at the secondary converter. The electronic current transformer may include the secondary signal cable.

C.2 Mathematical description of secondary output

For $t \geq t_{dr} - \varphi_{0r}/(2\pi f)$ the secondary voltage can be described as follows:

$$u_s(t) = U_{ssc}\sqrt{2}\,.\sin(2\pi.f.t + \varphi_s) + U_{sdc}(t) + u_{sres}(t);$$

where

U_{ssc} is the r.m.s. value of the symmetrical component of secondary voltage;

U_{sdc} is the secondary direct voltage including the exponential component;

u_{sres} is the secondary residual voltage including harmonic and subharmonic components;

f is the fundamental frequency;

φ_s is the secondary phase displacement;

t is the instantaneous value of the time.

t_{dr} is the rated delay time.

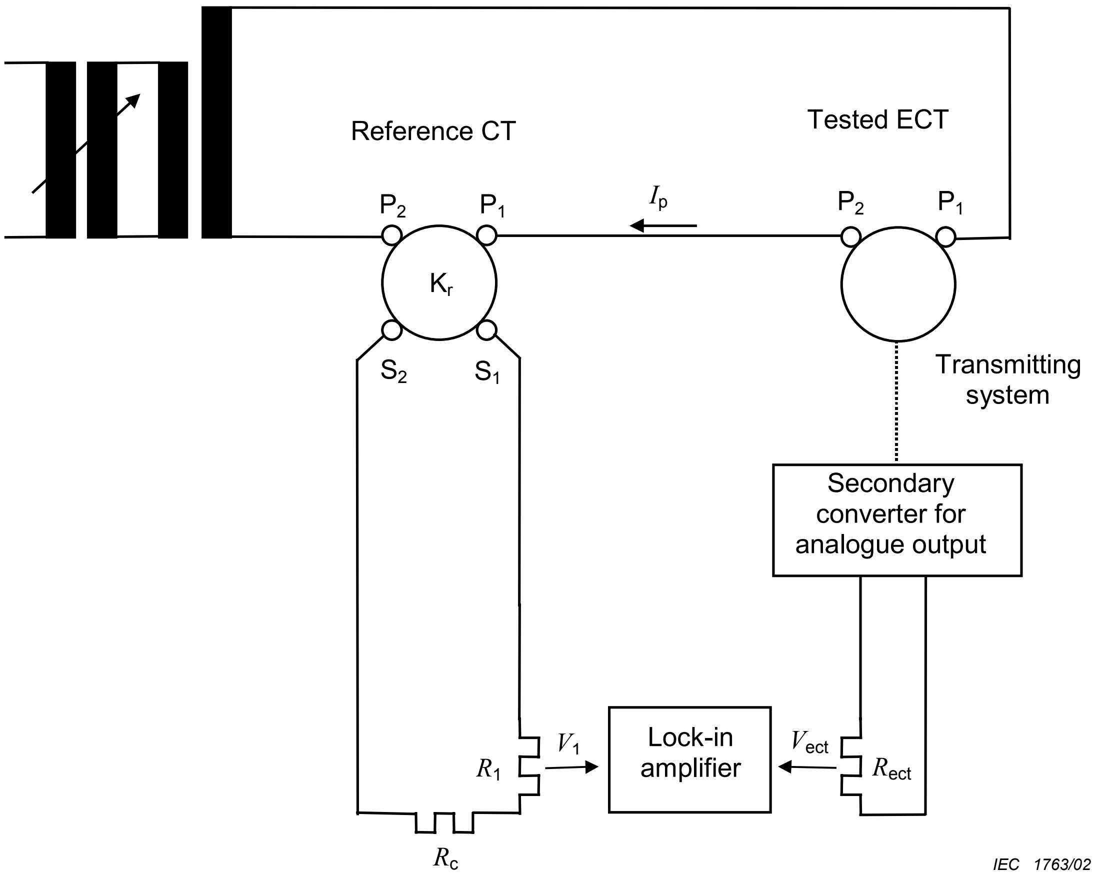
C.3 Secondary direct voltage offset (U_{sdc0})

The d.c. offset voltage is a general characteristic of electrical devices, which is caused by the need of biasing electrical components. Per definition it is measured at the output of the device in the case of an input signal of zero. Normally the offset voltage can be seen as independent of the signal as well as of the auxiliary power supply and therefore as an additive component of the output signal.

A special situation may occur if the power supply is not independent of the input signal as in the case where the power supply of the primary converter is derived from the primary current itself. In this case a stable supply and, as a result, a stable offset voltage is only achieved if the primary current is higher than wake-up current. Beneath this minimum primary current, especially in the case of zero, the offset voltage may change its value.

This special case should be discussed between manufacturer and purchaser to find a sufficient specification of U_{sdc0}. A proposal can be given in specifying the minimum primary current above which the U_{sdc0} is within the above-mentioned definition, for example, U_{sdc0} = 5 mV for I_p > 0,1 I_{pr}.

C.4 Test circuit for accuracy measurements in steady state



Key

K_r	Rated transformation ratio of reference CT
V_1	Voltage at the input of the lock-in amplifier
R_1	Burden used to adjust the voltage at the input of the lock-in amplifier
R_1 + R_c	Rated secondary burden of reference CT
V_{ect}	Secondary voltage for ECT with analogue output
R_{ect}	Rated secondary burden of ECT

R_1 and R_{ect} are required to be high accuracy burden

The voltage at the input of the lock-in amplifier shall be adjusted in nominal conditions. This voltage shall be equal to the nominal rated secondary voltage.

Figure C.1 – Test circuit for accuracy measurements in steady state

C.5 Information for low-power current transformers based on iron core coils

C.5.1 Scope

The iron-core-coil-based low-power current transformer (LPCT) represents a development of the classical inductive current transformer. Because of the low input power requirement of modern electricals, the LPCT can be dimensioned for high impedances R_b. As a consequence, a substantial characteristic of the classical inductive current transformer, its saturation in case of very high (displaced) primary currents, is improved and in this way the measuring range is expanded enormously.

C.5.2 Application

The reduction in total power consumption enables a saturation-free measuring of overcurrents up to short-circuit currents with high accuracy. Fully displaced short-circuit currents can be handled as well. In spite of the wider measuring range, LPCTs can be designed with smaller dimensions than comparable classical inductive current transformers. Consequently, a differentiation into measuring and protective instrument transformers becomes unnecessary since the entire field of application can be performed with a single (multi-purpose) current transformer.

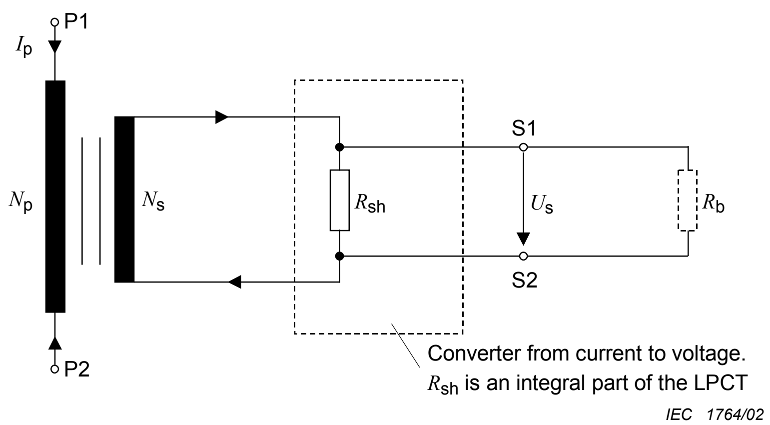
C.5.3 Principle

The LPCT consists of an inductive current transformer with primary winding, small core and a secondary winding with minimized losses which is connected to a shunt resistor R_{sh}. This resistor is an integral component of the LPCT and of great importance for the function and stability of the transformer. Therefore, the LPCT in principle supplies an output voltage.

The shunt resistor R_{sh} is designed in a way that the power consumption for the transformer is nearly zero. The secondary current I_s causes a voltage drop U_s across the shunt resistor which is proportional to the primary current in amplitude and phase. Furthermore, the transformer becomes the more ideal with respect to measuring range and accuracy the smaller the secondary power requirement of burden and internal losses becomes.

The function of the LPCT can be described as follows:

where R_{sh} for example, is designed in a way, that U_{smax} corresponds with I_{th}

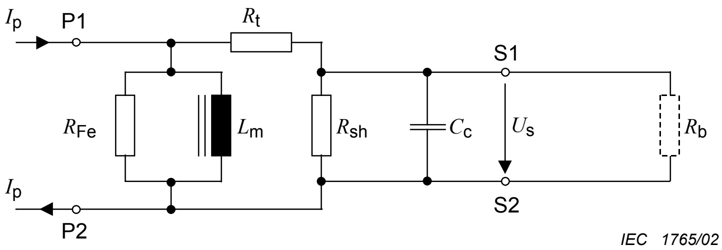


$$U_s = R_{sh} \cdot \frac{N_p}{N_s} \cdot I_p \text{ and}$$

$$I_p = K_R \cdot U_S \text{ with}$$

$$K_R = \frac{1}{R_{sh}} \cdot \frac{N_S}{N_P}$$

Figure C.2 – Iron-core-coil transformer



Key

I_P	primary current
R_{Fe}	equivalent iron loss resistor
L_m	equivalent magnetizing inductance
R_t	total resistance of secondary winding and wiring
R_{sh}	shunt resistor (converter from current to voltage)
C_C	equivalent capacitance of the cable
$U_S(t)$	secondary voltage
R_b	burden in ohms
P1, P2	primary terminals
S1, S2	secondary terminals

Figure C.3 – Equivalent circuit of the iron-core current transformer with voltage output

C.5.4 Output characteristics

The ratio of the classical current transformer (as standardized in IEC 60044-1) usually relates to the rated primary current. Because of the ability of the LPCT to handle high currents without saturation, it is more reasonable to relate the measurement range onto the maximum expected current of the network.

C.6 General information for stand-alone air-core coils and air-core coils

C.6.1 Scope

In high-voltage networks, Rogowski-type sensors are increasingly used for protective relay applications. Known since 1912, the Rogowski coil has an output which is proportional to the derivative of the current.

In the high-voltage application, the integration of the output of the sensor is not always performed at the coil itself, which can be electricals free, but rather in the relay, leading to cost reductions.

This annex recalls the principle of a stand-alone air-core coil and shows the derivative form of its output. Apart from this peculiar point, the other characteristics of the air-core coil (temperature behaviour, EMC, insulation requirement) are in accordance with this standard.

C.6.2 Principle

In an air-core coil, the secondary is wound on a non-magnetic former (see figure C.4). The absence of ferromagnetic material gives this sensor good linearity performance, which means no saturation, and hysteresis-free behaviour. As a consequence, air-core coils have good steady-state behaviour and transient response.

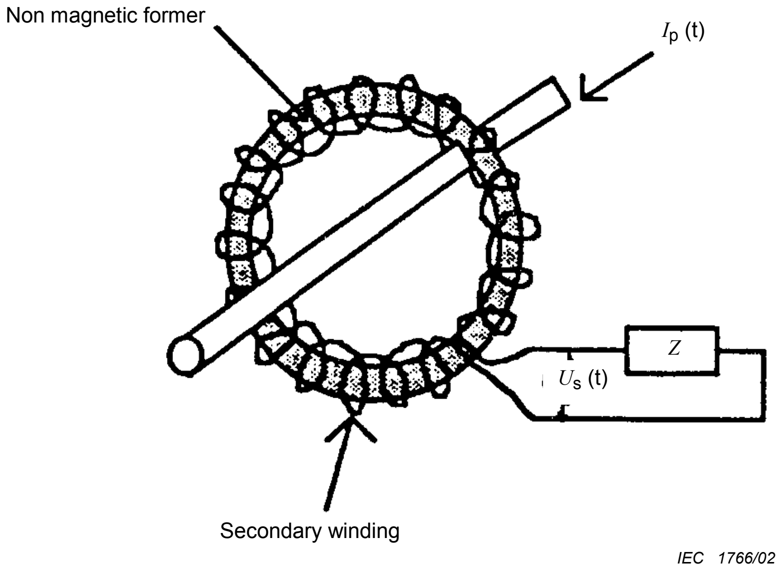


Figure C.4 – Stand-alone air-core coil

The Ampere theorem, when applied to an air-core coil, shows that the output voltage of the coil, when loaded by a high impedance Z, is a function of the primary current $I_P(t)$ going through the coil.

C.6.2.1 For ring core

a) Approximate equation for non-specified cross-section

$$e(t) \approx \mu_0 \cdot N \cdot A \cdot \frac{\partial i_p(t)}{\partial t}$$

b) Equation for rectangular cross-section

$$e(t) = \frac{m_0 \cdot N_w \cdot h}{2p} \cdot \ln \frac{ra}{ri} \cdot \frac{\partial i_p(t)}{\partial t}$$

where

μ_0 is the permeability of free space = $4\pi \cdot 10^{-7} \left[\frac{Vs}{Am} \right]$

N is the turn density [turns/m]

A is the single turn area [m²]

2ra is the outside diameter [m]

2ri is the inside diameter [m]

h is the height [m]

N_w is the turns of the ring air core

$e(t)$ is the output voltage of the air-core coil [V] with low burden $R_b \to \infty$

With the abbreviation

$$M = \mu_0 \cdot \frac{N_w \cdot h}{2\pi} \cdot \ln \frac{ra}{ri} \approx \mu_0 \cdot N \cdot A$$

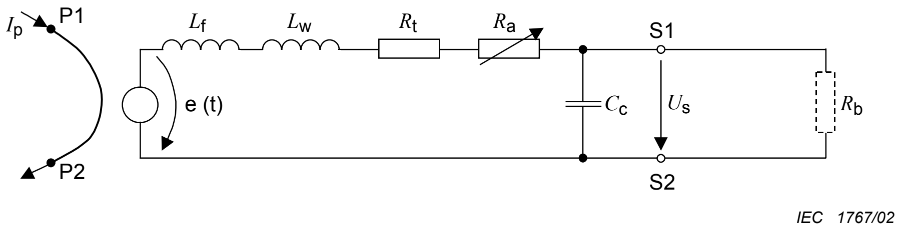
the output voltage of an air core coil is

$e(t) = \frac{M \cdot \partial i_p(t)}{\partial t}$ or for sinusoidal current under steady-state condition:

$$\boxed{\underline{E} = M \cdot j \cdot \omega \cdot \underline{I}_p}$$

C.6.2.2 Equivalent circuit

Figure C.5 shows the equivalent diagram of the air-core coil.



Key

I_P	primary current
$e(t)$	electromotive force of the air core coil
L_f	leakage inductance of secondary winding
L	$L_f + L_w$
L_w	wiring inductance
R_t	total resistance of secondary winding + wiring
$U_s(t)$	output voltage to be calibrated
R_a	calibration resistor (optional)
Z	load impedance or
R_b	load impedance with power factor 1
C_C	equivalent capacitance of the cable
P1, P2	primary terminals
S1, S2	secondary terminals

Figure C.5 – Equivalent circuit of stand-alone air-core current transformer with voltage output

The resistor R_a, which is optional, is used for calibration purposes. A correction factor mentioned on the rating plate can also be used. The resistor R_a or the correction factor compensates manufacturing tolerances on winding support dimensions and on the value of the number of turns. They also enable interchangeability between sensors and electricals.

The basis of the following equations is the equivalent circuit in figure C.5:

$$\underline{E} = j\varpi \cdot M \cdot \underline{I}_p$$

$$\underline{U}_S = \frac{R_b}{R_t + R_a + R_b + j\omega L} \cdot \underline{E}$$

$$\underline{U}_S = \frac{R_b}{R_t + R_a + R_b + j\omega L} \cdot j\omega \cdot M \cdot \underline{I}_p$$

for $R_b \rightarrow \infty$

$$\underline{U}_S = \underline{E} = j\omega \cdot M \cdot \underline{I}_p \qquad \underline{I}_p = -j \frac{\underline{E}_S}{\omega \cdot M}$$

C.6.2.3 Phasor diagram

$$\underline{U}_S\left(1+\frac{R_t+R_a}{R_b}+\frac{j\omega L}{R_b}\right)=\underline{E} \quad \rightarrow \quad \frac{\underline{U}_S}{\omega\cdot M}\cdot\left(1+\frac{R_t+R_a}{R_b}+\frac{j\omega\cdot L}{R_b}\right)=\underline{\frac{E}{\omega\cdot M}=\left|I_p\right|}$$

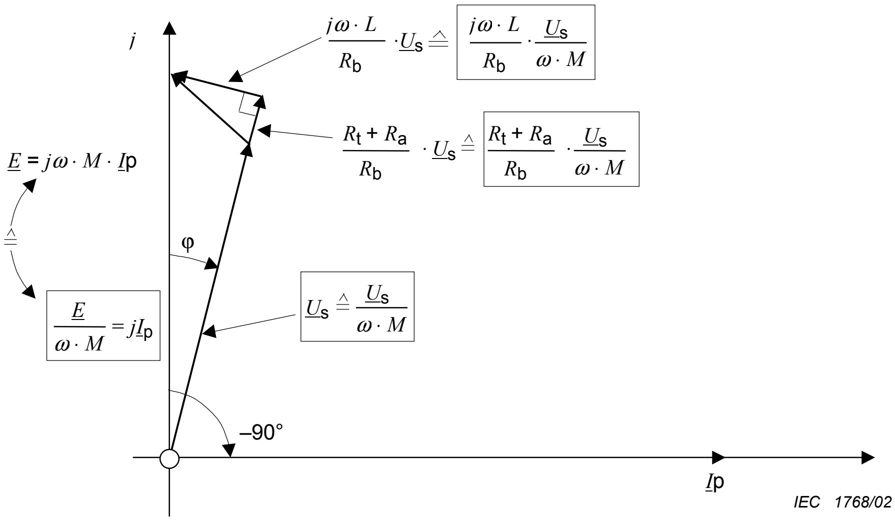


Figure C.6 – Phasor diagram – Stand-alone air-core coil

Phase-displacement φ:

$$\tan\varphi=-\frac{\omega L}{R_t+R_a+R_b}\approx-\frac{\omega L}{R_b}$$

$$\varphi = -\arctan\frac{\omega\cdot L}{R_t+R_a+R_b}\approx-\arctan\frac{\omega\cdot L}{R_b}$$

$$\text{Error: } \underline{\varepsilon}=\frac{\underline{U}_S-\underline{E}}{\underline{E}}$$

$$\left|\underline{\varepsilon}\right|=\frac{\sqrt{(R_t+R_a)^2+(\omega L)^2}}{\sqrt{(R_t+R_a+R_b)^2+(\omega L)^2}}$$

or out the figure

$$\varepsilon\approx\frac{(R_t+R_a)\cdot\frac{\underline{U}_s}{R_b}}{\underline{E}}=\frac{R_t+R_a}{R_a+R_t+R_b+j\omega L}$$

$$\left|\underline{\varepsilon}\right|=\frac{R_t+R_a}{\sqrt{(R_a+R_t+R_b)^2+(\omega L)^2}}\approx\frac{R_t+R_a}{R_b}$$

$$\left|\underline{\varepsilon}\right| = \frac{U_S - U_S\left(1 + \dfrac{R_t + R_a}{R_b}\right) \cdot (\cos\varphi)^{-1}}{U_S\left(1 + \dfrac{R_t + R_a}{R_b}\right) \cdot (\cos\varphi)^{-1}}$$

with cos φ = 1:

$$\left|\underline{\varepsilon}\right| = \frac{1}{\left(1 + \dfrac{R_t + R_a}{R_b}\right)} - 1$$

$$\left|\underline{\varepsilon}\right| = -\frac{R_t + R_a}{R_t + R_a + R_b} \approx -\frac{R_t + R_a}{R_b}$$

C.6.3 Guidance for measurements

In the practical application of the stand-alone air-core coil the integrator is part of the protection or measuring system.

To measure the instantaneous error of a stand-alone air-core coil an integrator must be used with an appropriate time-constant.

The input impedance of the integrator must be the rated impedance of the stand-alone air-core coil.

Annex D
(normative)

Frequency response and accuracy requirements on harmonics for electronic current and voltage transformer

D.1 General

The requirements in clause D.2 are relevant for all ECTs and EVTs. The requirements in clause D.3 are relevant for ECTs and EVTs involving digital data processing or transmission even if they have an analogue output. The accuracy requirements on harmonics in clause D.4 are only relevant if specified.

The accuracy test versus frequency on ECTs are presented in clause D.5.

D.2 General requirements

D.2.1 Normal service conditions of the network

Under normal service conditions the primary current I_p and the frequency f will remain between fixed limits due to the regulation of the network. For example:

$$0{,}2\ I_{pr} \leq I_p \leq 1{,}2.\ I_{pr} \qquad \text{and} \qquad 0{,}99\, f_r \leq f \leq 1{,}01\, f_r$$

Under normal service conditions, electronic current transformers designed for measurement purposes are used, more often than not, in combination with measurement electronic voltage transformers, i.e. for metering.

D.2.2 Abnormal service conditions of the network

Due to troubles on the network, the primary current and the frequency f can be significantly different from their rated values for instance

$$10\ I_{pr} \leq I_p \leq 50\ I_{pr} \qquad \text{and} \qquad 0{,}96\, f_r \leq f \leq 1{,}02\, f_r$$

Electronic current transformers used for protective purposes shall be designed to transmit correctly the image of the primary current during normal and abnormal conditions, in order to inform the protection relay of any critical change in the condition of the network.

Electronic current transformers used for metering purposes need not be designed to transmit correctly the image of the primary current during abnormal conditions. Nevertheless, it shall recover its rated performances shortly after the network has returned to normal conditions.

D.2.3 Requirements on signal-to-noise ratio

The requirements on noise are specified in 6.1.6.

The output of the electronic transformer can contain some perturbations added to the white noise common to all electrical systems. Such perturbation can be generated by the electronic transformer over a broad frequency band, and in the absence of any primary current. The source of these perturbations may be clock signals of the converters, multiplexer commutation noise, d.c./d.c. converter, commutation frequencies.

The test procedure is subject to an agreement between manufacturer and purchaser. The following procedure is recommended:

– with no primary signal, measure the output of the instrument transformer over the specified bandwidth (see D.2.4), using a spectrum analyser. This gives an image of the noise induced by the instrument transformer itself.

Another perturbation may come from distortion of the 50 Hz fundamental (creating its own harmonics), or from modulation of harmonics of the fundamental (creating interharmonics at the output of the secondary converter). The manufacturer shall give the user some indication about this source of perturbation. A simple measurement which would give an useful indication may be:

– with a ‘pure’ 50 Hz primary signal, measure the output of the electronic transformer over the specified bandwidth (see D.2.4), using a spectrum analyser for example. This would give an image of the harmonic distortion induced by the instrument transformer itself.

D.2.4 Bandwidth requirements

The manufacturer shall give the curve of the transfer function of the transformer, which will give an overall view of the frequency performances of the electronic transformer.

For a transformer involving digital data transmission, the manufacturer shall specify the maximum frequency which can be measured without aliasing. This frequency is called f_a. It is the maximum frequency the transformer can possibly measure and correctly transmit. For transformers with a digital output f_a is usually half the output data rate used. The transfer function shall be given up to at least twice f_a (for example, up to the data rate).

D.2.5 Other considerations

When power is applied to electronic units of the electronic transformer, start-up transient may produce large output signals unrelated to any power system output. The same situation may occur at shutdown of the system. These spurious outputs are quite normal for an electronic system. Anyway, if mishandled by the relays, they could lead to misoperations.

The user shall be aware of that when designing its control system.

For electronic transformers with a digital output, this situation does not create any problem with the relays because the self-diagnosis information contained in the digital frames indicate non-valid data in such case.

For electronic transformers with an analogue output the following simple precautions are recommended:

– the manufacturer shall make the spurious outputs following start-up and shutdowns as small as possible;

– the electronic transformer shall be powered up before its corresponding relays are energized.

Filters included in the transformer may also yield over- or undershoot responses, or possibly damped high-frequency behaviour to abnormal conditions, such as fault on the line and disconnector switches. These errors, if they happen, may lead to misoperation of high-speed relays. Furthermore, difference of transient response of electronic transformers may lead to misoperations in busbar differential protection (wideband high-speed differential schemes).

A good way to check that the electronic transformer behaves correctly in these situations is to submit it to disconnector switches test or short-circuit test with full asymmetry, and check its output during switching.

NOTE The same problem arises with conventional transformers which often show resonance or ferro-resonance: their transfer curve is not flat and their response to fast transient may be complex.

D.3 Requirements on ECTs and EVTs involving digital data transmission or processing

Note that the following requirements are relevant for both transformers with digital and with analogue output if they somehow involve digital data transmission or processing. The type test is described in D.5.2

D.3.1 Requirements on the anti-aliasing filter

Digital data transmission limits the bandwidth (f_a, see D.2.4) to half the digital sampling or data rate used. If different data rates along the transmission path are used, the lowest frequency is the limiting factor. Frequencies above f_a are mirrored to frequencies below f_a. From the point of view of accuracy, the most critical frequencies are those mapped on f_r.
The first frequency which is mapped on f_r is $2\,f_a - f_r$.

Hence, a so-called anti-aliasing filter shall be used and it shall fulfil the following requirement:

Attenuation for $f \geq 2\,f_a - f_r$ shall be ≥ 40 dB

Usually f_a is half the data rate f_{dr} ($f_a = 2\,f_{dr}$). If f_a or $2\,f_a - f_r$ is not known, it can be found by doing a frequency sweep of the primary signal.

The attenuation is calculated according to the following formula:

$$\text{Attenuation} = 20 \cdot \log \frac{I_p \cdot I_{sr}}{I_s \cdot I_{pr}} \quad \text{dB}$$

where

I_p is the r.m.s. value of primary current at frequency f, with $f \geq 2\,f_a - f_r$

I_s is the r.m.s. value of secondary output at the mirrored frequency, that is, at $2\,f_a - f$;

I_{pr} is the rated primary current;

I_{sr} is the rated secondary output.

For EVT replace current I by voltage U

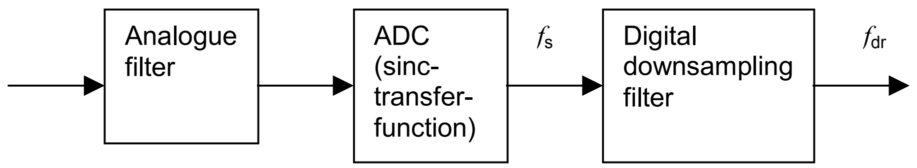
EXAMPLE:

For a data rate f_{dr} = 2 400 Hz and f_r = 50 Hz we get f_a = 1 200 Hz, $2\,f_a - f_r$ = 2 350 Hz.

Even if there is 10 % of I_{pr} at 2 350 Hz, this will only cause a measurement error at f_r which has to be smaller than 0,1 %.

D.3.2 Examples for anti-aliasing filters

The figure D.1 shows an example of a digital data acquisition system.



IEC 1769/02

f_s sampling rate

f_{dr} data rate

Figure D.1 – Digital data acquisition system

Usually f_s is larger than f_{dr}. In this case f_a is equal to f_{dr} / 2, otherwise f_a is equal to f_s / 2.

If the sampling frequency f_s is equal to the data rate f_{dr} no digital filter is necessary. In this case analogue Bessel filters are recommended with, for example,

- 4th order
- cut-off frequency f_c = (f_{dr})/3
- transfer function (Laplace notation):

$$\mathrm{bessel4}(p) := \left[\frac{1}{(1+0.7742p+0.3889p\cdot p)\cdot(1+1.3396p+0.4889p\cdot p)}\right]$$

(where p = j*f/f_c)

The advantages of such a filter are:

- excellent transient response (no overshoot, short settling time)
- reasonable attenuation for frequencies higher than the data rate
- constant group delay over a wide bandwidth, which means that phase displacement introduced by this filter is a linear function of frequency up to f_c (approximately). The influence of the filter on phase displacement is the same as a pure delay included in the transmission system. Therefore, this influence on phase displacement can be neglected provided that its equivalent delay time is included in the rated delay time of the ECT.

The equivalent delay time of the Bessel filter is equal to $\frac{1.01}{\text{Data rate}}$

Oversampling and the usage of digital filters brings significant advantages, like

- simple analogue input filter;
- fewer problems with tolerances or temperature drift of analogue components.

For digital filtering FIR filters are recommended, since they have a perfectly constant group delay and a good transient response. To design the filter the Remez exchange algorithm (or Parks-McClellan equi-ripple algorithm) is recommended.

If IIR filters are used Bessel filters are recommended (for example, the one above) transferred into the digital domain using the matched-z transformation to ensure maximum phase linearity and constant group delay. The usage of the common bilinear transformation is not recommended.

D.4 Accuracy requirements on harmonics

NOTE The different accuracy classes defined in the following clauses shall apply to both ECT and EVT.

D.4.1 Common accuracy classes

Due to the use of specific devices (non-linear loads, FACTS, railway,) harmonics can be generated on the network. The amount of harmonics depends on the network and the voltage level. Harmonics are of interest for metering, quality and protection purposes. Accuracy classes to each specific need are given. The accuracy requirements on electronic transformers with a digital output are the same as those of the transformers with an analogue output. The type test is described in D.5.1.

D.4.1.1 Power metering

Accuracy class	Percentage current (ratio) error (+/–) at harmonics shown below				Phase displacement (+/–) at harmonics shown below							
					Degrees				Centiradians			
	2nd to 4th harmonic	5th and 6th harmonic	7th to 9th harmonic	10th to 13th harmonic	2nd to 4th	5th and 6th	7th to 9th	10th to 13th	2nd to 4th	5th and 6th	7th to 9th	10th to 13th
0,1	1 %	2 %	4 %	8 %	1	2	4	8	1,8	3,5	7	14
0,2	2 %	4 %	8 %	16 %	2	4	8	16	3,5	7	14	28
0,5	5 %	10 %	20 %	20 %	5	10	20	20	9	18	35	35
1	10 %	20 %	20 %	20 %	10	20	20	20	18	35	35	35

With these requirements, the contribution of harmonics measurement errors would add roughly 15 %, in the worst case, on the theoretical error of the corresponding power metering class accuracy (i.e. for a class 0.2 CT with a class 0.2 VT, the accuracy of corresponding power metering class is 0,4 for the energy transported by the 50 Hz wave. Since energy transported by harmonics is also measured, the total error on energy transported by the fundamental and its harmonics would be 0,4 % + 0,15*0,40 % = 0,46 %). Such a small error can be accepted.

D.4.1.2 Quality metering

According to EN 50160 and IEC 61000-4-7, for such purposes, harmonics up to the 40th order (in some cases even to the 50th order) are measured. IEC 61000-4-7 specifies that the relative error (related to the measured value) shall not exceed 5 %. If measurements of phase angles have to be performed additionally, the respective error shall not exceed 5°.

Accuracy class	Percentage current (ratio) error (+/–) at harmonics shown below		Phase error (+/–) at harmonics shown below			
			Degrees		Centiradians	
Special quality metering	1st to 2nd harmonic	3rd to 50th harmonic	1st to 2nd harmonic	3rd to 50 harmonic	1st to 2nd harmonic	3rd to 50th harmonic
	1 %	5 %	1	5	1,8	9

D.4.1.3 Protection for usual purposes

For usual applications, harmonics up to the 5th rank can be relevant. 16,66 Hz or 20 Hz are relevant to cover phenomena due to railway power frequency.

Accuracy class	Percentage current (ratio) error (+/–) at harmonics shown below		Phase error (+/–) at harmonics shown below			
			Degrees		Centiradians	
	1/3rd (16,7 or 20 Hz only) harmonic	2nd to 5th harmonic	1/3rd (16,7 or 20 Hz only) harmonic	2nd to 5th harmonic	1/3rd (16,7 or 20 Hz only) harmonic	2nd to 5th harmonic
All protection classes XPXX	10 %	10 %	10	10	18	18

D.4.1.4 Comparison with conventional CTs and VTs

The quality metering class requires a performance which cannot be achieved by any traditional transformer: VT show a worse behaviour in frequency that CT. Moreover, some transformers such as CVT are tuned on a very narrow bandwidth and could not even reach the requirements of the protection or metering class (D.4.1.2 and D.4.1.3).

D.4.2 Special accuracy classes

D.4.2.1 Special high bandwidth protection accuracy class

For some applications like travelling-wave relays, there is a need for frequencies as high as 500 kHz. The use of relays based on travelling-wave analysis seems a promising solution for very accurate fault location. For instance, new devices based on such principles claims to be much more accurate than conventional reactance fault locators. Anyway, such relays are not quite operational at the moment, and this field is still under development, but CT and VT suitable for these relays should have a very large frequency range, hence the "extended" range, up to 500 kHz.

Accuracy class	Maximum peak instantaneous error (+/–) at frequencies shown below
Special high bandwidth protection	From f_r to 50 k Hz
	10 %

The bandwidth (–3 dB cut-off frequency) of the electronic transformer shall be 500 kHz, at least.

NOTE 1 Travelling wave relays are designed specially for this purpose and are very specific (very large bandwidth, etc.). Usually the manufacturer supplies the relay/fault locator together with the current/voltage sensors and their associated electronics. In fact, many such devices act just like disturbance recorders, storing the data during the fault and doing some post-processing afterwards to locate the default.

NOTE 2 Due to its high bandwidth, this class is not suitable for the standardized digital outputs.

D.4.2.2 Special d.c. protection accuracy class for electronic voltage transformers

Electronic voltage transformers should be able to give some indication on the amount of d.c. voltage on the line, in case of trapped charges for instance. In such case the user does not want a very accurate image of the voltage; the important information is the polarity of the residual voltage on the line.

For this special class, all the requirements on harmonics detailed in D.3.1.3 shall also apply.

Additional requirement

Accuracy class	Maximum peak instantaneous error (+/–) at frequencies shown below
Special d.c. protection (for EVT)	from 0 Hz (d.c.) to f_r
	10 %

NOTE Care should be taken, with an analogue output, that the input transformers of the connected relays do not saturate, since the EVT may not discharge the line (constant DC-output for the EVT). Of course, with the digital output, there is no such problem.

D.5 Test arrangement and test circuit

D.5.1 Test for accuracy versus harmonics

The test circuit can be adapted from the one defined in B.6.2 or clause C.4.

For the ECT test, the test current can be supplied by a power amplifier. As reference CT a coaxial shunt as commonly used for short-circuit tests is recommended.

For the EVT test, the use of existing devices is recommended: signalling voltages used for the transmission of data in the public distribution system are sinusoidal waves covering the range from 110 Hz to 148,5 kHz, with a magnitude suitable for this purpose (see EN 50160 for more details).

For each specified harmonic frequency, a primary current/voltage according to the following tables is applied. For each frequency amplitude and phase error are calculated by comparing the reference with the transformer under test according to the well known procedures (see Annex B for digital output).

Test currents and voltages for the common accuracy classes (D.4.1)

Magnitude of the harmonic currents (% of I_{pr}) or voltages (% of U_{pn})	
2nd to 5th harmonic	**6th harmonic and upwards**
10 %	5 %

Test currents and voltages for special accuracy classes (D.4.2)

Accuracy class	**Magnitude of currents(or voltage) for accuracy tests versus transient conditions (% of I_{pr}) or (% of U_{pn})**			
	0 Hz, d.c.	**DC to 0,99*f_r**	**1,01*f_r to the frequency of the 5th harmonic**	**From the frequency of the 5th harmonic to 250 k Hz**
Special high bandwidth	–	20 %	10 %	5 %
Special d.c. (for EVT)	100 %	20 %	20 %	–

D.5.2 Type test for proper anti-aliasing

A primary signal with frequency 2 $f_a - f_r$ is applied. By measuring the frequency of the output signal it shall be checked whether this input frequency is really mirrored on f_r.

The attenuation in calculated and the limit given in D.3.1 is checked.

The magnitude of the primary signal shall be at least 1 % of the rated primary signal.

Note that due to the fact that aliasing occurs the input signal and the output signal do not have the same frequencies. Therefore test arrangements using bridge configurations cannot be used. The easiest way to do the test is to calculate or measure the r.m.s. values for input and output separately using a digital system or a simple multimeter for analogue

Annex E
(informative)

Graph explaining the accuracy requirements

The graph shows the accuracy limits of a multipurpose ECT (i.e. an ECT which obeys measuring and protective requirements), which is also specified for transient response.

The marks show at which primary current the accuracy is actually tested during type tests. The lines show in which primary current range the accuracy is supposed to be maintained.

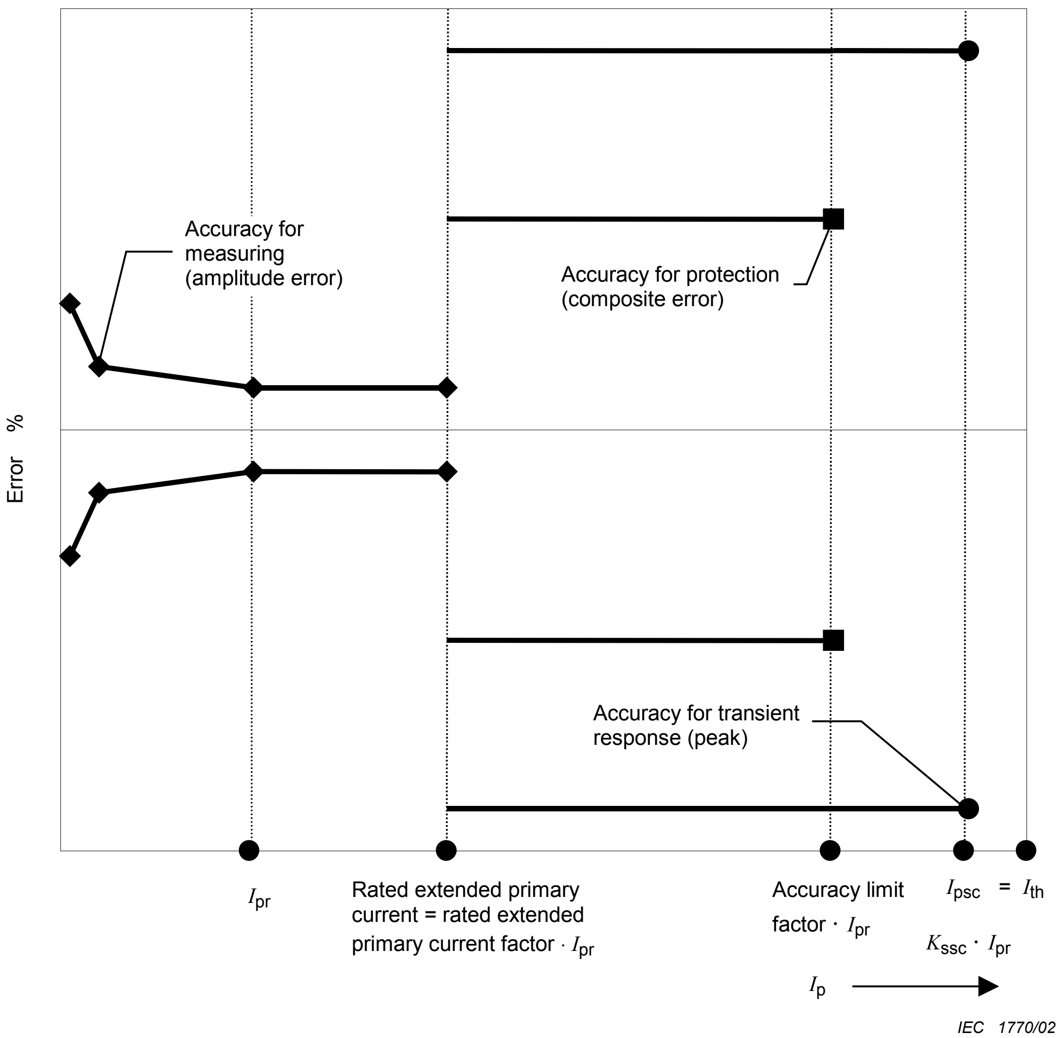


Figure E.1 – Accuracy limits of a multi-purpose ECT

If an application requires a small deviation between the phase and/or amplitude error between the ECTs on different phases, the user shall select a set of electronic current transformers with similar calibration data, as is also done with conventional transformers. The calibration data is available from routine testing. A special test is not needed.

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ISBN 2-8318-6445-3

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Typeset and printed by the IEC Central Office
GENEVA, SWITZERLAND