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Edition 1.0 2016-04

INTERNATIONAL STANDARD

Instrument transformers –
Part 6: Additional general requirements for low-power instrument transformers

colour inside

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INSTRUMENT TRANSFORMERS –

Part 6: Additional general requirements for low-power instrument transformers

FOREWORD

International Standard IEC 61869-6 has been prepared by IEC technical committee 38: Instrument transformers.

This first edition of IEC 61869-6 cancels and replaces the relevant parts of IEC 60044-7, published in 1999, and of IEC 60044-8, published in 2002[1].

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1 IEC 60044-7 and IEC 60044-8 will eventually be replaced by the IEC 61869 series, but until all the relevant parts will be published, these two standards are still in force.

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

FDIS	Report on voting
38/501/FDIS	38/507/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.

A list of all parts in the IEC 61869 series, published under the general title *Instrument transformers*, can be found on the IEC website.

This Part 6 is to be read in conjunction with, and is based on, IEC 61869-1:2007, *General Requirements* – however, the reader is encouraged to use its most recent edition.

This Part 6 follows the structure of IEC 61869-1:2007 and supplements or modifies its corresponding clauses.

When a particular clause/subclause of Part 1 is not mentioned in this Part 6, that clause/subclause applies. When this standard states "addition", "modification" or "replacement", the relevant text in Part 1 is to be adapted accordingly.

For additional clauses, subclauses, figures, tables, annexes or notes, the following numbering system is used:

– clauses, subclauses, tables, figures and notes that are numbered starting from 601 are additional to those in Part 1;
– additional annexes are lettered 6A, 6B, etc.

An overview of the planned set of standards at the date of publication of this document is given below. The updated list of standards issued by IEC TC 38 is available at the website: www.iec.ch.

PRODUCT FAMILY STANDARDS		PRODUCT STANDARD IEC	PRODUCTS	OLD STANDARD IEC
IEC 61869-1 GENERAL REQUIREMENTS FOR INSTRUMENT TRANSFORMERS		**61869-2**	ADDITIONAL REQUIREMENTS FOR CURRENT TRANSFORMERS	60044-1 60044-6
		61869-3	ADDITIONAL REQUIREMENTS FOR INDUCTIVE VOLTAGE TRANSFORMERS	60044-2
		61869-4	ADDITIONAL REQUIREMENTS FOR COMBINED TRANSFORMERS	60044-3
		61869-5	ADDITIONAL REQUIREMENTS FOR CAPACITOR VOLTAGE TRANSFORMERS	60044-5
	IEC 61869-6 ADDITIONAL GENERAL REQUIREMENTS FOR LOW-POWER INSTRUMENT TRANSFORMERS	**61869-7**	ADDITIONAL REQUIREMENTS FOR ELECTRONIC VOLTAGE TRANSFORMERS	60044-7
		61869-8	ADDITIONAL REQUIREMENTS FOR ELECTRONIC CURRENT TRANSFORMERS	60044-8
		61869-9	DIGITAL INTERFACE FOR INSTRUMENT TRANSFORMERS	
		61869-10	ADDITIONAL REQUIREMENTS FOR LOW-POWER PASSIVE CURRENT TRANSFORMERS	
		61869-11	ADDITIONAL REQUIREMENTS FOR LOW-POWER PASSIVE VOLTAGE TRANSFORMERS	60044-7
		61869-12	ADDITIONAL REQUIREMENTS FOR COMBINED ELECTRONIC INSTRUMENT TRANSFORMER OR COMBINED PASSIVE TRANSFORMERS	
		61869-13	STAND ALONE MERGING UNIT	
		61869-14	ADDITIONAL REQUIREMENTS FOR CURRENT TRANSFORMERS FOR DC APPLICATIONS	
		61869-15	ADDITIONAL REQUIREMENTS FOR DC VOLTAGE TRANSFORMERS FOR DC APPLICATIONS	

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

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

A bilingual version of this publication may be issued at a later date.

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

INSTRUMENT TRANSFORMERS –

Part 6: Additional general requirements for low-power instrument transformers

1 Scope

This part of IEC 61869 is a product family standard and covers only additional general requirements for low-power instrument transformers (LPIT) used for a.c. applications having rated frequencies from 15 Hz to 100 Hz covering MV, HV and EHV or used for d.c. applications. This product standard is based on IEC 61869-1:2007, in addition to the relevant product specific standard.

This part of IEC 61869 does not cover the specification for the digital output format of instrument transformers.

This part of IEC 61869 defines the errors in case of analogue or digital output. The other characteristics of the digital interface for instrument transformers are standardised in IEC 61869-9 as an application of the standards, the IEC 61850 series, which details layered substation communication architecture.

This part of IEC 61869 considers additional requirements concerning bandwidth. The accuracy requirements on harmonics and requirements for the anti-aliasing filter are given in the normative Annex 6A.4.

The general block diagram of single-phase LPITs is given in Figure 601.

According to the technology, it is not absolutely necessary that all parts described in Figure 601 are included in the instrument transformer.

As an example, for low-power passive transformers (LPITs without active electronic components) the blocks are composed only with passive components and there is no power supply.

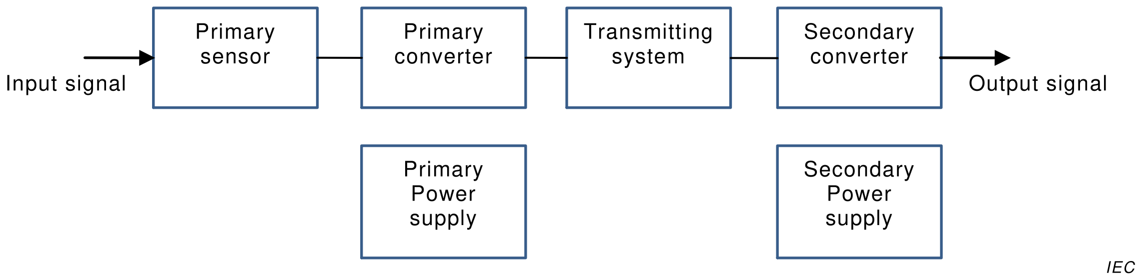


Figure 601 – General block diagram of a single-phase LPIT

2 Normative reference

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

Clause 2 of IEC 61869-1:2007 is applicable with the following additions:

IEC 60068-2-6:2007, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60255-27:2013, *Measuring relays and protection equipment – Part 27: Product safety requirements*

IEC 60603-7-1:2011, *Connectors for electronic equipment – Part 7-1: Detail specification for 8-way, shielded, free and fixed connectors*

IEC 60794-2:2002, *Optical fibre cables – Part 2: Indoor cables – Sectional specification*

IEC 60794-3:2014, *Optical fibre cables – Part 3: Outdoor cables – Sectional specification*

IEC 60812:2006, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*

IEC 61000-4-1:2006, *Electromagnetic compatibility (EMC) – Part 4-1: Testing and measurement techniques – Overview of IEC 61000-4 series*

IEC 61000-4-2:2008, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3:2006, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*
IEC 61000-4-3:2006/AMD1:2007
IEC 61000-4-3:2006/AMD2:2010

IEC 61000-4-4:2012, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*

IEC 61000-4-5:2014, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-6:2013, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-7:2002, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*
IEC 61000-4-7:2002/AMD1:2008

IEC 61000-4-8:2009, *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test*

IEC 61000-4-9:1993, *Electromagnetic compatibility (EMC) – Part 4-9: Testing and measurement techniques – Section 9: Pulse magnetic field immunity test*
IEC 61000-4-9:1993/AMD1:2000

IEC 61000-4-10:1993, *Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques –Section 10: Damped oscillatory magnetic field immunity test. Basic EMC Publication*
IEC 61000-4-10:1993/AMD1:2000

IEC 61000-4-11:2004, *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests*

IEC 61000-4-13:2002, *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 61000-4-13:2002/AMD1:2009

IEC 61000-4-16:1998, *Electromagnetic compatibility (EMC) – Part 4-16: Testing and measurement techniques – Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz*
IEC 61000-4-16:1998/AMD1:2001
IEC 61000-4-16:1998/AMD2:2009

IEC 61000-4-18:2006, *Electromagnetic compatibility (EMC) – Part 4-18: Testing and measurement techniques – Damped oscillatory wave immunity test*
IEC 61000-4-18:2006/AMD1:2010

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 61025:2006, *Fault tree analysis (FTA)*

IEC 61076-2-101:2012, *Connectors for electronic equipment – Product requirements – Part 2-101: Circular connectors – Detail specification for M12 connectors with screw-locking*

IEC TS 61850-2:2003, *Communication networks and systems in substations – Part 2: Glossary*

IEC 61850-7-4:2010, *Communication networks and systems for power utility automation – Part 7-4: Basic communication structure – Compatible logical node classes and data object classes*

IEC 61869-1:2007, *Instrument transformers – Part 1: General requirements*

IEC 61869-2:2012, *Instrument transformers – Part 2: Additional requirements for current transformers*

IEC 61869-3:2011, *Instrument transformers – Part 3: Additional requirements for inductive voltage transformers*

IEC TR 61869-103:2012, *Instrument transformers – Part 103: The use of instrument transformers for power quality measurement*

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

CISPR 11:2015, *Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement*

ISO/IEC/IEEE 21451-4:2010, *Information technology – Smart transducer interface for sensors and actuators – Part 4: Mixed-mode communication protocols and Transducer Electronic Data Sheet (TEDS) formats*

EN 50160:2010, *Voltage characteristics of electricity supplied by public distribution systems*

3 Terms and definitions

For the purposes of this document, the terms and definitions in IEC 61869-1:2007 apply, with the following modifications and additions.

3.1 General terms and definitions

3.1.601
low-power instrument transformer
LPIT
arrangement, consisting of one or more current or voltage transformer(s) which may be connected to transmitting systems and secondary converters, all intended to transmit a low-power analogue or digital output signal to measuring instruments, meters and protective or control devices or similar apparatus

EXAMPLE An arrangement consisting of three current sensors, three voltage sensors connected to one merging unit delivering one digital output is considered an LPIT.

Note 1 to entry: LPITs are commonly called non-conventional instrument transformers (NCIT).

Note 2 to entry: The output power produced by these devices is typically lower or equal to 1 VA.

Note 3 to entry: This note applies to the French language only.

3.1.602
low-power current transformer
LPCT
low-power instrument transformer for current measurement

Note 1 to entry: This note applies to the French language only.

3.1.603
low-power voltage transformer
LPVT
low-power instrument transformer for voltage measurement

Note 1 to entry: This note applies to the French language only.

3.1.604
measuring LPIT
LPIT intended to transmit an output signal to measuring instruments and meters

3.1.605
protective LPIT
LPIT intended to transmit an output signal to protective and control devices

3.1.606
multipurpose LPIT
LPIT intended for both measurement and protection applications

3.1.607
electronic LPIT
LPIT that includes active components

3.1.608
passive LPIT
LPIT that includes only passive components

3.1.609
input signal
signal corresponding to the current or to the voltage applied between the primary terminals of the LPIT

3.1.610
primary sensor
electrical, optical or other device intended to provide information about the input signal in order to transmit it to the secondary converter, either directly or by means of a primary converter

3.1.611
primary converter
electrical, optical or other arrangement that converts the signal coming from one or more primary sensors into a signal suitable for the transmitting system

3.1.612
primary power supply
auxiliary power supply to the primary converter and/or primary sensor

Note 1 to entry: Can be combined with secondary power supply (see 3.1.620).

3.1.613
transmitting system
short- or long-distance coupling arrangement between primary and secondary parts intended to transmit the signal

Note 1 to entry: Depending on the technology used, the transmitting system can also be used for power transmission.

3.1.614
secondary converter
arrangement that converts the signal transmitted through the transmitting system into a signal proportional to the input signal, to supply measuring instruments, meters and protective or control devices

Note 1 to entry: For analogue output, the secondary converter directly supplies measuring instruments, meters and protective or control devices. For digital output, the secondary converter is connected to a merging unit before supplying the secondary equipment.

3.1.615
logical device merging unit
logical device (in the meaning of IEC 61850-7-4) to do the time-coherent combination of logical nodes current transformer (TCTR) and/or logical nodes voltage transformer (TVTR) for building a standard digital output

3.1.616
merging unit
MU
physical device (IED according to IEC 61850-2) in which a logical device merging unit is implemented

Note 1 to entry: The merging unit can be part of one of the instrument transformers in the field or may be a separate unit, for example, in the control room.

Note 2 to entry: The inputs of the merging unit may be proprietary or standardized.

Note 3 to entry: This note applies to the French language only.

3.1.617
stand-alone merging unit
SAMU
merging unit with standardized inputs (analogue or digital)

EXAMPLE 1 SAMU can be used with instrument transformers for retrofit purposes.

EXAMPLE 2 Digital input of the stand-alone merging unit could be specified according to former IEC 60044-8 digital output or according to IEC 61869-9. This possibility ensures the backward compatibility between IEC 60044-8 and the new IEC 61869 series.

Note 1 to entry: This note applies to the French language only.

3.1.618
merging unit clock input
electrical or optical input of the merging unit that can be used to synchronize several merging units if required

3.1.619
merging unit power supply
auxiliary power supply of the merging unit

Note 1 to entry: A merging unit power supply can be combined with the secondary power supply (see 3.1.620).

3.1.620
secondary power supply
auxiliary power supply of the secondary converter

Note 1 to entry: A secondary power supply can be combined with primary power supply (see 3.1.612) or a power supply of other instrument transformers.

3.1.621
output signal
analogue or digital signal at the secondary terminals

Note 1 to entry: In an electrical steady-state condition, the output signal is defined by the following equation:

a) For an analogue output:

$$y_{\mathrm{s}}\,(t) = Y_{\mathrm{s}}\sqrt{2}\sin(2\pi f t + \varphi_{\mathrm{s}}) + Y_{\mathrm{sdc}} + y_{\mathrm{s\,res}}(t)$$

where

Y_{s}	is the r.m.s. value of secondary converter output, when $Y_{\mathrm{sdc}} + y_{\mathrm{s\,res}}(t) = 0$;
f	is the fundamental frequency;
φ_{s}	is the secondary phase;
Y_{sdc}	is the secondary direct signal;
$y_{\mathrm{s\,res}}(t)$	is the secondary residual signal including harmonic and subharmonic components;
t	is the instantaneous value of the time;
f, Y_{s}, φ_{s}	being constant for steady-state condition.

b) For a digital output:

$$y_{\mathrm{s}}\,(n) = Y_{\mathrm{s}}\sqrt{2}\sin(2\pi f t_n + \varphi_{\mathrm{s}}) + Y_{\mathrm{sdc}} + y_{\mathrm{s\,res}}(n)$$

where

y_{s}	is a digital number at the merging unit output representing the actual instantaneous value of the primary signal;
Y_{s}	is the r.m.s. value of a certain merging unit output, when $Y_{\mathrm{sdc}} + y_{\mathrm{s\,res}}(n) = 0$;
f	is the fundamental frequency;
φ_{s}	is the secondary phase;
Y_{sdc}	is the secondary direct output;

$y_{\mathrm{s\ res}}(n)$	is the secondary residual output including harmonic, sub-harmonic and inter-harmonic components;
n	is the data sample counter;
t_n	is the effective time where the primary signal (current or voltage) of the n[th] data set have been sampled;
f, Y_{s}, φ_{s}	being constant for steady-state condition.

Note 2 to entry: LPIT can exhibit specific characteristics as voltage offset, delay time, etc. Hence, while not present within IEC 61869-1:2007, IEC 61869-2, IEC 61869-3 and IEC 61869-5, the above equations are required for an accurate presentation of the requirements related to LPIT. The definitions of errors, while compatible with those of IEC 61869-2, IEC 61869-3 and IEC 61869-5, are also improved.

3.1.622
input signal in steady state condition
electrical signal at the primary terminals in steady state condition

Note 1 to entry: In a steady-state condition, the input signal is defined by the following equation

$$x_{\mathrm{p}}(t) = X_{\mathrm{p}}\sqrt{2}\sin(2\pi f t + \varphi_{\mathrm{p}}) + x_{\mathrm{p\ res}}(t)$$

where

X_{p}	is the r.m.s. value of primary input at the fundamental frequency when $x_{\mathrm{p\ res}}(t)=0$;
f	is the fundamental frequency;
φ_{p}	is the primary phase;
$x_{\mathrm{p\ res}}(t)$	is the primary residual input including harmonic, sub-harmonic and inter-harmonic components and primary direct current;
t	is the instantaneous value of the time;
f, X_{p}, φ_{p}	being constant for steady-state condition.

3.1.623
rated secondary output signal
$\boldsymbol{U}_{\mathbf{sr}}$
$\boldsymbol{Y}_{\mathbf{sr}}$
r.m.s. value of the component at rated frequency f_{r} of the secondary output on which the performance of the LPIT is based

3.1.624
secondary direct voltage offset
$\boldsymbol{U}_{\mathbf{sdco}}$
direct voltage component of the secondary output of a low power instrument transformer when $x_{\mathrm{p}}(t) = 0$

3.1.625
connecting point
point provided to connect electrical cables during site installation and test installation

Note 1 to entry: The connecting points are specified by the manufacturer.

3.1.626
low-voltage components
all electric or electrical components of an LPIT separated from the primary circuit at the full rated withstand voltage level

Note 1 to entry: Examples of low voltage components are the secondary converter, the merging unit, and the primary converter if placed at ground level.

3.1.627
wake-up time
delay time needed by some kind of LPIT to turn on after the primary current has been switched on, due to the fact that they are powered by the line current

Note 1 to entry: During this delay, the output of the LPIT is zero.

3.1.628
wake-up current
minimum value of the primary current necessary to wake up the LPIT (see 3.1.627)

3.2 Terms and definitions related to dielectric ratings and voltages

3.2.601
rated primary voltage
$U_{\mathbf{pr}}$
value of the primary voltage which appears in the designation of the LPVT and on which its performance is based

[SOURCE: IEC 60050-321:1986, 321-01-12, modified – The complement to term "of a voltage transformer" has been removed and, in the definition, "voltage transformer" has been replaced by "LPVT".]

3.2.602
transient response of an LPVT
response of the secondary output to a transient change of the primary voltage

Note 1 to entry: For example during short circuit or when reclosing with trapped charges.

3.2.603
voltages in transient conditions
input signal and output signal of a LPVT during transients in the network

Note 1 to entry: In the transient condition, primary and secondary voltages are defined as follows:

$$u_{\mathrm{p}}(t) = U_{\mathrm{p}}\sqrt{2}\sin(2\pi f t + \varphi_{\mathrm{p}}) + U_{\mathrm{p\,dc}}(t) + u_{\mathrm{p\,res}}(t)$$

$$u_{\mathrm{s}}(t) = U_{\mathrm{s}}\sqrt{2}\sin(2\pi f t + \varphi_{\mathrm{s}}) + U_{\mathrm{s\,dc}}(t) + u_{\mathrm{s\,res}}(t)$$

where U_{p} is the actual primary voltage.

Note 2 to entry: Transient conditions are induced by a sudden change of one or more parameters of the primary input equation given in 3.1.622.

3.3 Terms and definitions related to current ratings

3.3.601
rated primary current
$I_{\mathbf{pr}}$
value of the primary current which appears in the designation of the LPCT and on which its performance is based

[SOURCE: IEC 60050-321:1986, 321-01-11, modified – The complement to term "of a current transformer" has been removed and, in the definition, "current transformer" has been replaced by "LPCT".]

3.3.602
rated extended primary current
$I_{\mathbf{epr}}$
primary current up to which the same accuracy as the accuracy at the rated primary current is guaranteed, and which is not bigger than the rated continuous thermal current I_{cth}

3.3.603
rated extended primary current factor
$K_{\mathbf{pcr}}$
ratio of the rated extended primary current to the rated primary current

3.3.604
rated accuracy limit primary current
value of primary current up to which the LPCT will comply with the requirements for composite error

[SOURCE: IEC 60050-321:1986, 321-02-29, modified – The complement to term "of a protective current transformer" has been removed and, in the definition, "current transformer" has been replaced by "LPCT".]

3.3.605
rated short-time thermal current
$I_{\mathbf{th}}$
maximum value of the primary current, which an LPCT will withstand for a specified short time without suffering harmful effects

[SOURCE: IEC 60050-321:1986, 321-02-22, modified – A symbol has been added, and, in the definition "transformer" has been replaced by "LPCT" and “the secondary winding being short-circuited” has been deleted.]

3.3.606
rated dynamic current
$I_{\mathbf{dyn}}$
peak value of the primary current which an LPCT will withstand, without being damaged electrically or mechanically by the resulting electromagnetic forces

[SOURCE: IEC 60050-321:1986, 321-02-24, modified – A symbol has been added, and, in the definition "transformer" has been replaced by "LPCT" and “the secondary winding being short-circuited” has been deleted.]

3.3.607
rated continuous thermal current
$I_{\mathbf{cth}}$
value of the current which can be permitted to flow continuously in the primary terminals of an LPCT, the analogue secondary output being connected to the rated burden, without the temperature rise exceeding the values specified

[SOURCE: IEC 60050-321:1986, 321-02-25, modified – A symbol has been added, and, in the definition "primary winding" has been replaced by "primary terminals of an LPCT" and "secondary winding" by “the analogue secondary output”.]

3.3.608
rated primary short-circuit current
$I_{\mathbf{psc}}$
r.m.s. value of the a.c. component of a transient primary short-circuit current on which the accuracy performance of a LPCT is based

Note 1 to entry: While I_{th} is related to the thermal limit, I_{psc} is related to the accuracy limit. Usually, I_{psc} is smaller than I_{th}.

3.3.609
rated symmetrical short-circuit-current factor
$K_{\mathbf{ssc}}$
ratio of the rated primary short circuit current to the rated primary current I_{psc} and I_{pr}

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

3.3.610
specified primary time constant
T_p
specified value of the time constant of the d.c. component of the primary short-circuit current on which the transient performance of the LPCT is based

Note 1 to entry: An example is shown in Figure 602.

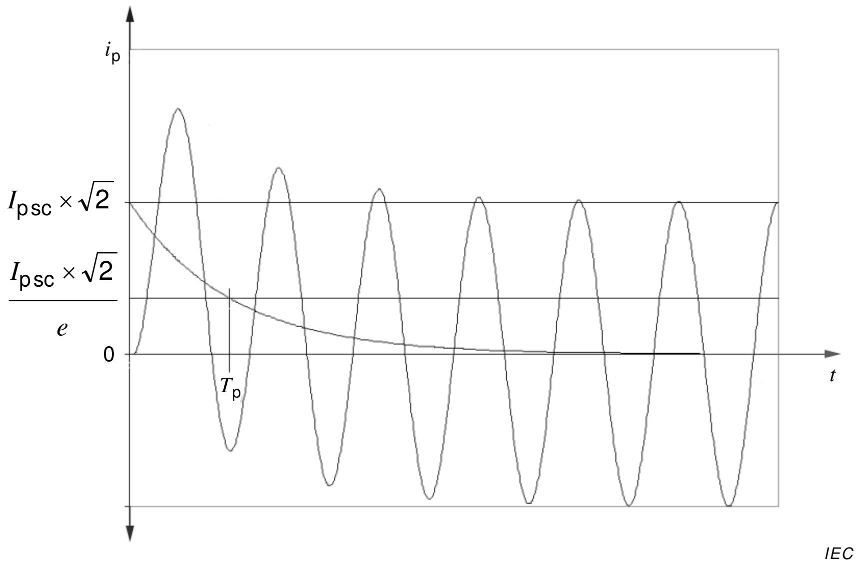


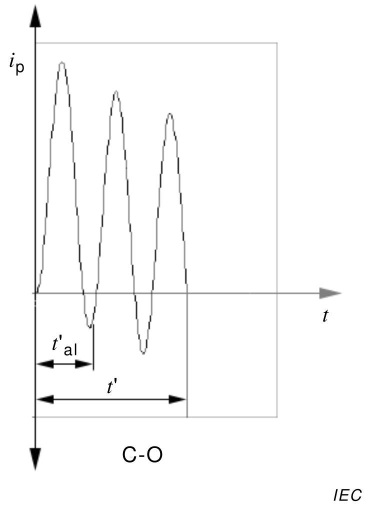
Figure 602 – Primary time constant T_p

3.3.611
fault repetition time
t_{fr}
time interval between interruption and re-application of the primary short-circuit current during a circuit breaker auto-reclosing duty cycle in case of a non-successful fault clearance

3.3.612
specified duty cycle

3.3.612.1
C-O
duty cycle in which, during the specified energization, the primary short-circuit current is assumed to have the worst-case inception angle

Note 1 to entry: See Figure 603.



Single energization: C – t' – O

where

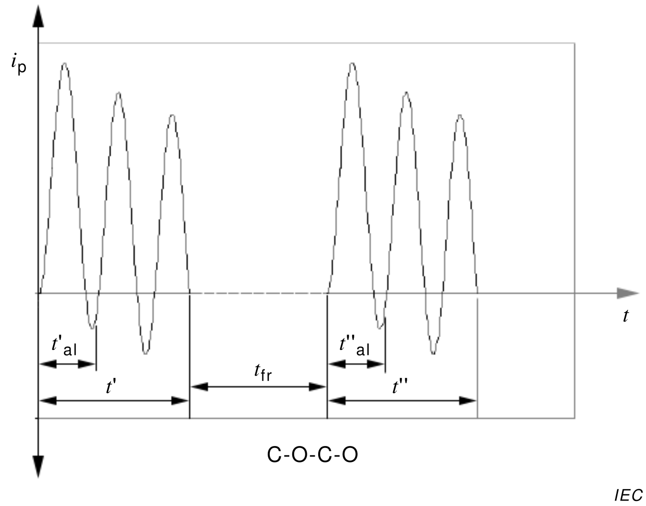
t' is the duration of first fault;

t'_{al} is the specified time to accuracy limit in the first fault.

Figure 603 – Duty cycles, single energization

3.3.612.2
C-O-C-O
duty cycle in which, during each specified energization, the primary short-circuit current is assumed to have the worst-case inception angle

Note 1 to entry: See Figure 604.



Double energization: C– t' – O – t_{fr} – C– t'' – O
(both energizations being in the same polarity of magnetic flux when applicable)

where
t' is the duration of first fault;
t'' is the duration of the second fault;
t_{fr} is the fault repetition time;
t'_{al} is the specified time to accuracy limit in the first fault;
t''_{al} is the specified time to accuracy limit in the second fault.

Figure 604 – Duty cycles, double energization

3.3.613
primary current in transient condition
$\boldsymbol{i_p(t)}$
input signal of a low-power current transformer during transients in the network

Note 1 to entry: In the transient condition, primary current is defined as follows:

$$i_p(t) = I_{psc}\sqrt{2}\left[\sin(2\pi f t + \varphi_p) - \sin(\varphi_p)^{\frac{-t}{T_p}}\right] + i_{p\,res}(t)$$

where

I_{psc}	is the r.m.s. value of the symmetrical component of primary current;
f	is the frequency;
T_p	is the primary time constant;
φ_p	is the primary phase;
$i_{p\,res}(t)$	is the primary residual current including harmonic and subharmonic components and primary direct current;
t	is the instantaneous value of time.

3.4 Terms and definitions related to accuracy

3.4.3
ratio error
ε
The definition 3.4.3 of IEC 61869-1:2007 is applicable with the following addition:

Note 601 to entry: The ratio error for current (ε_i) or voltage (ε_u) for analogue and for digital output is defined by the following formula:

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

$$\varepsilon = \frac{K_\mathrm{r} Y_\mathrm{s} - X_\mathrm{p}}{X_\mathrm{p}} \times 100$$

where

K_r is the rated transformation ratio;

X_p is the r.m.s. value of the actual input signal when $x_{\mathrm{p\ res}}(t)$ = 0;

Y_s is the r.m.s. value of output signal when $Y_{\mathrm{sdc}} + y_{\mathrm{s\ res}}(t) = 0$.

This definition is only related to components at rated burden and rated frequency of both primary signal and secondary signal and does not take into account direct signal components. This definition is compatible with IEC 61869-2, IEC 61869-3 and IEC 61869-5.

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

$$\varepsilon = \frac{K_\mathrm{r} Y_\mathrm{s} - X_\mathrm{p}}{X_\mathrm{p}} \times 100$$

where

K_r is the rated transformation ratio;

X_p is the r.m.s. value of the actual primary signal when $x_{\mathrm{p\ res}}(t)$ = 0;

Y_s is the r.m.s. value of the digital output when $Y_{\mathrm{sdc}}(n) + y_{\mathrm{s\ res}}(t_n) = 0$.

This definition is only related to components at rated burden and rated frequency of both primary signal and secondary signal and does not take into account direct signal components. This definition is compatible with IEC 61869-2, IEC 61869-3 and IEC 61869-5.

3.4.4
phase displacement
$\Delta\varphi$
The definition 3.4.4 of IEC 61869-1:2007 is applicable with the following additions:

Note 601 to entry: For LPIT phase displacement is not always coincident with phase error, as in some cases phase displacement may include variable components (errors) and fixed components (phase offset and delay time) which are not to be considered as errors.

Conventional Instrument Transformers, covered by IEC 61869-2, IEC 61869-3 and IEC 61869-5, are to be considered as special cases, in which phase displacement is equivalent to phase error because there is no phase offset and no delay time.

Note 602 to entry: This definition is strictly valid for analog output.

For digital output the presence of a timestamp in the data frame allows for the compensation of the delay time, so that its contribution to phase displacement may be neglected.

3.4.6
burden
The definition 3.4.6 of IEC 61869-1:2007 is replaced by the following:

impedance of the secondary analogue circuit expressed as parallel combination of resistor and capacitor given in ohm and farad

3.4.8
rated output
S_r
not applicable

3.4.601
delay time
$t_{\mathbf{d}}$
actual time between an event taking place on the primary and its result(s) appearing in the output

Note 1 to entry: Delay time can result in low-power instrument transformers due to, for instance, band limiting filters and digital processing.

Note 2 to entry: For instrument transformers with analogue output, delay time should be constant, as any deviation would result in phase error.

Note 3 to entry: For instrument transformers with digital output, see IEC 61869-9.

3.4.602
rated delay time
$t_{\mathbf{dr}}$
rated value of delay time for an LPIT with analogue output

3.4.603
phase offset
$\varphi_{\mathbf{o}}$
phase displacement of an LPIT due to the technology employed and which is not affected by the frequency

Note 1 to entry: An example of such technology is the Rogowski coil.

3.4.604
rated phase offset
$\varphi_{\mathbf{or}}$
rated value of phase offset of an LPIT

3.4.605
phase error
$\varphi_{\mathbf{e}}$
difference between the actual phase displacement and the sum of rated phase offset and phase shift due to rated delay time

Note 601 to entry: The phase error is calculated according to the following formula:

$$\varphi_{\mathrm{e}} = \Delta\varphi - (\varphi_{\mathrm{or}} + \varphi_{\mathrm{tdr}}) = \varphi_{\mathrm{S}} - \varphi_{\mathrm{P}} - (\varphi_{\mathrm{or}} + \varphi_{\mathrm{tdr}})$$

and

$$\varphi_{\mathrm{tdr}} = -2\pi f t_{\mathrm{dr}}$$

where

φ_{P} is the primary phase

φ_{S} is the secondary phase

3.4.606
accuracy limit factor
$K_{\mathbf{ALF}}$
ratio of the rated accuracy limit primary current to the rated primary current

[SOURCE: IEC 60050-321:1986, 321-02-30, modified – The complement to term "of a protective current transformer" has been removed, and a symbol has been added.]

3.4.607
composite error
ε_c
under steady-state conditions, 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

Note 1 to entry: 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:

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

where

K_r 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.

For stand-alone Rogowski coils, see IEC 61869-10.

Note 2 to entry: 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:

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

where

K_r 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 effective time where primary currents of the n^{th} data set have been sampled;

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

[SOURCE: IEC 60050-321:1986, 321-02-26, modified – "Secondary current" has been replaced by "secondary output" in the definition and the Note has been replaced by two new notes to entry.]

3.4.608
transient response of an LPIT
response of the secondary output to a transient change of the primary signal

3.4.609
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

Note 1 to entry: For an analogue output, the instantaneous error current is defined by the following formula:

$$i_\varepsilon(t) = \mathrm{K}_{\mathrm{ra}} \cdot u_{\mathrm{s}}(t) - i_{\mathrm{p}}(t - t_{\mathrm{dr}})$$

For stand-alone Rogowski coils, see IEC 61869-10.

Note 2 to entry: For digital output, the instantaneous error current is defined by the following formula:

$$i_\varepsilon(n) = \mathrm{K}_{\mathrm{rd}}\ i_{\mathrm{s}}(n) - i_{\mathrm{p}}(t_n)$$

3.4.610
peak instantaneous error
$\hat{\varepsilon}$
peak value ($\hat{i}_\varepsilon$) of instantaneous error current for the specified duty cycle, expressed as a percentage of the peak value of the rated primary short-circuit current

Note 1 to entry: The peak instantaneous error is expressed by the following formula:

$$\hat{\varepsilon} = \frac{\hat{i}_\varepsilon}{\sqrt{2} \times I_{\mathrm{psc}}} \times 100\ \%$$

3.4.611
instantaneous voltage error for transient conditions
$\varepsilon_u(t)$
$\varepsilon_u(n)$
ratio of the difference between the instantaneous values of the secondary output multiplied by the rated transformation ratio and the primary voltage and the peak of the primary voltage expressed in percent (%)

Note 1 to entry: For an analogue output, the instantaneous voltage error is expressed by the following formula:

$$\text{Voltage error } \varepsilon_u(t)\ \% = \frac{K_{\mathrm{r}} u_{\mathrm{s}}(t) - u_{\mathrm{p}}\left(t - t_{\mathrm{dr}}\right)}{U_{\mathrm{p}}\sqrt{2}} \times 100$$

where u_{P}(t) and u_{S}(t) are described for a limited range of time by the equations given in 3.2.603 and U_{p} is the r.m.s. value of the primary voltage.

The chosen origin of time is the instant of the sudden change of the parameters described in 3.1.622.

Note 2 to entry: For a digital output, the instantaneous voltage error is expressed by the following formula:

$$\text{Voltage error } \varepsilon_{\mathrm{u}}(n)\ \% = \frac{K_{\mathrm{r}} u_{\mathrm{s}}(n) - u_{\mathrm{p}}\left(t_{\mathrm{n}}\right)}{U_{\mathrm{p}}\sqrt{2}} \times 100$$

where $u_{\mathrm{P}}(t_{\mathrm{n}})$ and $u_{\mathrm{S}}(n)$ are described for a limited range of time by the equations given in 3.2.603 and U_{p} is the r.m.s. value of the primary voltage.

The chosen origin of the time is the instant of the sudden change of the parameters described in 3.1.622

Note 3 to entry: The capacitive sensor with phase shift offset is described in IEC 61869-11[2].

3.5 Terms and definitions related to other ratings

3.5.1
rated frequency
f_r
The definition 3.5.1 of IEC 61869-1:2007 is replaced by the following:

frequency at which the low-power instrument transformer is designed to operate

[SOURCE: IEC 60050-421:1990, 421-04-03, modified – "Transformer or reactor" has been replaced by "low-power instrument transformer".]

3.5.601
rated frequency range
range of frequency for which the rated accuracy class is applicable

3.5.602
rated auxiliary power supply voltage
U_{ar}
auxiliary power supply voltage value on which the requirements of a specification are based

3.5.603
rated supply current
I_{ar}
current required from the auxiliary power supply, including the MU power supply if required, in the rated conditions

3.5.604
maximum supply current
I_{amax}
maximum current required by the auxiliary power supply, including the MU power supply if required, in the worst conditions

3.7 Index of abbreviations and symbols

The table in 3.7 of IEC 61869-1:2007 is replaced by the following table:

AIS	air-insulated switchgear
C–O C–O–C–O	specified duty cycle
CT	current transformer
CVT	capacitive voltage transformer
f_r	rated frequency
F	mechanical load
F_{rel}	relative leakage rate
GIS	gas-insulated switchgear
I_{amax}	maximum supply current
I_{ar}	rated supply current
I_{cth}	rated continuous thermal current

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2 Under consideration.

I_{dyn}	rated dynamic current
I_{epr}	rated extended primary current
$i_{p(t)}$	primary current in transient condition
I_{pr}	rated primary current
I_{psc}	rated primary short-circuit current for transient performance
I_{th}	rated short-time thermal current
$i_{\varepsilon}(t)$, $i_{\varepsilon}(n)$	instantaneous error current
IT	instrument transformer
K	actual transformation ratio
K_{ALF}	accuracy limit factor
K_{r}	rated transformation ratio
K_{pcr}	rated extended primary current factor
K_{ssc}	rated symmetrical short-circuit factor for transient performance
LPCT	low-power current transformer
LPIT	low-power instrument transformer
LPVT	low-power voltage transformer
MU	merging unit
R_{br}	rated burden
SAMU	stand-alone merging unit
t_{d}	delay time
t_{dr}	rated delay time
t_{fr}	fault repetition time
U_{sys}	highest voltage for system
U_{m}	highest voltage for equipment
U_{pr}	rated primary voltage
U_{sdco}	secondary direct voltage offset
U_{ar}	rated auxiliary power supply voltage
T_{p}	specified primary time constant for transient performance
VT	voltage transformer
$\Delta\varphi$	phase displacement
ε	ratio error
ε_{c}	composite error
$\hat{\varepsilon}$	maximum peak instantaneous error
$\varepsilon_{u}(t)$, $\varepsilon_{u}(n)$	instantaneous voltage error for transient conditions
φ_{o}	phase offset
φ_{or}	rated phase offset
φ_{e}	phase error

4 Normal and special service conditions

4.2 Normal service conditions

4.2.3 Vibrations or earth tremors

Clause 4.2.3 of IEC 61869-1:2007 is replaced by the following:

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

4.2.601 Partially outdoor LPIT

In the case of an LPIT 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.

5 Ratings

5.3 Rated insulation levels and voltages

5.3.5 Insulation requirements for secondary terminals

Clause 5.3.5 of IEC 61869-1:2007 is applicable with the following addition:

Insulation requirements for secondary terminals and the low voltage component are given in Table 601.

In cases where the total electrical cable length of the transmitting system up to the secondary equipment does not exceed 10 m, and the associated earthing impedance is sufficiently low, the common mode voltage is not supposed to exceed a safe value. The secondary terminal and the low voltage component insulation requirement in such cases can be reduced to a level meeting the requirements defined in the IEC 60255-27:2013, Table C.3.

The insulation level shall meet PEB (protection by equipotential bonding) system requirements for 150 V working voltage.

In case where the total electrical cable length of the transmitting system up to the secondary equipment does exceed 10 m, the requirement of IEC 61869-1 applies.

Table 601 – Secondary terminal and low voltage component withstand capability

Transmitting system of the LPIT	Power frequency voltage withstand capability	Impulse voltage withstand capability
Electrical cable length <10 m.	820 V	1,5 kV 1,2/50 μs
Electrical cable length ≥10 m.	3 kV	5 kV 1,2/50 μs
Optical connectors	NA	NA

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

5.3.601.1 General

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.

5.3.601.2 AC voltage

The preferred rated values of a.c. voltages are given below:

110 V – 230 V

5.3.601.3 DC voltage

The preferred rated values of d.c. voltages are given below:

24 V – 48 V – 110 V – 220 V

5.3.601.4 Insulation requirements for power supply terminals

They shall be capable of meeting the requirements defined in the IEC 60255-27:2013, Table C.7.

5.4 Rated frequency

Subclause 5.4 of IEC 61869-1:2007 applies with the following additions:

For measuring accuracy classes, the rated frequency range is from 99 % to 101 % of the rated frequency (f_r).

For protection accuracy classes, the rated frequency range is from 96 % to 102 % of the rated frequency (f_r).

The accuracy outside the rated frequency range, if specified, is defined in Annex 6B.

5.5 Rated output

5.5.601 Rated burden (R_{br})

The standard value of rated burden is defined by a resistance in parallel with a capacitance according to the following table:

Resistance	Capacitance
2 MΩ	50 pF

For use on devices backward compatible with IEC 60044-8, 2 kΩ/5 000 pF and 20 kΩ/500 pF are acceptable.

The impact of the total burden impedance range on accuracy is covered under accuracy clauses.

Attention should be paid to the parallel capacitance of electrical measuring instruments or electrical protective devices. If the transmitting cable is not part of the sensor, the capacitance of the cable has to be considered as part of the burden. Typical cable capacitance is in the range from 15 pF/m to 100 pF/m.

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

The standard values for rated delay time are:

50 μs, 100 μs, 500 μs

5.6 Rated accuracy class

Subclause 5.6 of IEC 61869-1:2007 is applicable with the following modification:

See specific product standard and harmonic requirements in Annex 6A.

6 Design and construction

6.7 Mechanical requirements

Subclause 6.7 of IEC 61869-1:2007 is applicable with the following modification:

These requirements apply only to free-standing LPIT having $U_{\mathrm{m}} \geq 72{,}5$ kV.

6.11 Electromagnetic compatibility (EMC)

6.11.3 Requirements for immunity

6.11.3.601 General

Table 602 gives a list of type tests for electronic LPIT with the associated test levels and assessment criteria.

If the LPIT is designed without an active electronic component, it is by definition considered as a passive LPIT and is therefore not subjected to the tests of this subclause.

NOTE EMC immunity tests for highly accurate passive LPITs are under consideration. Performances of such devices may be affected by their shielding capability.

Table 602 – Immunity requirements and tests

Test	Reference standard	Test level	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 × 0,1 s [c] interruption × 0,05 s [c]	A
Surge immunity test	IEC 61000-4-5	4	B
Conducted immunity test (150 kHz to 80 MHz)	IEC 61000-4-6	3	A
Conducted immunity test (0 kHz to 150 kHz)	IEC 61000-4-16	4	A
Electrical fast transient/burst test	IEC 61000-4-4	4	B
Oscillatory waves immunity test	IEC 61000-4-18	3	B
Electrostatic discharge test	IEC 61000-4-2	3	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

Test	Reference standard	Test level	Assessment criteria
Radiated, radiofrequency, electro-magnetic field immunity test	IEC 61000-4-3	3	A

a Only applicable to LPIT with a.c. power port.

b Only applicable to LPIT 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 primary voltage or lower).

B Temporary degradation of performances of measurements, which are not relevant for protection or self-diagnosis and 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.

6.11.3.602 Harmonic and interharmonic disturbance

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

6.11.3.603 Slow voltage variation

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

6.11.3.604 Voltage dips and short interruption

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

6.11.3.605 Surge immunity

The purpose of this test is to verify the immunity of the LPIT 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.

6.11.3.606 Conducted immunity tests (150 kHz to 80 MHz)

The purpose of this test is to verify the immunity of the LPIT against the conducted disturbances that can be transferred by inductive or capacitive coupling to the supply cables, signal cables and earthings.

6.11.3.607 Conducted immunity test (0 kHz to 150 kHz)

The purpose of this test is to verify the immunity of the LPIT against the power frequency disturbances that can be transferred by inductive or capacitive coupling to the supply cables, signal cables and earthings.

6.11.3.608 Electrical fast transient/burst

The purpose of this test is to verify the immunity of the LPIT 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).

6.11.3.609 Oscillatory wave immunity

The purpose of this test is to verify the immunity of the LPIT 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.

6.11.3.610 Electrostatic discharge

The purpose of this test is to verify the immunity of the LPIT 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 LPIT 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.

6.11.3.611 Power-frequency magnetic field immunity

The purpose of this test is to verify the immunity of the LPIT 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 LPIT to main circuits.

6.11.3.612 Pulse magnetic field immunity

The purpose of this test is to verify the immunity of the LPIT 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.

6.11.3.613 Damped oscillatory magnetic field immunity

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

6.11.3.614 Radiated, radiofrequency, electromagnetic field immunity

The purpose of this test is to verify the immunity of the LPIT 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.

6.11.4 Requirement for transmitted overvoltages

Subclause 6.11.4 of IEC 61869-1:2007 is applicable with the following addition:

The main cause of overvoltage is the switching of HV equipment. This requirement is not applicable if a non-conductive transmitting system (such as optical fibre) is used (see Figure 601).

6.11.601 Emission requirements

Besides the emission requirements considered to be covered with a radio interference voltage test (RIV test) and transmitted overvoltage test, LPIT shall also comply with limits given in CISPR 11:2015 for equipments of Group 1 – class A, and shall be tested accordingly.

Low-power passive instrument transformers are not subjected to these requirements.

6.13 Markings

Subclause 6.13 of IEC 61869-1:2007 is applicable with the following addition:

o) insulation level on secondary terminals

Additional markings shall be defined in the specific standards.

6.601 Requirements for optical transmitting system and optical output link

6.601.1 General

If used for transmitting system and/or output link, the optical fibre cables shall comply with IEC 60794-2 for indoor applications and IEC 60794-3 for outdoor applications. The transmitting system and output link cables should be protected against rodent attack.

If optical fibre cables are protected by conductive material, attention should be paid to grounding and exported potential.

6.601.2 Optical connectors

No optical fibre connectors are allowed outdoors without appropriate environmental protection.

6.601.3 Fibre optic terminal box

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

6.601.4 Total cable length

The low-power instrument transformer shall be capable of operating with maximum length of transmitting system cable and output link as specified by the manufacturer.

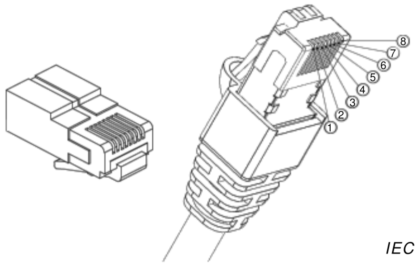
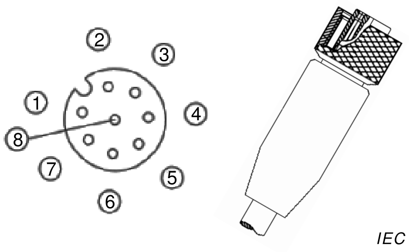
The manufacturer shall take into account that the total cable length could reach 1 km for very high-voltage air-insulated substations.

6.602 Requirements for electrical transmitting system and electrical wires for output link

6.602.1 Connectors

The connector description is given in Table 603.

Table 603 – Connectors

<table>
<tr>
<td>8 way, shielded, free connector (RJ45)
IEC 60603-7-1
</td>
<td>The pin assignment is defined in the specific product standard</td>
</tr>
<tr>
<td>8 way, shielded M12 free connector, female contacts, with locking nut
IEC 61076-2-101
</td>
<td>
<table>
<tr><td>M12 connector:</td><td>Pin:</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr>
<tr><td colspan="2">LPIT</td><td>S1</td><td>S2</td><td>a</td><td>n</td><td>T1-</td><td>T2+</td><td>+V</td><td>gnd</td></tr>
</table>
- S1, S2: current transformer secondary terminals as defined in IEC 61869-2:2012, 6.13.201.3
- a, n: voltage transformer secondary terminals as defined in IEC 61869-3:2011, 6.13.301.3
- T1-, T2+: used for TEDS connection (Transducer Electronic Data Sheet, ISO/IEC/IEEE 21451-4:2010).
The voltage level shall not exceed 5 V DC
- +V, gnd: power supply
</td>
</tr>
</table>

Screw terminals may also be used instead of connectors.

6.602.2 Earthing of the output cable

If double-shielded cable (electrically separated circuit) 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.

6.603 Signal-to-noise ratio

Noise (and bandwidth) requirements depend on the application(s). Accordingly, there is no one common set of requirements that is applicable to all instrument transformers. The supplier of the low-power instrument transformer shall provide noise spectral information. The noise specifications may be in various forms. The recommended forms of specifications are noise spectral density equations or graphs (noise distribution as a function of frequency).

If the noise is white noise (Gaussian distribution) and random (as usually is), it will average to zero over time. Accordingly, the impact of noise on measurement depends on integration time (effective measurement bandwidth) and the nature of an application. The choice of appropriate noise level depends on the application. The provider of the instrument transformer should provide white noise spectral density in the form of a number with unit of equivalent primary current per square root of frequency (i.e. $A/\sqrt{Hz}$).

EXAMPLE For an optical CT where the dominant contributor to device noise is the “optical shot noise,” the noise is white and can be provided in amperes (equivalent primary) per square root of hertz. Alternatively, normalizing to rated values, it can be given in PUs (per units) per square root of hertz. If an optical CT has a rated primary current of 400 A, a rated secondary output of 4 V, and 10 mV of noise on its output (equivalent noise to 1 A on the primary) over its bandwidth of 10 kHz, then the noise can be given as 0,01 $A/\sqrt{Hz}$ or 0,000 025 $PU/\sqrt{Hz}$, or −92 $dB/\sqrt{Hz}$.

Alternatively, signal to noise ratio at the rated current with 10 kHz bandwidth will be +52 dB or 400 (52 dB = $20 \times \log_{10}(400/1)$).

As a general guidance, noise levels lower than –50 dB/$\sqrt{\text{Hz}}$ to –70 dB/$\sqrt{\text{Hz}}$ relative to the rated current (or 0,003 PU/$\sqrt{\text{Hz}}$ to 0,0003 PU/$\sqrt{\text{Hz}}$) are typically sufficient for most common applications.

NOTE For additional information, see IEC/TR 61869-103.

6.604 Failure detection and maintenance announcement

LPIT 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 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 LPIT power supply, till the LPIT has stabilized, the analogue output shall remain zero and any digital output shall be flagged as invalid. When the LPIT has stabilized, the operation of the LPIT shall be automatically self-restored. LPIT maintenance requirement, where detected, shall be announced. For digital output this shall result in the activation of the corresponding quality bits transmitted in the digital data stream.

6.605 Operability

In order to facilitate the operation and maintenance of the LPIT, the position of parts to which access is required shall be in an accessible position. These parts may include switches, socket outlets, fuses, inputs and outputs, etc.

6.606 Reliability and dependability

The manufacturer shall provide information according to relevant standards, like IEC 60812 and IEC 61025, on the dependability and reliability of the LPIT. 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 shall be provided describing the relationship between sub-parts and how the redundancy, if any, is managed. Parts subjected to maintenance and relevant maintenance procedures shall 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 LPIT are comparable to those of the electrical components in the substation. Hence, the reliability and dependability of LPIT shall be treated similarly.

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 or appropriate documentation.

No other component can be replaced without recalibration of the complete LPIT.

6.607 Vibrations

The output of LPIT shall operate correctly when subjected to vibration levels appropriate to its application. Different parts of the LPIT may be subjected to different vibration levels in accordance with IEC 60068-2-6.

– Endurance by sweeping: frequency range 10 Hz to 150 Hz, 20 sweep cycles in each axis.

– Endurance test at fixed frequencies for 30 min.

The test vibration level shall be

– indoor equipment: amplitude 10m/s^2,
– outdoor equipment and equipment mounted on GIS switchgear: amplitude 20 m/s^2.

7 Tests

7.1 General

7.1.2 List of tests

Subclause 7.1.2 of IEC 61869-1:2007 is applicable with the following modified Table 10.

Table 10 – List of tests

Tests	Subclause
Type tests	**7.2**
Temperature-rise test	7.2.2
Impulse voltage test on primary terminals	7.2.3
Wet test for outdoor type Transformers	7.2.4
Electromagnetic compatibility tests	7.2.5
Test for accuracy	7.2.6
Verification of the degree of protection by enclosures	7.2.7
Enclosure tightness test at ambient temperature	7.2.8
Pressure test for the enclosure	7.2.9
Low-voltage component voltage withstand test	7.2.601
Routine tests	**7.3**
Power-frequency voltage withstand tests on primary terminals	7.3.1
Partial discharge measurement	7.3.2
Power-frequency voltage withstand tests between sections	7.3.3
Power-frequency voltage withstand tests on secondary terminals	7.3.4
Test for accuracy	7.3.5
Verification of markings	7.3.6
Enclosure tightness test at ambient temperature	7.3.7
Pressure test for the enclosure	7.3.8
Power-frequency voltage withstand test for low-voltage components	7.3.601
Special tests	**7.4**
Chopped impulse voltage withstand test on primary terminals	7.4.1
Multiple chopped impulse test on primary terminals	7.4.2
Measurement of capacitance and dielectric dissipation factor	7.4.3
Transmitted overvoltage test	7.4.4
Mechanical tests	7.4.5
Internal arc fault test	7.4.6
Enclosure tightness test at low and high temperatures	7.4.7
Gas dew point test	7.4.8
Corrosion test	7.4.9

Tests	Subclause
Fire hazard test	7.4.10
Vibration test	7.4.601
Tests for accuracy versus harmonics and low frequencies	6A.5
Sample tests	**7.5**

7.2 Type tests

7.2.1 General

7.2.1.1 Information for identification of specimen

Subclause 7.2.1.1 of IEC 61869-1:2007 is applicable with the following addition:

The software version, if applicable, shall be included in the design identification records.

7.2.2 Temperature-rise test

Subclause 7.2.2 of IEC 61869-1:2007 is applicable with the following addition:

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

The LPIT is deemed to have passed this test if

a) the temperature rise is in accordance with requirements given in 6.4 of IEC 61869-1:2007.
b) after cooling to ambient temperature, it satisfies the following requirements:
   1) it is not visibly damaged,
   2) its errors shall be within the limits of the relevant accuracy class.

7.2.3 Impulse voltage withstand test on primary terminals

7.2.3.1 General

Subclause 7.2.3.1 of IEC 61869-1:2007 is applicable with the following addition:

Dielectric tests shall be made on LPIT completely assembled, as in service. The outside surfaces of insulating parts shall be carefully cleaned.

7.2.5 Electromagnetic compatibility (EMC) tests

7.2.5.2 Immunity test

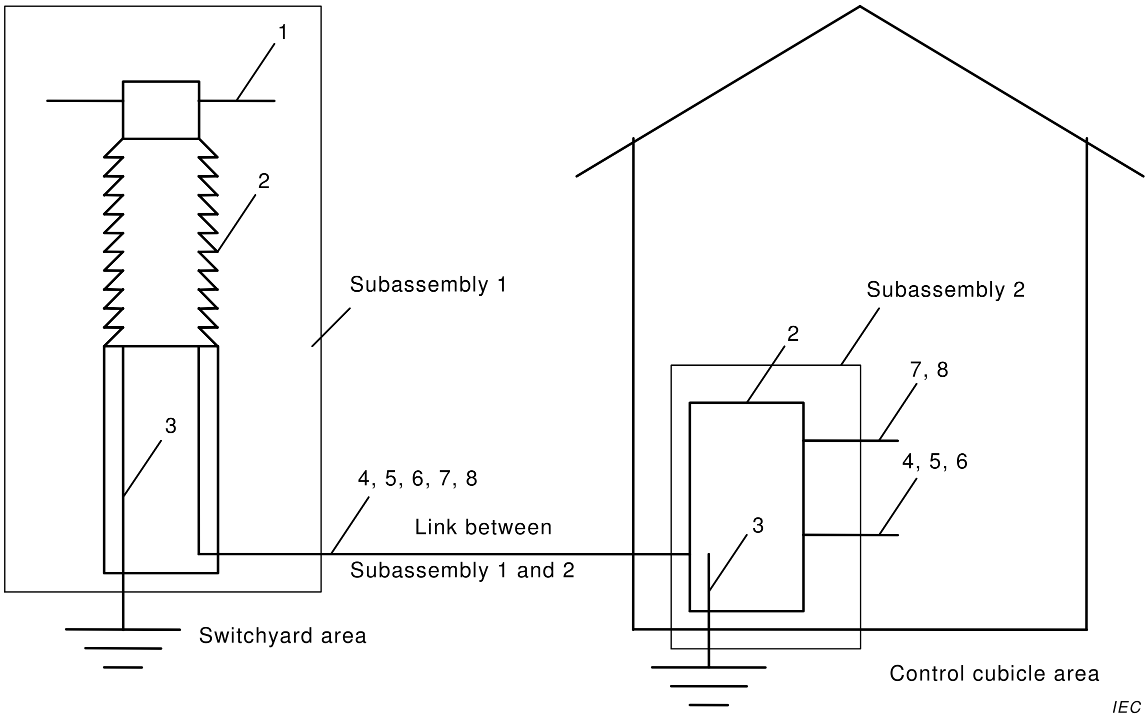
7.2.5.2.601 General

The tests shall be made to prove compliance with 6.11.3.

The test shall be performed on a port-by-port basis, guidance for the identification of ports being given in Figure 605, Figure 606, and Figure 607 below.

In many cases an LPIT 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 LPIT have to be carried out on each major subassembly the full LPIT being in operation or the missing subassemblies being simulated.

Examples of major subassembly divisions are given in Figure 605, Figure 606, and Figure 607 below.



Key

1 HV line
2 Enclosure port
3 Ground signal 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 605 – Examples of subassembly subjected to EMC tests – Usual structure used in HV AIS applications

Key

1 Control device

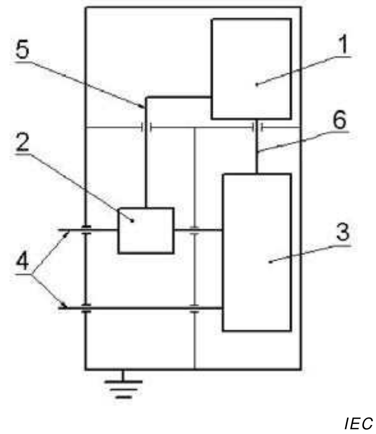
2 LPIT supply for control device

3 Switching device

4 MV line

5 Communication link and/or power

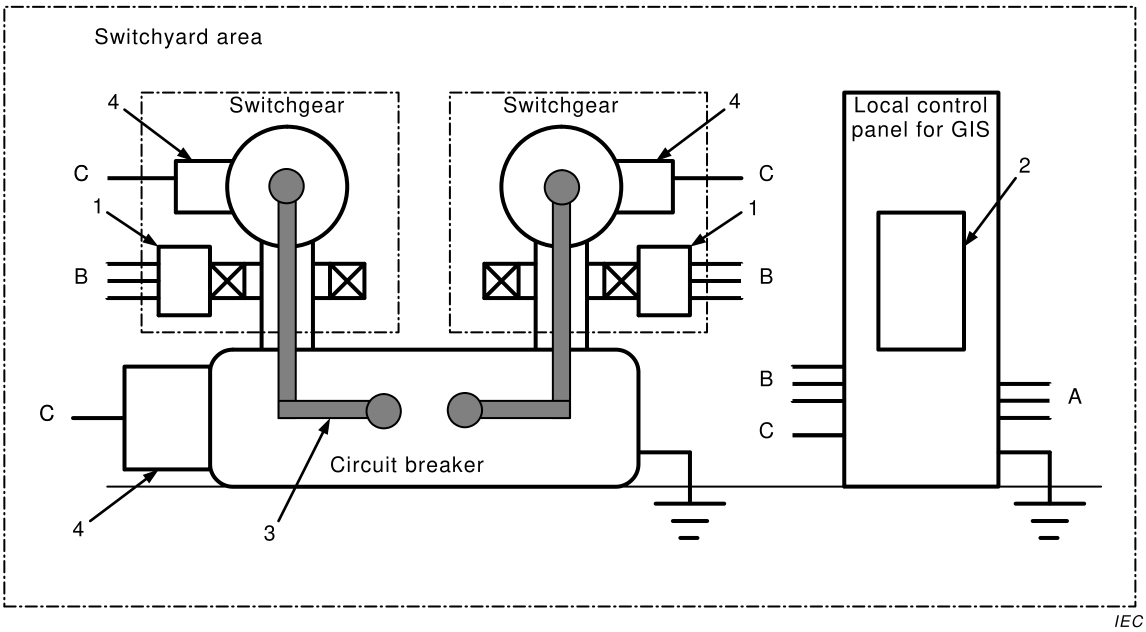
6 Communication link



Switchgear cubicle

NOTE MV switchgears do not have galvanic insulation between the switchgear area and the control cubicle as in the HV AIS example. Usually, all items are inside a metal case that is grounded as well as walls of different compartments inside.

Figure 606 – Examples of subassembly subjected to EMC tests – Usual structure used in MV applications



Key
1 Low-power instrument transformers with IED (intelligent electronic device)
2 Control unit (with merging unit) installed in local control panel
3 HV line enclosed in earthed metal tank
4 Operating mechanisms of circuit breaker or switchgear
A Communication link and/or power supply from upper systems; protection relays and/or control units
B Communication link and/or power supply for IEDs of low-power instrument transformers
C Communication link and/or power supply for operating mechanisms
NOTE HV gas insulated switchgear does not have galvanic insulation between switchgear and local control panel and/or control cubic area as shown in AIS example

Figure 607 – Examples of subassembly subjected to EMC tests – Usual structure used in HV GIS applications

7.2.5.2.602 General conditions during immunity 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 LPIT and test equipment and between primary and secondary converters should be the maximum specified by the manufacturer and the arrangement of the cable shall, as far as practicable, represent in-service conditions.

7.2.5.2.603 Harmonic and interharmonic disturbance test

The test shall be performed according to the test procedure of IEC 61000-4-13. The test level is class 2 (full harmonic distortion 10 %). The assessment criterion is given in 6.11.3.602 and Table 602.

7.2.5.2.604 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 6.11.3.603 and Table 602.

7.2.5.2.605 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 6.11.3.604 and Table 602.

7.2.5.2.606 Surge immunity test

The test shall be performed according to the test procedure of IEC 61000-4-5:2014. The test generator to be used is the combination wave (hybrid) generator (IEC 61000-4-5:2014, 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 test level 4 (4 kV Line-Earth (L-E), 2 kV Line-Line (L-L)). The assessment criterion is given in 6.11.3.605 and Table 602.

7.2.5.2.607 Conducted immunity tests (150 kHz to 80 MHz)

The test shall be performed according to the test procedure of IEC 61000-4-6, the test level and the assessment criteria are given in 6.11.3.606, and Table 602.

7.2.5.2.608 Conducted immunity tests (0 Hz to 150 kHz)

The test shall be performed according to the test procedure of IEC 61000-4-16, the test level and the assessment criteria are given in 6.11.3.607, and Table 602.

7.2.5.2.609 Electronic fast transient/burst test

The test shall be performed according to the test procedure of IEC 61000-4-4:2012, the test level being severity level 4 (4 kV test voltage on power supply port and 2 kV on input/output, signal, data and control ports (common mode), repetition rate 5 kHz). The test will be carried out using the coupling/decoupling network on the power supply port and the capacitive coupling clamp on the input/output, signal, data control and communication ports. The assessment criterion is given in 6.11.3.608 and Table 602.

7.2.5.2.610 Damped oscillatory wave immunity test

The test shall be performed according to the test procedure of IEC 61000-4-18:2006. The test generator to be used is the damped oscillatory wave generator (IEC 61000-4-18:2006, 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. Test frequency will be 100 kHz or 1 MHz at 400 repetitions per second. The assessment criterion is given in 6.11.3.609 and Table 602.

7.2.5.2.611 Electrostatic discharge test

The test shall be performed according to the test procedure of IEC 61000-4-2:2008. The test level is severity level 3. The test shall be performed according to the test procedure of IEC 61000-4-2 applied only on the physical boundary of the equipment under test (enclosure).The assessment criterion is given in 6.11.3.610 and Table 602.

7.2.5.2.612 Power-frequency magnetic field immunity test

The test shall be performed according to the test procedure of IEC 61000-4-8:2009. Test level is severity level 5 (100 A/m for 1 min and 1000 A/m for 1 s). The assessment criterion is given in 6.11.3.611 and Table 602.

7.2.5.2.613 Pulse magnetic field immunity test

The test shall be performed according to the test procedure of IEC 61000-4-9:1993. Test level is severity level 5 (1 000 A/m peak). The assessment criterion is given in 6.11.3.612 and Table 602.

7.2.5.2.614 Damped oscillatory magnetic field immunity test

The test shall be performed according to the test procedure of IEC 61000-4-10:1993. Test level is severity level 5 (100 A/m test field). The assessment criterion is given in 6.11.3.613 and Table 602.

7.2.5.2.615 Radiated, radiofrequency, electromagnetic field immunity test

The test shall be performed according to the test procedure of IEC 61000-4-3:2006. Test level is severity level 3 (10 V/m field strength). The assessment criterion is given in 6.11.3.614 and Table 602**.**

7.2.5.601 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.

7.2.6 Test for accuracy

7.2.6.601 General

The following accuracy tests are applied to measuring LPIT and to protective LPIT. Test circuits are given in Annex 6D.

7.2.6.602 Basic accuracy tests

7.2.6.602.1 Basic accuracy tests for measuring LPIT

To prove compliance with the specified accuracy class, tests shall be made at each value of input signal given in the specific standards at rated frequency, at rated burden (if relevant), and at ambient temperature, unless otherwise specified.

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

7.2.6.602.2 Basic accuracy test for protective LPIT

To prove compliance with the specified accuracy class, the test shall be made at rated input signal 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.

7.2.6.602.3 Basic accuracy test for multipurpose LPIT

Basic accuracy test for multipurpose low-power instrument transformers shall include the basic accuracy tests described in 7.2.6.602.1 and in 7.2.6.602.2.

7.2.6.603 Temperature cycle accuracy test

In addition to the basic accuracy tests made in accordance with 7.2.6.602, the temperature cycle accuracy test shall be performed in the following conditions:

- at rated frequency;
- at rated primary signal, applied continuously, in case of maximum or ambient temperature (without continuous primary signal in case of minimum temperature);
- 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 608 shall be performed.

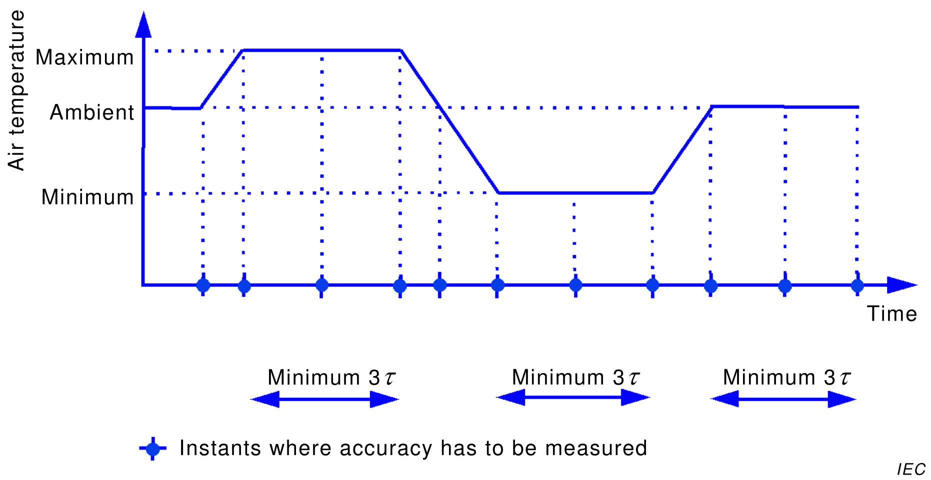


Figure 608 – Temperature cycle accuracy test

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 low-power instrument transformer depends mainly on the size and construction of the transformer.

For LPIT, partially indoor, partially outdoor, the tests shall be made for indoor and outdoor parts, each one at both extremes of the 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.

7.2.6.604 Test for accuracy versus frequency

In addition to the basic accuracy tests made in accordance with 7.2.6.602, tests for accuracy shall be made at the two extremes of rated frequency range given in 5.4 at rated input signal, at rated burden (if relevant) and at constant ambient temperature.

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

NOTE For the tests, an accuracy measurement system calibrated at rated frequency can be acceptable.

7.2.6.605 Test for accuracy in relation to replacement of components

To prove compliance with 6.606 the following test shall be performed. The ability of the LPIT 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 input signal and rated burden (if relevant).

7.2.6.606 Additional accuracy tests for protective LPIT

Additional accuracy tests, for example transient, are defined in the relevant product standards.

7.2.601 Low-voltage component voltage withstand test

7.2.601.1 Test conditions

The atmospheric conditions during the test shall be

- ambient air temperature: 10 °C to 30 °C;
- relative humidity: 45 % to 75 %;
- air pressure: 86 kPa to 106 kPa.

7.2.601.2 Application of the test voltage

The test voltage shall be applied to the connecting points of the LPIT, non powered, 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, the secondary converter and merging unit can be independent circuits.

For devices with an insulating enclosure, the exposed conductive parts needed for testing 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.

7.2.601.3 Power-frequency voltage withstand test

The power-frequency voltage withstand tests shall be made by applying the insulation requirements for low-voltage components specified in 5.3.5

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 substantially sinusoidal with a frequency between 45 Hz and 65 Hz.

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.

7.2.601.4 Impulse-voltage withstand test

The impulse-voltage withstand tests shall be made by applying the voltage given in 5.3.5.

A standard lightning impulse in accordance with IEC 60060-1 shall be used. The parameters are:

– 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. After the test, the electronic shall still comply with basic accuracy tests.

7.3 Routine tests

7.3.1 Power-frequency voltage withstand tests on primary terminals

Requirements of IEC 61869-1:2007, 7.3.1 are applicable with the following addition:

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

7.3.4 Power-frequency voltage withstand tests on secondary terminals

Subclause 7.3.4 of IEC 61869-1:2007 is applicable with the following modifications:

The test voltage is defined in 5.3.5.

7.3.5 Test for accuracy

The routine test is, in principle, the same as the type test in 7.2.6.602. However, routine tests at a reduced number of test points are permissible if type tests on a similar LPIT have demonstrated that such a reduced number of tests is sufficient to prove compliance with a specified accuracy class.

7.3.601 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 7.2.601). The duration of the test can either be 1 min as described in 7.2.601 or 1 s at 1,1 times the specified test voltage level defined in 5.3.5.

7.4 Special tests

7.4.601 Vibration tests

7.4.601.1 Vibration 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 according to 6.607.

7.4.601.2 Vibration test for primary parts

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

7.4.601.2.1 Vibration test for primary parts during short-time current

This test is performed to determine that the low-power instrument transformer 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 a 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 low-power instrument transformer 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 low-power instrument transformer should be connected via a rigid connection to the circuit-breaker.

7.4.601.2.2 Vibration tests for primary parts mechanically coupled to a switchgear

7.4.601.2.2.1 General

These tests shall apply to LPIT’s mounted on AIS circuit-breaker, GIS switchgear, medium voltage switchgear and dead tank circuit-breaker.

7.4.601.2.2.2 Vibration during operation

This test is performed to determine that the low-power instrument transformer operates correctly in the presence of vibration resulting from circuit-breaker and disconnector 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 low-power instrument transformer 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.

7.4.601.2.2.3 Vibration endurance test

The circuit-breaker shall be operated without primary current 2 000 times (class M1) or 10 000 times (class M2) as described in IEC 62271-100. Low-power instrument transformer accuracy at rated current and rated voltage shall be measured before and after the test. The low-power instrument transformer error following the test shall 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 a low-power instrument transformer test on such a circuit-breaker may be considered valid for other circuit-breakers, subject to agreement between manufacturer and purchaser.

601 Information to be given with enquiries, tenders and orders

601.1 Designation

When specifying an LPIT for an enquiry or an order, the relevant items necessary to determine its performance are given in the relevant product standards.

601.2 Dependability

The manufacturer shall provide a reliability and dependability credibility file (see 6.606).

Annex 6A
(normative)

LPIT frequency response and accuracy requirements for harmonics

6A.1 General

The requirements in 6A.2 are relevant for all LPIT. The requirements in 6A.3 are relevant for LPIT involving digital data processing or transmission even if they have an analogue output.

The accuracy tests versus frequency on LPIT are presented in 6A.5.

6A.2 Requirements for noise and distortion

The requirements on noise are specified in 6.603.

The output of the LPIT can contain some perturbations added to the white noise common to all electrical systems. Such perturbation can be generated by the LPIT over a broad frequency band, and in the absence of any primary signal.

NOTE The source of these perturbations may be clock signals of the converters, multiplexer commutation noise, d.c./d.c. converter, commutation frequencies.

The following procedure is recommended:

– with no primary signal, measure the output of the instrument transformer 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 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 a useful indication may be:

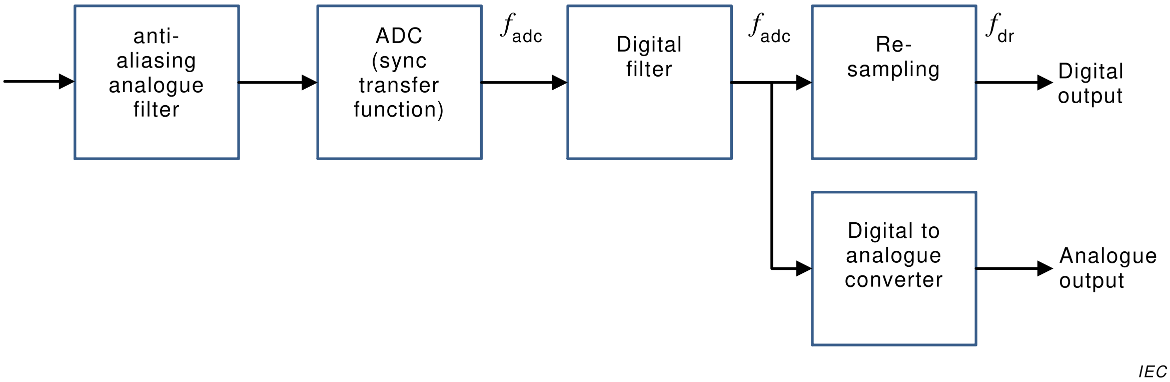
– with a 'pure' sinusoidal primary signal at rated frequency and magnitude, measure the output of the instrument transformer using a spectrum analyser for example. This would give an image of the harmonic distortion induced by the instrument transformer itself.

6A.3 Anti-aliasing filter requirements for LPIT using digital data processing

Digital and discrete time data processing limits the bandwidth to half the digital sampling rate f_s. If different sampling rates along the signal processing path are used, the lowest rate is the limiting factor. For instrument transformers with digital output, the lowest rate is usually the output sampling rate. Frequencies above f_s / 2 are mirrored to frequencies below f_s / 2. From the point of view of accuracy, the most critical frequencies are those mapped on to the power system frequency f_r. The first frequency which is mapped on f_r is

$$f_s - f_r$$

Figure 6A.1 shows an example of a digital data acquisition system.



Key

f_{adc} ADC sampling rate

f_{dr} Output sampling rate

Figure 6A.1 – Digital data acquisition system example

If f_{adc} is larger than f_{dr}.the signal bandwidth is equal to f_{dr} / 2, otherwise the signal bandwidth is equal to f_{adc} / 2.

Hence, a so-called anti-aliasing filter shall be used. Minimum anti-aliasing filter attenuation requirements are specified as a function of the instrument transformer accuracy class in Table 6A.1.

Table 6A.1 – Anti-aliasing filter

Accuracy class	**Anti-aliasing filter attenuation** ($f \geq f_s - f_r$)
0,1	≥34 dB
0,2	≥28 dB
0,5	≥20 dB
1	≥20 dB
All Protection classes	≥20 dB

Attenuation, expressed in decibels (dB), is calculated according to the following formula:

$$\text{Attenuation} = 20 \log_{10} \frac{I_p \times I_{sr}}{I_s \times I_{pr}} \text{(dB)}$$

where

I_p is the r.m.s. value of the primary current at frequency f, with $f \geq f_s - f_r$;

I_s is the r.m.s. value of the secondary output at the mirrored frequency, that is, at $f_s - f_r$;

I_{pr} is the rated primary current;

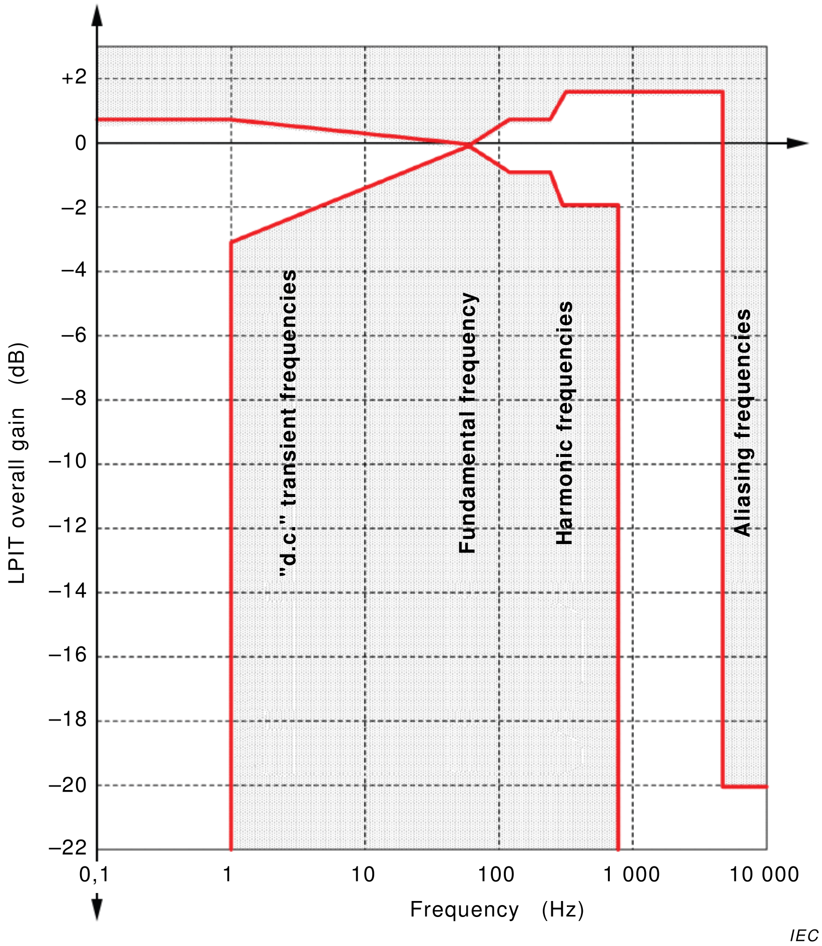
I_{sr} is the rated secondary output.

For low-power voltage transformer, replace current I by voltage U.

6A.4 LPIT accuracy requirements for harmonics and low frequencies

6A.4.1 General

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. Figure 6A.2 illustrates the harmonic and anti-aliasing frequency response magnitude requirements for metering accuracy class 1 where f_r = 60 Hz and f_s = 4 800 Hz. Specific accuracy requirements for each class are given in the following subclauses.



Key

Prohibited region for response

Figure 6A.2 – Frequency response mask for metering accuracy class 1 (f_r = 60 Hz, f_s = 4 800 Hz)

6A.4.2 Measuring accuracy classes

Table 6A.2 gives the limit of errors for the measuring classes.

Table 6A.2 – Measuring accuracy classes

Accuracy class (at f_r)	**Ratio error at low frequency**		**Ratio error (+/–) at harmonics**					**Phase displacement (+/–) at low frequency**	**Phase error (+/–) at harmonics**			
								Degrees	Degrees			
	0 Hz	1 Hz	2^{nd} to 4^{th}	5^{th} and 6^{th}	7^{th} to 9^{th}	10^{th} to 13^{th}	Above 13^{th}	1 Hz	2^{nd} to 4^{th}	5^{th} and 6^{th}	7^{th} to 9^{th}	10^{th} to 13^{th}
0,1	+1 % −100 %	+1 % −30 %	1 %	2 %	4 %	8 %	+8 % −100 %	45	1	2	4	8
0,2 0,2S	+2 % −100 %	+2 % −30 %	2 %	4 %	8 %	16 %	+16 % −100 %	45	2	4	8	16
0,5 0,5S	+5 % −100 %	+5 % −30 %	5 %	10 %	20 %	20 %	+20 % −100 %	45	5	10	20	20
1	+10 % −100 %	+10 % −30 %	10 %	20 %	20 %	20 %	+20 % −100 %	45	10	20	20	20
3 5	–	–	–	–	–	–		–	–	–	–	–
NOTE 0 Hz in the first column means d.c. coupling is allowed but not required.												

The transition between points defined in the above table shall be a straight line when shown in log/log scale.

The above limits apply equally to low-power voltage and current transformers.

6A.4.3 Accuracy class extension for quality metering and low bandwidth d.c. applications

According to EN 50160 and IEC 61000-4-7, for such purposes, harmonics up to the 40^{th} order (in some cases even to the 50^{th} order) are measured. IEC 61000-4-7 specifies that the relative error (related to the measured value) shall not exceed 5 %.

These extensions can be applied to all accuracy classes to indicate better performances at high frequencies.

The limit of accuracy for quality measurement and instrument transformers for d.c. application are given in Table 6A.3.

Table 6A.3 – Accuracy classes extension for quality metering and low bandwidth d.c. applications

Accuracy class	**Ratio error (+/–) at frequencies shown below**			**Phase error (+/–) at frequencies shown below**		
				Degrees		
	$(0,1 \leq f < 1)$ kHz %	$(1 \leq f < 1,5)$ kHz %	$(1,5 \leq f < 3$ kHz) %	$(0,1 \leq f < 1)$ kHz	$(1 \leq f < 1,5)$ kHz	$(1,5 \leq f < 3)$ kHz
0,1	1	2	5	1	2	5
0,2 0,2S	2	4	5	2	4	5
0,5 0,5S	5	10	10	5	10	20
1	10	20	20	10	20	20
For d.c. applications the phase errors are not applicable.						

The accuracy classes 0,2S and 0,5S apply only for low-power current transformers.

The above limits of the Table 6A.3 apply equally to both, low-power voltage transformers and low-power current transformers.

The limits of accuracy for high bandwidth instrument transformers for d.c. application with high bandwidth application are given in Table 6A.4.

Table 6A.4 – Accuracy classes extension for high bandwidth d.c. applications

Accuracy class	Ratio error (+/–) at frequencies shown below			Phase error (+/–) at frequencies shown below		
				Degrees		
	(0,1 ≤ f < 5) kHz %	(5 ≤ f < 10) kHz %	(10 ≤ f < 20) kHz %	(0,1 ≤ f < 5) kHz	(5 ≤ f < 10) kHz	(10 ≤ f < 20) kHz
0,1	1	2	5	1	2	5
0,2 0,2S	2	4	5	2	4	5
0,5 0,5S	5	10	10	5	10	20
1	10	20	20	10	20	20
For d.c. applications the phase errors are not applicable.						

Class 0,2S and 0,5S apply only for low-power current transformers.

The above limits apply equally to both, low-power voltage and low-power current transformers.

6A.4.4 Protective accuracy classes

Table 6A.5 applies to all protective accuracy classes. 16,7 Hz or 20 Hz are relevant to cover possible influences coming from railway power frequencies (for electrical network with rated frequency at 50 Hz or 60 Hz).

Table 6A.5 – Protective accuracy classes

Accuracy class	Ratio error (+/–) at frequencies and harmonics shown below		Phase error (+/–) at frequencies and harmonics shown below	
			Degrees	
	1/3rd component (16,7 Hz or 20 Hz) %	2nd to 5th harmonic %	1/3rd component (16,7 Hz or 20 Hz)	2nd to 5th harmonic
All protection classes	10	10	10	10

Above limits apply equally to both low-power voltage and low-power current transformers.

6A.4.5 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 claim to be much more accurate than conventional reactance based fault locators. 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. No consensus for general requirements for this kind of application is available at the date of the publication. Table 6A.6 and the bandwidth is given for information only.

Table 6A.6 – Accuracy classes for special high bandwidth protection

Accuracy class	Maximum peak instantaneous error (+/–) at frequencies shown below	
Special high bandwidth protection	From f_r to 50 kHz	At 500 kHz
	10 %	30% (3dB)

NOTE 1 Travelling wave relays are designed especially for this purpose and are very special (very large bandwidth, etc.). Although conventional CT's often have sufficient bandwidth it is customary for the manufacturer to supply the relay/fault locator together with the current/voltage transformers 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 fault.

NOTE 2 Due to the high bandwidth, this class is not suitable for the standardized digital outputs.

6A.4.6 Special accuracy classes for d.c. coupled low-power voltage transformers

Low-power voltage transformers of this class shall be able to give some indication on the amount of d.c. voltage on the a.c. line. In this case the user does not need 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 6A.4.4 shall also apply.

Additional requirement are given in Table 6A.7.

Table 6A.7 – Accuracy classes for special d.c. coupled low-power voltage transformers

Accuracy class	Maximum peak instantaneous error (+/–) at frequencies shown below
Special d.c. protection (for low-power voltage transformer)	from 0 Hz (d.c.) to f_r
	10 %

Care should be taken with an analogue output that the input transformers of the connected relays do not saturate, since the low-power voltage transformer may not discharge the line (constant d.c.-output for the low-power voltage transformer). Of course, with digital output, there is no such problem.

6A.5 Tests for accuracy versus harmonics and low frequencies

The tests are carried out to demonstrate that an LPIT complies with the accuracy requirement on harmonics and low frequencies given in the clause 6A.4.2. In an ideal case, tests on harmonics should be made with the rated input signal at the rated frequency plus a percentage of the rated primary input signal at each considered harmonic frequency. Such a primary input signal 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 a primary input signal. 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.

6A.6 Test arrangement and test circuit

6A.6.1 Test for accuracy for harmonics and low frequencies

Frequency response requirements defined in Table 6A.2 above are very important for achieving device interoperability. Verification of these requirements may, however, be quite difficult and requires intimate knowledge of physical properties and limitations of the tested device's technology. Frequency response testing shall fulfil the harmonics requirement described in Table 6A.2.

The use of a suitable test setup is required (see IEC TR 61869-103 for more details).

Ferromagnetic circuit based devices (conventional CTs, VTs, CVTs and SAMU auxiliary input transformers) are susceptible to ferromagnetic core saturation and cannot in general be tested at low frequencies using full voltage/current levels. For these devices, measurements at frequencies below the nominal system frequency should be performed with test signal magnitude reduced in inverse proportion with the frequency:

$$I_{\text{test}} = I_{\text{pr}} \times \frac{f_{\text{test}}}{f_{\text{r}}}$$

Rogowski coil/air coil based devices provide output whose magnitude increases with frequency. To avoid measurement circuit clipping, testing above the nominal system frequency should be performed with test signal magnitude reduced in proportion with the frequency:

$$I_{\text{test}} = I_{\text{pr}} \times \frac{f_{\text{r}}}{f_{\text{test}}}$$

Opto-electronic based devices are normally insensitive to test signal frequency. The test signal level at different frequencies will be determined primarily by the test laboratory capabilities.

Test currents and voltages for the special d.c. coupled low-power voltage transformers (6A.4.6) are shown in Table 6A.8.

Table 6A.8 – Accuracy classes for harmonics

Accuracy class	Magnitude of currents(or voltage) for accuracy tests (% of I_{pr}) or (% of U_{pr})	
	DC to f_r step every 10 Hz	f_r to the 5th harmonic step every harmonic
Special d.c. (for low-power voltage transformers)	20 %	20 %

6A.6.2 Type test for proper anti-aliasing

The attenuation is calculated and the limit given in 6A.3 is checked. Where agreed to by the user and manufacturer, injection may be into the secondary converter.

The magnitude of the primary signal shall be at least 1 % of the rated primary signal.

NOTE 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 systems.

Annex 6B
(informative)

Transient performances of low-power current transformers

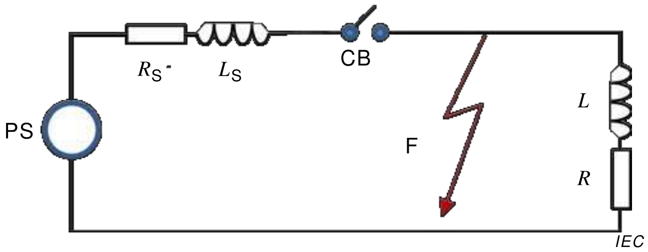
6B.1 General

Power system short-circuit currents contain alternating current (a.c.) and transient components. The transient component is also known as direct current (d.c.) component. As is described later in this annex, the a.c. component is at power system frequency, while the d.c. component decays exponentially over time. Current sensors, both conventional iron-core-based current transformers (CT) and low-power current transformers (LPCT) represent short-circuit currents with some errors. AC component errors may affect protection relay operation, while d.c. component errors are not usually relevant for relay protection using phasor-based algorithms as the d.c. component is filtered out. However, the d.c. component can cause saturation of current sensors that have non-linear elements such as iron-core CTs, distorting the a.c. component representation. DC component error may depend on the magnitude and duration of the d.c. component. If the current sensors do not saturate and do not have non-linear elements, d.c. components do not contribute to a.c. component errors.

Requirements for conventional CTs that use magnetic materials, which have non-linear characteristics, are provided in IEC 61869-2. Low-power current transformers that are based on different technologies like optical CTs that are appreciably linear (linearity defined by electronics) or Rogowski coils that by design do not have non-linear elements are not subject to the limitation of conventional CTs caused by phenomena such as saturation. The goal of this annex is to summarize benefits of using low-power current transformers for improved transient performances.

6B.2 Short-circuit currents in power systems

Figure 6B.1 shows a simplified circuit diagram of a power system and illustrates a fault (short-circuit) in the network. During normal operation, currents are limited by the load impedance. When a fault occurs, the current increases and is limited by the source and line impedances that are much smaller than the load impedance. Fault current is interrupted by a circuit breaker. The short-circuit current is modelled by Equation 6B.1 (pre-fault current is not represented). The fault current waveform is shown in Figure 6B.2. The first term in Equation 1 represents the decaying d.c. component of the fault current, while the second term represents the a.c. component. When the d.c. component is minimal, the fault current is considered symmetric.



$$T_p = \frac{L_S}{R_S}$$

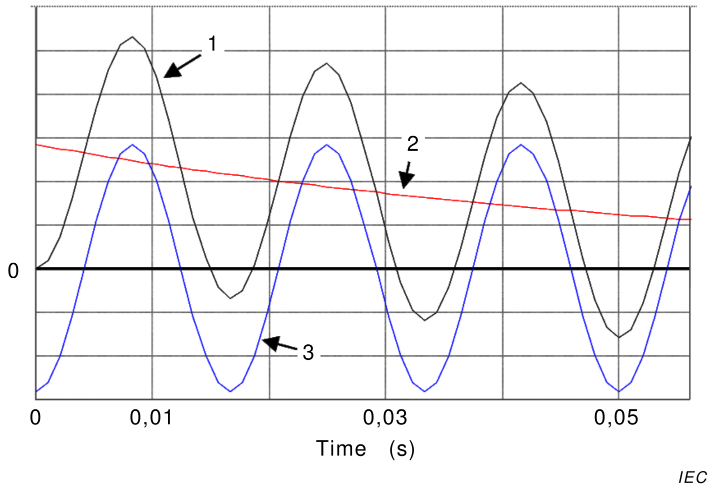
Key

R_s, L_s	Source impedance
CB	Circuit breaker
F	Fault (short circuit)
PS	Power system
R, L	Load impedance

Figure 6B.1 – Illustration of a fault in a power system

$$i(t) = \sqrt{2} \times I_{psc} \times \left[e^{-t/Tp} \times \cos\theta - \cos(\omega t + \theta) \right] \qquad (6B.1)$$

$i(t)$	short-circuit current instantaneous value
I_{psc}	short-circuit current r.m.s. value
θ	fault incidence angle
T_p	primary circuit time constant



Key

1 Short-circuit current

2 DC component

3 AC component

Figure 6B.2 – Short-circuit current a.c. and d.c. components

Assuming that the source and line are practically inductive, symmetric fault current is obtained for θ = 90° (see Figure 6B.3), while a full-offset (asymmetric) fault current is obtained for θ = 0° (see Figure 6B.4).

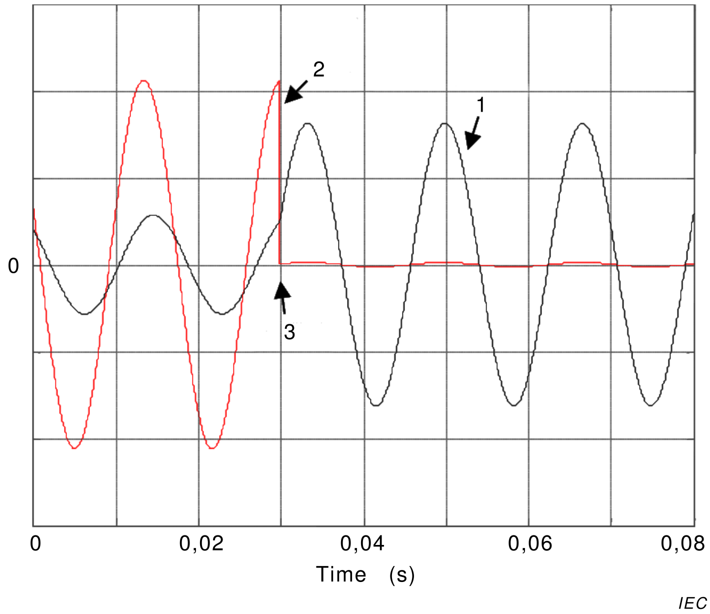


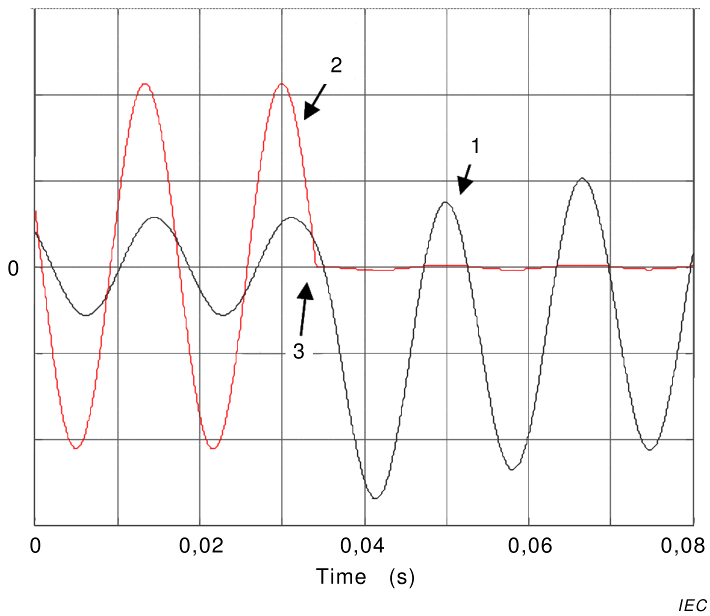
Figure 6B.3 – Symmetric fault current

Key

1 Short-circuit current

2 Voltage

3 Fault incidence angle θ = 90°



Key

1 Short-circuit current

2 Voltage

3 Fault incidence angle θ = 0°

Figure 6B.4 – Asymmetric fault current

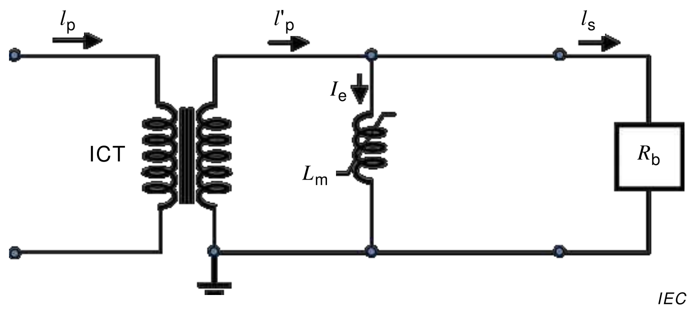
When a fault occurs, protective relays initiate circuit breaker operation that interrupts the fault current. Fault current interruption is within two to five cycles after the breaker operation is initiated by the relay. Because the majority of faults are temporary, the circuit breaker may be designed to reclose after a pre-set period of time. If the fault is permanent, the fault current will be re-established and the circuit breaker will open again and, in the majority of cases, will not close again (will lockout). Therefore, IEC standards specify that the CT performance shall be tested for two consecutive short-circuit current periods.

The actual power system is a complex electric network, so Equation 1 is not adequate to accurately estimate short-circuit current values. It can only be used to approximate values. Short-circuit current a.c. and d.c. components depend on factors such as the primary time constant, fault location, and the network configuration. The primary circuit time constant near substations can be long (e.g. 200 ms), but a few kilometres from the substation (due to the line resistance) can be much shorter (e.g. 60 ms). Short-circuit current magnitudes also depend on the fault location (distance from the substation) and type of fault. To properly specify CT requirements during transient periods, power system parameters shall be accurately determined.

6B.3 Conventional current transformer equivalent circuit

In most cases, for relay applications, adequate CT transient analysis can be performed by a simplified CT equivalent circuit of Figure 6B.5.

Generally, CT parameters that should be represented include the magnetizing branch L_m (a non-linear element) and the CT burden. Typically, microprocessor-based relays are low-burden devices having a low resistance as seen by the CT and can be neglected. Therefore, the CT burden R_b may be represented only by the CT wire resistance and lead resistance.



Key

I_p Primary current (short-circuit current in the power system)

I_s CT secondary current

L_m CT magnetizing branch

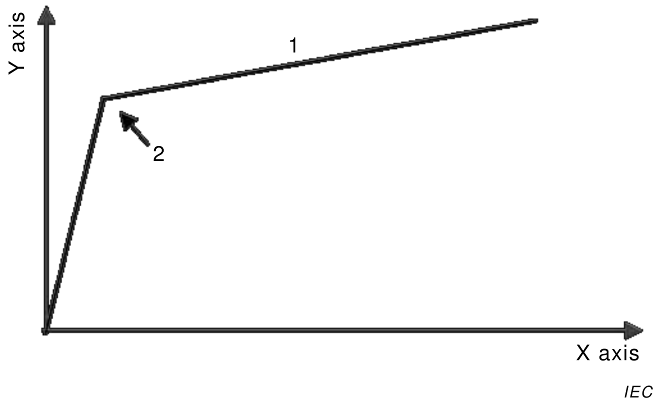
R_b CT burden

ICT Ideal current transformer

Figure 6B.5 – Equivalent electrical circuit of a conventional CT

The CT magnetizing branch L_m has a non-linear volt-current (flux-current) characteristic as illustrated in Figure 6B.6.

The flux is proportional to the integral of the voltage.



Key

1 Saturation region

2 Knee point

Y axis Magnetic flux

X axis Exciting (magnetizing) current

Figure 6B.6 – Flux-current characteristic for a conventional CT without remanence representation

During normal operation magnetizing branch impedance is much higher than the CT burden impedance, so just a fraction of the CT secondary current flows through the magnetizing branch. For simplified representation, it can be considered that magnetizing branch is open-circuited and can be ignored.

However, during faults when primary currents are high, voltage across the magnetizing branch increases and can exceed the knee-point value. When this happens, the magnetizing branch impedance will rapidly decrease (saturation occurs) and the current through the magnetizing branch will increase. During severe saturation periods most of the CT secondary current flows through the magnetizing branch and only a fraction of the current flows through the CT burden, resulting in a high CT transformation error. For simplified representation, it can be considered that the CT burden is short-circuited and no current flows through it. The current in the secondary circuit has near-zero value.

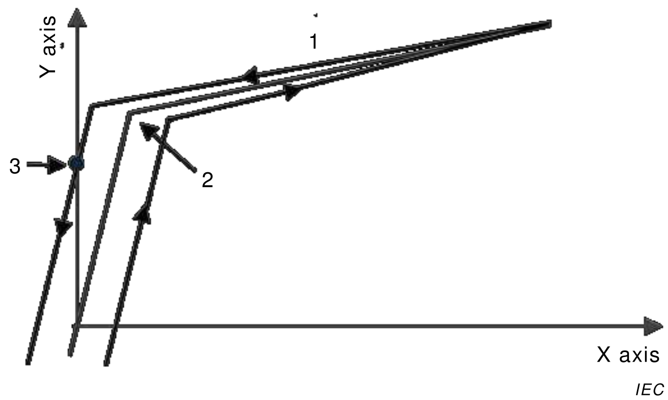
The above explanation is appropriate for studying protection relay operation during CT saturation. However, the phenomena of CT saturation may be more accurately described as a weakening of the mutual coupling between the primary and secondary windings. When a CT saturates the induced CT secondary current decreases (will not increase at the same rate as the primary current) which results in a high CT transformation error.

During steady-state conditions, the CT saturation depends on the CT secondary voltage magnitude, which is a function of the CT secondary current and the CT burden. To avoid saturation, the CT secondary voltage shall be below the knee-point value of the volt-current characteristic.

During transient conditions, such as short-circuits, the flux is influenced by both the a.c. and d.c. components of the primary current. The longer the primary circuit time constant the more likely the knee-point will be reached. To avoid saturation, the size of the CT core may be increased and/or the burden decreased.

When the short-circuit current is interrupted, the magnetic core will not return immediately to its initial conditions because the transient exponential current will continue to flow through the secondary circuit, decaying with the time constant of the secondary circuit T_s. Secondary current flowing after primary current is interrupted is called subsidence current. Due to the high CT core reactance, T_s can be much longer than the primary circuit time constant T_p. Depending on the size of the CT core, the CT secondary circuit time constant T_s can have values of 2 s to 5 s. If another fault occurs before this current decay, the combined effect of the two faults may cause CT saturation where either alone would not.

Another recognized problem for CTs (that use the core without air gap) is remanent flux. Because of the CT core material hysteresis, when the fault current is interrupted during the CT saturation the CT core may retain remanent flux, as illustrated in Figure 6B.7. Remanent flux cannot decay and can be retained in the CT core for a long period of time. The CT core can retain remanent flux at about 80 % of the saturation flux. If a fault occurs when the CT retains remanent flux then the CT may saturate sooner than without the remanent flux. This will happen when the flux caused by the fault current adds to the remanent flux. However, if the flux caused by the fault current is in the opposite direction of the retained flux, the CT may not saturate at all.



Key

1 Saturation region

2 Knee point

3 Remanent flux

Y axis Magnetic flux

X axis Exciting (magnetizing) current

Figure 6B.7 – Representation of hysteresis and remanent flux for a conventional CT

A common practice for reducing remanence is the introduction of an air gap into the core. However, air gaps increase manufacturing costs, and have negative impact on other performance parameters.

6B.4 Types of current transformers

6B.4.1 Types of conventional CTs

Conventional CTs may have high accuracy during steady-state conditions. However, during faults involving high currents they may saturate, resulting in distorted secondary current waveforms and high transformation errors. Remanence in the CT core can contribute to faster and more severe saturation. To achieve required performance for relay protection applications, different designs of conventional CTs have been developed and applied, especially related to the CT core design. IEC standards specify requirements for different CT classes such as P, PR, PX, PXR, TPX, TPY, and TPZ. This annex includes a summary of the protective CT classes presented in Table 6B.1 defined by IEC 61869-2:2012 standard (Table 204).

Table 6B.1 – Protective CTs

Designation	Limit for remanent flux	Explanation
P	No [a]	Defining a CT to meet the composite error requirements of a short-circuit current under symmetrical steady state conditions
PR	Yes	
PX	No [a] [b]	Defining a CT by specifying its magnetizing characteristic
PXR	Yes [b]	
TPX	No [a]	Defining a CT to meet the transient error requirements under the conditions of an asymmetrical short-circuit current
TPY	Yes	
TPZ	Yes	

[a] Although there is no limit of remanent flux, air gaps are allowed, e.g. in split core CT's.

[b] To distinguish between PX and PXR, the remanent flux criteria is used.

6B.4.2 Types of low-power current transformers

There are several different types of low-power current transformers defined by IEC 61869 standard series. IEC 61869-8[3] specifies requirements for electronic CTs such as optical CTs. IEC 61869-10 specifies requirements for low-power iron-core CTs and Rogowski coils. General requirements for electronic CTs and low-power current transformers are covered by IEC 61869-1 and this standard. IEC 61869-9 specifies requirements for digital interface for instrument transformers.

Optical CT technology is based on the Faraday effect, a phenomenon where the orientation of polarized light rotates proportional to the strength of the magnetic field component in the direction of the optical path. Transient performance is determined by the electronics. For applications with relays designed for low-power current transformer inputs, secondary output voltage at rated current usually is 200 mV and frequency bandwidth such as 0,5 Hz to 10 kHz.

Low-power iron-core CTs have similar designs to conventional CTs but employ a minimized iron core, resulting in a reduced size and weight. An internal resistor is connected across the output terminals, producing the output voltage directly proportional to the current. Because of the iron core, they can saturate similar to conventional CTs, which shall be considered when selecting these low-power current transformers. Usually, secondary output voltage at rated current is 22,5 mV.

Rogowski coils have linear volt-current characteristics because the wire is wound over a non-magnetic core. When design criteria are met, Rogowski coils achieve high accuracy and the same sensor can be used for both protection and metering. They produce an output voltage that is a scaled time derivative $\mathrm{d}i(t)/\mathrm{d}t$ of the primary current. Rogowski coils are frequency-dependent devices with a linear volt-frequency characteristic. Rogowski coils cannot saturate and can be applied in systems with high fault currents and high d.c. components. Typically, secondary output voltage at rated current is 22,5 mV or 150 mV and frequency bandwidth from 0,1 Hz to over 1 MHz (depending on the design).

Class TPE low-power current transformers are designed for relay protection applications. The accuracy is defined by the highest permissible percentage composite error at the rated accuracy limit primary current prescribed for the accuracy class concerned. Class TPE designates transient protection electronic class CTs. Class TPE is defined by a maximum peak instantaneous error of 10 % at the accuracy limit condition, the rated primary circuit time constant, and the rated duty cycle. The peak instantaneous error includes d.c. and a.c. components. This is equivalent to the definition of TPY-class CTs.

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3 Under consideration

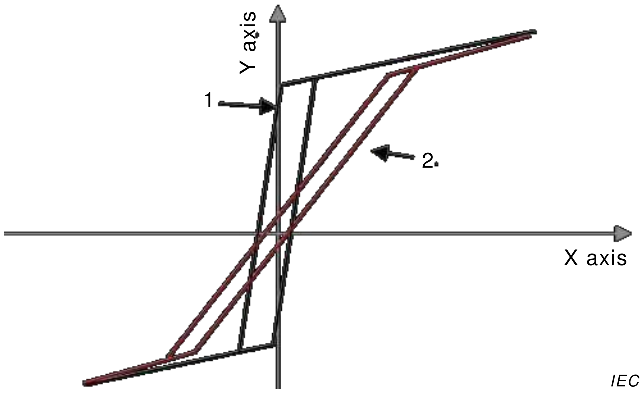
6B.5 Transient performance of current transformers

6B.5.1 Transient performance of conventional current transformers

When short-circuit currents are low and the primary circuit time constant is short as not to saturate CTs, gapless CTs may be used. However, it is important to verify that CTs will not saturate during steady-state conditions (a.c. component).

When short-circuit currents are high and the d.c. component is significant, the gapless CT transient performance shall be defined and the appropriate CT selected. To avoid saturation, CTs shall be adequately sized or have designed protection systems that will operate fast, before the CT saturation. In most cases when a fault occurs with high d.c. component, CT's will not saturate in the first several milliseconds following the fault inception. However, remanent flux may decrease time-to-saturation, which needs to be considered.

Gapped class CTs such as TPZ, TPY, PR and PXR are often used to avoid saturation and reduce the remanence. The impact of air gap on the flux-current characteristic is shown in Figure 6B.8. Air gap minimizes remanence and effects of the d.c. component on the CT transient performance. However, the d.c. component may not be correctly transferred to the secondary circuit and the phase displacement is larger than conventional protective class CTs.



Key

1 CT without air gap

2 CT with air gap

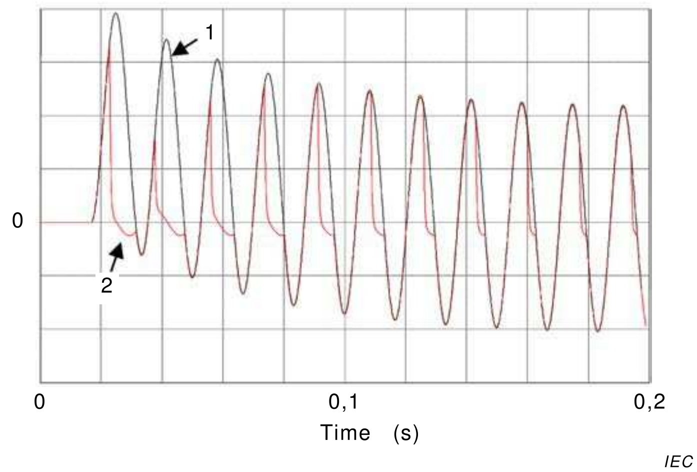
Y axis Magnetic flux

X axis Exciting (magnetizing) current

Figure 6B.8 – Comparison of flux-current characteristics for gapped and gapless CTs

If the phase displacement has to be kept small, TPY-class CTs should be used. In this design, the magnetic core size is increased to avoid saturation. Depending on the primary circuit time constant, the required CT core size increase can be significant. Assuming that there is no remanence in the CT core, and to avoid saturation for the maximum d.c. offset, dimensioning transient factor K_{tf} is defined by equation $K_{tf} = 1 + T_p\omega$. For example, for T_p = 100 ms, K_{tf} is 32 for a power frequency of 50 Hz. The air gap in the CT core reduces remanent flux. Transient error includes both a.c. and d.c. components.

Figure 6B.9 shows primary current with d.c. offset and the CT secondary current distorted due to the CT saturation caused by the primary current d.c. component. Figure 6B.10 shows r.m.s. value of the primary current (includes a.c. and DC components); r.m.s. value of the primary current a.c. component only; and r.m.s. value of the primary current a.c. component for a saturated CT. The shaded area in Figure 6B.10 is the primary current a.c. component that was not transferred to the CT secondary circuit due to CT saturation. This results in reduced value of the short-circuit current derived by the relay which may affect proper operation of protective relays.

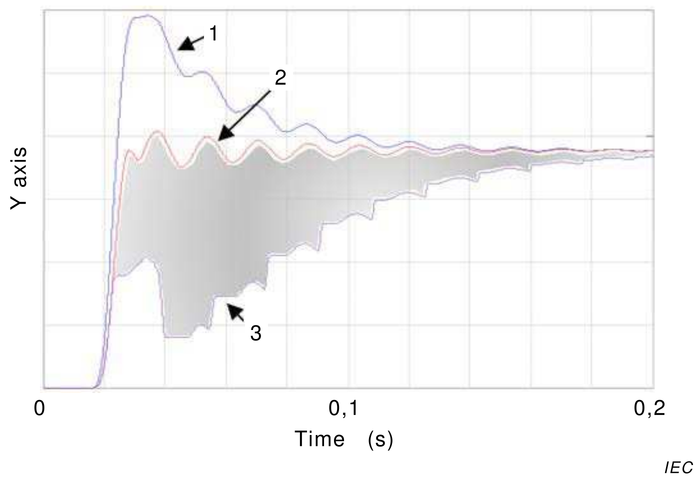


Key

1 Primary current

2 CT secondary current distorted due to saturation

Figure 6B.9 – Secondary current distorted due to the CT saturation



Key

1 Primary current with d.c. offset

2 AC component for non-saturated CT

3 AC component for saturated CT

Y axis Current r.m.s. value

The shaded area is the secondary current r.m.s. value that the relay cannot sense due to CT saturation.

Figure 6B.10 – AC component for non-saturated and saturated CT

6B.5.2 Transient performance of low-power current transformers

Low-power current transformers have a wider range of applications than conventional CTs. They do not saturate at high currents and high d.c. components do not affect their performance. The primary current a.c. component can be correctly transferred (without distortion) to the low-power current transformer secondary side. Protection solutions based on low-power current transformers may employ low cut-off (roll-off) frequency (below 1 Hz). TPE-class CTs implicitly define low cut-off frequency (related to the low-power current transformer secondary time constant) to limit peak instantaneous error of the d.c. component below 10 %.

A longer primary time constant requires a lower cut-off frequency to obtain the same peak instantaneous error of the d.c. component.

If a low-power current transformer is applied in a network with a longer primary time constant than the rated time constant or if its low cut-off frequency is higher than specified for TPE-class low-power current transformers, the peak instantaneous error of the d.c. component will increase. However, if the low-power current transformers operating characteristic is sufficiently linear, the peak instantaneous error of the a.c. component will remain low or within the specified limits. The transient behaviour is similar to conventional TPZ-class CTs. As the relay protection algorithms usually depend only on the peak instantaneous errors of a.c. components, the impact on the relay operation may be minimal. If the low-power current transformers operating characteristic is non-linear, the peak instantaneous error of the a.c. component will increase and may exceed an acceptable limit. Manufacturers should therefore specify acceptable peak instantaneous errors of a.c. components for their applications.

Example: Assume a rated primary time constant of 60 ms, which is equivalent to frequency of 2,67 Hz, and a low-power current transformers designed with a low cut-off frequency of 0,5 Hz. This satisfies error limits for TPE class low-power current transformers. If, for any reason, a primary fault current has a longer time constant like 200 ms (equivalent to a frequency of 0,8 Hz), the d.c. component error will be higher but will not cause error of the a.c. component. Therefore, the impact on the relay protection operation may be minimal.

Cut-off frequencies are also defined by this standard that specifies frequency response boundaries for digital interface for instrument transformers. Low and high cut-off frequencies are specified. DC coupling is also allowed. IEC standards specify amplitude and phase characteristic within the pass-band boundaries to ensure interoperability of protection devices and stop-band attenuation to prevent signal aliasing. The transition band is not specified to allow for different hardware and software implementations.

These systems can transmit the a.c. component with low errors while removing part of or the entire d.c. component. This implies that the primary time constant can be long without affecting the accuracy of the a.c. component measurement.

6B.6 Summary

Conventional iron core-based CTs may saturate during faults. A major cause for saturation is the fault current d.c. component. CTs can be adequately sized to avoid saturation or, in some cases, the protection system can be made to operate fast enough so that the CT will not saturate. An air gap in the CT core reduces flux remanence and the impact of the d.c. component.

Low-power current transformers have a wider range of applications than conventional CTs. Low-power current transformers, such as optical CTs and Rogowski coils, have linear characteristics and do not saturate. They can be applied for faults involving high currents and high d.c. components. However, they require electronics for signal conditioning or adequately designed relays to accept these types of signals. Protection solutions based on low-power current transformers may employ low cut-off frequency. The d.c. component may be filtered out, but the a.c. component is accurately represented.

Annex 6C
(informative)

Transient performances of low-power voltage transformers

6C.1 Overview

This annex gives the information required to deal with transient performance conditions.

In order to improve understanding of these conditions it is useful to create a simple modelling of the low-power voltage transformer which makes it easy to describe the theoretical considerations.

6C.2 General

6C.2.1 Defining primary and secondary voltages

Primary and secondary voltages can be described by the following equations:

$$u_{\mathrm{p}}(t) = U_{\mathrm{p}}\sqrt{2} \times \sin(2\pi f t + \varphi_{\mathrm{p}}) + U_{\mathrm{pdc}}(t) + u_{\mathrm{p\ res}}(t)$$

$$u_{\mathrm{s}}(t) = U_{\mathrm{s}}\sqrt{2} \times \sin(2\pi f t + \varphi_{\mathrm{s}}) + U_{\mathrm{sdc}}(t) + u_{\mathrm{s\ res}}(t)$$

where

U_{p}	is the r.m.s. value of the primary voltage when $U_{\mathrm{p\ dc}}(t) = 0$ and $u_{\mathrm{p\ res}}(t) = 0$;
U_{s}	is the r.m.s. value of secondary voltage when $U_{\mathrm{s\ dc}}(t) = 0$ and $u_{\mathrm{s\ res}}(t) = 0$;
f	is the fundamental frequency of the network in hertz;
$U_{\mathrm{p\ dc}}(t)$	is the primary direct voltage, caused for example by trapped charges in volts;
$U_{\mathrm{s\ dc}}(t)$	is the secondary direct voltage, caused, for example, by $U_{\mathrm{p\ dc}}(t)$ and/or EVT internally produced offset in volts;
φ_{p}	is the primary phase in radians;
φ_{s}	is the secondary phase in radians;
$u_{\mathrm{p\ res}}(t)$	is the primary residual voltage, including harmonic and subharmonic components;
$u_{\mathrm{s\ res}}(t)$	is the secondary residual voltage, including harmonic and subharmonic components;
t	is the instantaneous value of time, in seconds.

f, U_{p}, U_{s}, $U_{\mathrm{p\ dc}}$, $U_{\mathrm{s\ dc}}$, φ_{p}, φ_{s} being constant for steady-state conditions.

For the purposes of metering and protection, LPVTs shall give a correct measurement of the components at frequency f. Other terms of the equations describe unwanted components which can add errors to the measured signal.

6C.2.2 Normal service conditions of the network

Under normal service conditions the primary voltage U_{p} and the frequency f will remain between fixed limits due to the regulation of the network. For example

$$0{,}8\ U_{\mathrm{pr}} \leq U_{\mathrm{p}} \leq 1{,}2\ U_{\mathrm{pr}}$$

$$0{,}99\, f_r \leq f \leq 1{,}01\, f_r$$

Under normal service conditions LPVTs designed for measurement purposes are used, more often than not, in combination with measurement CTs, i.e. for metering.

6C.2.3 Abnormal service conditions of the network

Due to troubles on the network the primary voltage U_p and the frequency f can be significantly different from their rated values.

Low-power voltage transformers used for metering purposes shall withstand these situations without damage, but their accuracy class is not subject to IEC standards and can be the object of an agreement between the manufacturer and the user in accordance with the desired performances.

Low-power voltage transformers used for protective purposes are designed to correctly transmit the signal during normal and abnormal conditions in order to inform the protection relay of any critical change in the condition of the network.

6C.2.4 Rated secondary voltages

Usually, electronic equipment is supplied by bipolar voltages of ±12 V to ±15 V which allows output signal values of ±10 V peak with full linearity. Therefore, the rated secondary voltage value of low-power voltage transformers shall be chosen in such a way that the maximum value remains within these limits. The same observation applies to the low-voltage transformer digital output.

EXAMPLE:

Given a voltage factor k_1 = 1,9 and a full offset voltage by trapped charges k_2 = 2.

With a rated value of 3,25/$\sqrt{3}$ V for a phase-to-earth low-power voltage transformer, the maximum voltage is given by

$$U_{max} = k_1 \times k_2 \times 3{,}25\sqrt{2}/\sqrt{3} = 10{,}08 \text{ V peak}$$

6C.2.5 Steady-state conditions

For steady-state conditions the value of the direct voltage component is constant:

$$\lim_{t \to \infty} U_{p\,dc}(t) = U_{p\,dc}$$

$$\lim_{t \to \infty} U_{s\,dc}(t) = U_{s\,dc}$$

$$u_p(t) = U_p\sqrt{2} \times \sin(2\pi f t + \varphi_p) + U_{pdc} + u_{p\,res}(t)$$

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

6C.3 Transient conditions

6C.3.1 Theoretical considerations

6C.3.1.1 Network phenomena

Lots of phenomena on networks, beside the normal service conditions, shall be considered when designing high-voltage equipment. Some of these have a direct influence on dielectric design, others on the signal response requirements for example. The items listed below are a sample of the most important ones.

a) Continuous overvoltages on networks

Depending on the distance of a network part from a strong power source, the voltage can have a continuous value which is higher when compared to the rated value. The overvoltage is expressed by means of a factor by which the rated voltage shall be multiplied.

A usual value of this continuous overvoltage factor is 1,2.

b) Short-circuit to earth in a three-phase network with unearthed star point

An earth fault on one phase of such a network leads to overvoltages on the two unaffected phases. Theoretically, the overvoltage factor on this phase is the square root of 3. However, this factor depends on the distance of the earth fault from the observed network point. An earth fault can last for up to several hours, even days for network parts which are highly inaccessible, i.e. in winter.

A usual value for overvoltage factor is 1,9 for 8 h.

c) Atmospheric discharges on high-voltage overhead lines

Lightning generates overvoltages which cause a high degree of stress to high-voltage equipment. These overvoltages can reach the megavolt domain. Fortunately, the duration of this high level is usually limited to a few microseconds which means also that the amount of energy stressing the equipment is limited. But the rise-time of the wavefront of about 1 μs leads to stress frequencies of several megahertz which is dangerous for all insulation due to stray capacitances.

The worst effect of this phenomenon appears in the regions in which the characteristic impedances are discontinuous. This is the case of a transition from an overhead line to a power transformer where the characteristic impedance of the line is much smaller than that of the transformer. The travelling wave can be raised by reflection to twice the initial value on such occasions.

Such overvoltages often lead, also, to short interruptions on the network in the event of the arcing of a spark-gap acting as a limiting device. The protection system sees the arcing as a short circuit to earth and activates a circuit-breaker. This is usually enough to eliminate the arc and the circuit-breaker recloses.

d) Switching activities

Other phenomena are caused by switching activities on high-voltage networks. These can lead to parasitic resonance with transient overvoltages which have frequencies different from the rated power frequency. The frequencies, in the domain of kilohertz and up to megahertz (in GIS), are mainly determined by the actual configuration of the network. Also, the arcing of circuit-breakers leads to transient effects with overvoltages. Both switching on and off of small inductive currents may initiate overvoltages which are caused by resonance between non-linear components and capacitances.

6C.3.1.2 Types of transient conditions

A lot of different transient conditions are due to overvoltages and switching activities as described in 6C.3.1.1.

As a remedy against these overvoltages there exists a number of different overvoltage limiting devices such as spark gaps and varistors. On the one hand these are necessary to protect the network and its components, on the other hand, they can also produce transient conditions which then have to be withstood. It is particularly important that low-power voltage transformers intended for the accurate transmission of a signal be designed accordingly. This leads to measuring device requirements stipulating a good frequency response up to several kilohertz.

Further transient conditions include sudden primary voltage changes due to a short circuit on the measured phase itself or to an earth fault on one of the other phases. A low-power voltage transformer shall be able, within a defined time of a few milliseconds, to reproduce these variations whilst respecting accuracy requirements for this time.

The most important transient condition problem for low-power voltage transformers using a pure capacitor divider as high-voltage sensor is due to the phenomenon of trapped charges. Same behaviour applies to all a.c. coupled voltage sensors.

During the switching-off of a line or cable, charges may be trapped on it. If the line is not intentionally earthed or discharged by a low-impedance device connected to it, the charges can remain for several days. The understanding of the phenomenon will be made easier with Figure 6C.1. The charge level depends on the phase position of the voltage when switching-off occurs. The worst case is when it occurs whilst the voltage is at its peak value U_p, meaning that the primary capacitor of the divider C_a stays charged, storing the charge $q_1 = C_\mathrm{a} \cdot U_\mathrm{p}$ while the secondary capacitor C_b is discharged by the parallel resistor R_2 of the connected device.

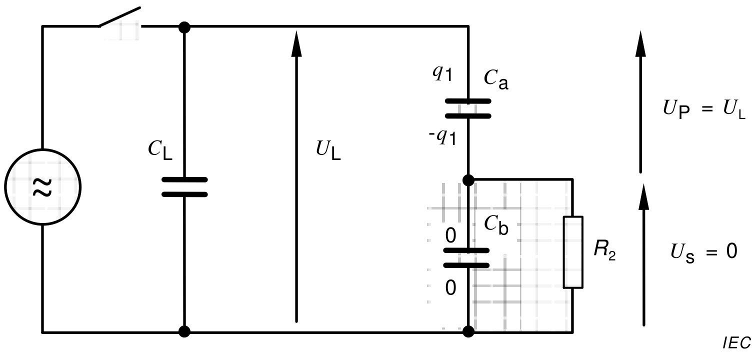
When the line is switched on again, the low d.c. impedance of the network discharges the line instantaneously which forces the charges of C_a to go to C_b. Thus, C_b will be charged now at

$$U_\mathrm{s} = -q_1 / (C_\mathrm{a} + C_\mathrm{b}) = -U_\mathrm{p}\ C_\mathrm{a} / (C_\mathrm{a} + C_\mathrm{b})$$

approximately equal to

$$-U_\mathrm{p}\ (C_\mathrm{a} / C_\mathrm{b})$$

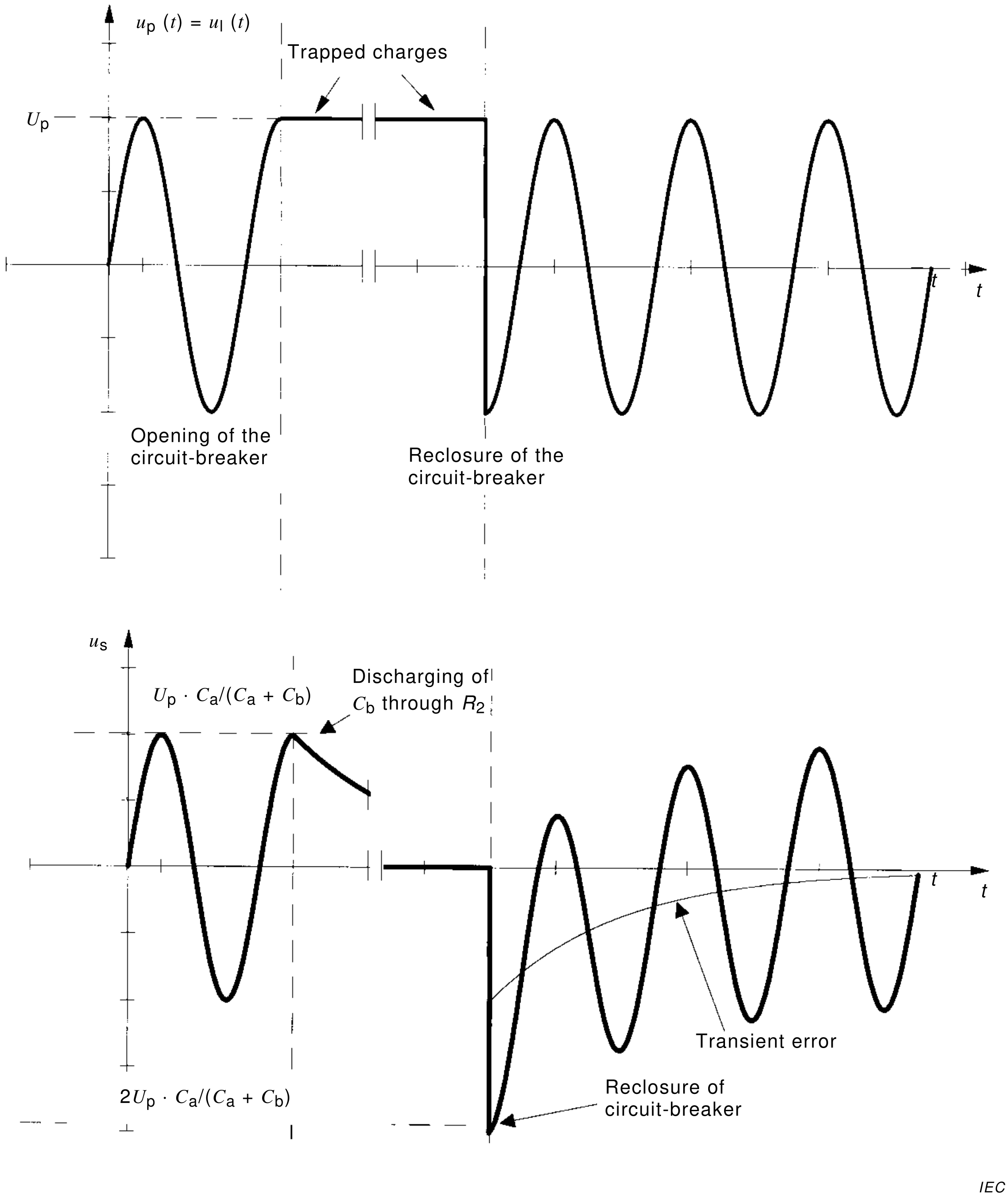
This voltage which decreases exponentially with the time constant $R_2 \cdot C_\mathrm{b}$ is superposed on the sinusoidal signal and results in a substantial error (see Figure 6C.1). The worst effect of this non-periodic component is the saturation of transformers incorporated in the low-power voltage transformer itself or in the protective relays connected to it. An excellent solution to this problem is the use of a mixed resistive-capacitive divider transmitting the correct signal during this transient condition. Trapped charge induced transformer saturation phenomena do not apply to digital and low voltage (±15 V peak) interfaces (see Figure 6C.2).



Key

C_L is the line capacitance.

Figure 6C.1 – Schematic diagram explaining the trapped charge phenomena



Key

U_p is the voltage on primary terminals.

U_s is the voltage on secondary terminals.

Figure 6C.2 – Voltages during trapped charges phenomena

6C.3.1.3 Equations of $u_p(t)$ and $u_s(t)$

The theoretical transient condition occurring in a network can be described using the following equations, previously introduced to deal with steady state conditions:

Primary voltage: $u_p(t) = U_p\sqrt{2} \cdot \sin(2\pi \cdot f \cdot t + \varphi_p) + U_{p\,dc} + u_{p\,res}(t)$

Secondary voltage: $u_s(t) = U_s\sqrt{2} \cdot \sin(2\pi \cdot f \cdot t + \varphi_s) + U_{s\ dc} + u_{s\ res}(t)$

A sudden change in one or more of the parameters creates transient conditions.

The comparison of $u_s(t)$ and $u_p(t)$ gives the performance quality of the low-power voltage transformer in transient conditions, as specified in Table 6C.1 and Table 6C.2.

Table 6C.1 – Primary short circuit

	$t < t_o$	$t = t_o$	$t \geq t_o + (1/f_r)$
$\mid u_p(t) \mid$	See equation above	0	0
U_p	$F_V\ U_{pr}$	0	0
$\mid u_s(t) \mid$	See equation above	$\mid u_s(t_o) \mid$	$\leq 0{,}1 \mid u_s(t < t_o) \mid$
NOTE t_o is the exact time when the short-circuit occurs.			

Table 6C.2 – Trapped charges

	$t < t_o$	$t = t_o$	$t_o < t < t_1$	$t \geq t_1$
U_p	$F_V\ U_{pr}$	0	0	$F_V\ U_{pr}$
$U_{p\ dc}$	0	$\pm F_V\ U_{pr}\sqrt{2}$	$\pm F_V\ U_{pr}\sqrt{2}$	0
$\mid u_s(t) \mid$	See equation above	$\mid u_s(t_o) \mid$	$\mid U_{s\ dc}(t) \mid$	1 [a]
NOTE The values in this table are for the worst case of opening at t_o and reclosing at t_1 with opposite polarity of U_p. t_o is the exact time when the circuit-breaker opens. t_1 is the exact time when the circuit-breaker recloses.				
[a] Limits: see requirements in Table 6C.3				

Table 6C.3 – Limits of instantaneous voltage error for protective electronic voltage transformers in case of trapped charges reclose

Comment	f/f_r	U_p/U_{pr}	$U_{p\ dc}/U_{pr}\sqrt{2}$ for $t \leq 0$	φ_p	ε_u %	
					$2 < f \cdot t \leq 3$	$3 < f \cdot t \leq 4{,}5$
Line charged with F_V per unit, reclosing in an opposite polarity of 1 per unit	1	1	F_V	$-\pi/2$	10 [a]	5 [a]
Idem with opposite polarity	1	1	$-F_V$	$+\pi/2$	10 [a]	5 [a]
[a] By agreement between manufacturer and purchaser, other values may be adopted.						

Where $f \cdot t$ is the product of the frequency f by the time t and represents the number of cycles for which the accuracy is considered.

Instantaneous error limits given in Table 6C.3 apply to a.c. coupled electronic voltage transformers with analogue output exceeding ±15 V peak.

AC-coupled low-power sensors with low-voltage analogue output and sensors with digital output complying with the frequency response mask defined in Table 6A.2 may not meet the requirement of Table 6C.3. In this case it is up to the secondary equipment downstream to implement additional filtering as required.

NOTE Compliance with Table 6A.2 implies a high-pass corner frequency of about 1 Hz, while compliance with Table 6C.3 implies a corner frequency of approximately 15 Hz.

6C.3.1.4 Simple modelization of the Low-power voltage transformer

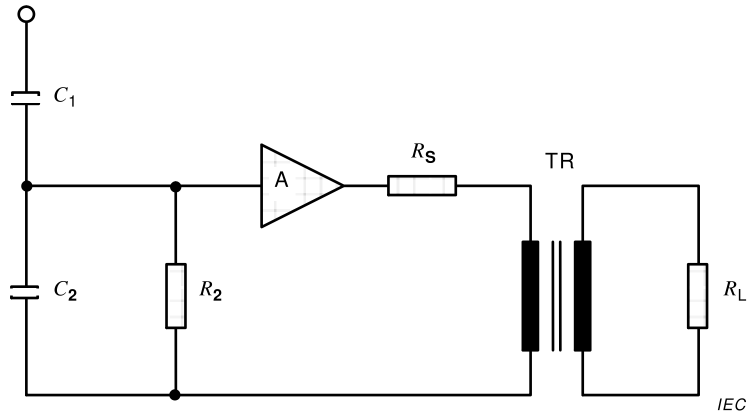
6C.3.1.4.1 General

Every time a practical test is impossible, behaviour of the low-power voltage transformer shall be verified by simulation. This requires an agreement between the manufacturer and the user regarding both the low-power voltage transformer model and the simulation software to be used.

Simulation is commonly used in other areas, i.e. simulation (using EMTP software) instead of real tests is a well-accepted means used to verify correct behaviour of a circuit-breaker in a network.

6C.3.1.4.2 Low-power voltage transformer model

The same model shall be applied for both the primary short-circuit and trapped charge condition. The agreement between the manufacturer and the user shall be based on the comparison of results from the real test and the simulation during primary short circuit. The model shall take into account the non-linearity of the low-power voltage transformer.



Components

C_1, C_2	capacitive voltage dividers
A	ideal amplifier with unity voltage gain
TR	inductive magnetic transformer
R_2	input impedance of A
R_S	total equivalent impedance of A's output circuit
R_L	burden

Figure 6C.3 – Modelization example of a simplified low-power voltage transformer

Let us assume that the low-power voltage transformer (in transient condition) can be described by the diagram of Figure 6C.3.

The model shall describe the network including the non-linearity of the inductive magnetic transformer TR. The simulation can be performed with different software, i.e. EMTP, Saber, Spice, etc. R_L is the burden and shall comply with the requirements of this standard (parallel or series burden). The modelization of the complete test arrangement shall be in accordance with 6C.3.3.

6C.3.1.5 Effects of transients on protective relays

In high-voltage substations VTs are connected to protective relays. The input stage of these relays is equipped with inductive magnetic VTs ensuring galvanic insulation. These transformers are very small in size and their primary winding is made with very thin wires. Consequently, they are very sensitive to the presence of any d.c. component at their input. This d.c. component can induce a saturation of their magnetic circuits. The resulting overcurrent can cause a thermal breakdown of the primary winding. Care should be taken by the user and manufacturer to verify the effect of the electronic VT on the relays during the presence of trapped charges. This is particularly important if the low-power voltage transformer has an output amplified to emulate conventional voltage transformers (above ±15 V peak) and is capable of transmitting direct voltage, or voltage at very low frequency.

6C.3.2 Definition of transient error

The instantaneous voltage error is defined by the following formula:

$$\varepsilon_u(t)\,\% = \frac{K_r \cdot u_s(t) - u_p(t)}{u_p\sqrt{2}} \times 100$$

where

$\varepsilon_u(t)$ % is the instantaneous voltage error;

K_r is the rated transformation ratio.

6C.3.3 Test of transient performance

6C.3.3.1 Transient performance test for capacitive voltage transformers

In IEC 61869-5, CVTs are subject to transient performance requirements, the primary short circuit alone being taken into consideration.

The test can be done by recording two signals. The first is the output of the CVT. The second is the output of a reference device representing the primary voltage and giving an accurate determination of the instant at which the short circuit occurs. The performance is simply controlled by direct measurement of the residual value of the first signal.

6C.3.3.2 Transient performance test for low-power voltage transformers

6C.3.3.2.1 General

The instantaneous voltage error for transient conditions is defined by the following formula:

$$\varepsilon_u(t)\,\% = \frac{K_r \cdot u_s(t) - u_p(t)}{u_p\sqrt{2}} \times 100$$

This formula can be rewritten as follows:

$$\varepsilon_u(t)\,\% = \left[u_s(t) - \frac{1}{K_r}u_p(t)\right]\frac{K_r}{u_p\sqrt{2}} \times 100$$

Using the steady-state error definition

$$\varepsilon_u\% = \frac{K_r \cdot U_s - U_p}{U_p} \times 100$$

U_p can be expressed by a function of U_s

$$U_p = \frac{K_r U_s}{1 + \varepsilon_u / 100}$$

Replacing U_p by this expression in the previous formula gives

$$\varepsilon_u(t)\% = \left[u_s(t) - \frac{1}{K_r} u_p(t)\right] \frac{1}{u_s\sqrt{2}} \left(1 + \varepsilon_u / 100\right) \times 100$$

Taking into account that

$$\frac{\varepsilon_u}{100} << 1$$

The test procedure can be simplified by using the following formula:

$$\varepsilon_u(t)\% = \left[u_s(t) - \frac{1}{K_r} u_p(t)\right] \frac{1}{u_s\sqrt{2}} \times 100$$

Note that the transient performance test can only be considered to be completed if the time occurrence of the primary short circuit and the reclosure on trapped charges are varied, covering all real network situations.

Effects of rated delay time. In order to avoid unwanted effects on protective relays two cases can be considered.:

a) No relationship between the low-power voltage transformer rated delay time and the CT. The test can be carried out without external compensation of the rated delay time t_{dr}.
b) The low-power voltage transformer is used with a CT having the same rated delay time. The test can be carried out using a pure time delay device inserted between the reference transformer and the differential amplifier. The delay time of this device can be set to a value given by $t_d = \varphi_e / 2\pi f_r$, φ_e and f_r being the values indicated on the rating plate.

6C.3.3.2.2 Primary short circuit

In the case of primary short-circuit testing we have $u_p(t) = 0$ for $t > 0$

Thus, the formula above becomes reduced to

$$\varepsilon_u\%(t) = u_s(t) \frac{1}{U_s\sqrt{2}} \times 100$$

which is the mathematical expression of the requirement expressed in this standard.

NOTE $U_s\sqrt{2}$ is the peak value of the low-power voltage transformers secondary output voltage for $t < 0$ (before the short circuit occurs). This simplified formula makes use of a calibrated primary voltage reference for primary short circuit testing unnecessary. Only one time reference is needed to identify the precise moment at which the short circuit occurs.

6C.3.3.2.3 Reclosure on a line with trapped charges

For $t < 0$

$$u_\mathrm{p}(t) = u_\mathrm{p\ dc}(t) + u_\mathrm{p\ res}(t)$$

$$u_\mathrm{s}(t) = u_\mathrm{s\ dc}(t) + u_\mathrm{s\ res}(t)$$

For $t \geq 0$

$$u_\mathrm{p}(t) = U_\mathrm{p}\sqrt{2} \cdot \sin(2\pi \cdot f \cdot t + \varphi_\mathrm{p}) + u_\mathrm{p\ res}(t)$$

$$u_\mathrm{s}(t) = U_\mathrm{s}\sqrt{2} \cdot \sin(2\pi \cdot f \cdot t + \varphi_\mathrm{s}) + u_\mathrm{s\ dc}(t) + u_\mathrm{s\ res}(t)$$

Then for $t \geq 0$

$$\varepsilon_u(t)\,\% = \left[u_\mathrm{s}(t) - \frac{1}{K_\mathrm{r}} u_\mathrm{p}(t)\right] \frac{1}{u_\mathrm{s}\sqrt{2}} \times 100$$

Replacing $u_\mathrm{s}(t)$ and $u_\mathrm{p}(t)$ by their expression, we get

$$\varepsilon_u\,\%(t) = \varepsilon_{u\,\mathrm{ac}}\%(t) + \varepsilon_{u\,\mathrm{tr}}\%(t)$$

with

$$\varepsilon_{u\,\mathrm{ac}}\%(t) = \frac{U_\mathrm{s}\sin(2\pi \cdot f \cdot t + \varphi_\mathrm{s}) - (U_\mathrm{p}/K_\mathrm{r})\sin(2\pi \cdot f \cdot t + \varphi_\mathrm{p})}{U_\mathrm{s}} \times 100$$

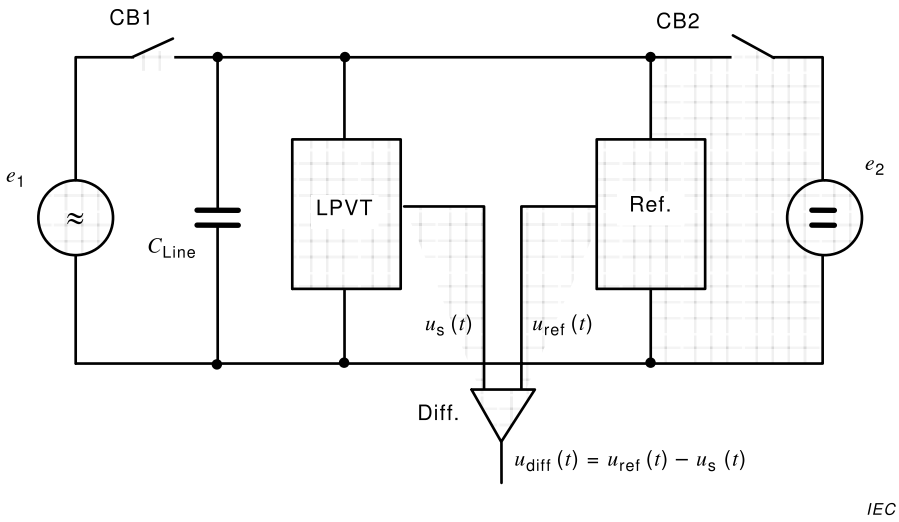
$$\varepsilon_{u\,\mathrm{tr}}\%(t) = \frac{u_\mathrm{s\,dc}(t) + u_\mathrm{s\,res}(t) - (u_\mathrm{p\,res}(t)/K_\mathrm{r})}{U_\mathrm{s}\sqrt{2}} \times 100$$

The first term $\varepsilon_{u\mathrm{tr}}\%(t)$ contains only sinusoidal components and is the steady-state error of the low-power voltage transformer. If the low-power voltage transformer is correctly adjusted, it can be neglected considering the second term $\varepsilon_{u\mathrm{tr}}\%(t)$ which is the error's transient component.

The worst case is where $u_\mathrm{p\,dc}(0) = F_\mathrm{V} U_\mathrm{s}\sqrt{2}$. The time constant of the low-power voltage transformer component $u_\mathrm{sdc}(t)$ has a substantial influence on the choice of a test procedure. We shall distinguish two cases: long- and short time constants.

6C.3.3.2.4 Short time constants

If $u_\mathrm{sdc}(t)$ decays with a time constant less than 100 ms, a realistic test arrangement is possible, as shown in Figure 6C.4.



Key

Ref. is a high-voltage reference divider with the same voltage ratio as the low-power voltage transformer.

Diff. is a calibrated differential amplifier with a low pass bandwidth characteristic determined by an agreement between user and manufacturer.

Figure 6C.4 – Testing arrangement for short time constant

$e_1(t)$ is set to the rated voltage and frequency, $e_2(t)$ is set to a d.c. value equal to the rated peak value, multiplied by the overvoltage factor F_V.

$$e_1 = U_{pr}\sqrt{2}\ \sin(2\pi f t)$$

$$e_2 = k\, U_{pr}\sqrt{2}$$

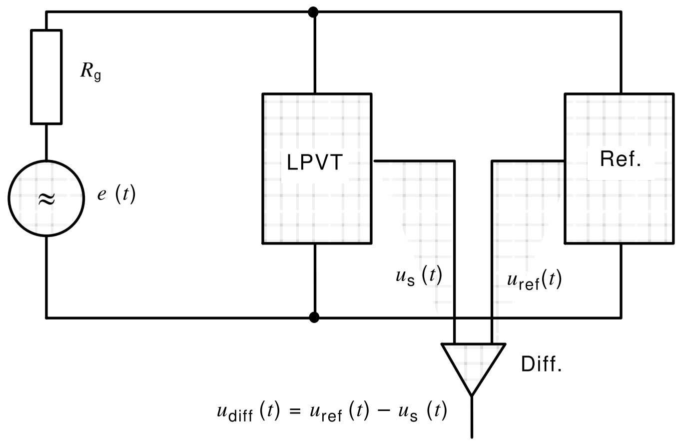
$C_{Line} \geq 1\ 000$ pF in order to ensure that the primary voltage decay is at least 10 times slower than the secondary voltage decay of the low-power voltage transformer during the trapped charge situation (CB1 and CB2 open).

Sequence of operation:

a)	CB1 open	CB2 closed	Charging the high-voltage capacitors (C_{Line}, low-power voltage transformer, etc.) up to the assigned value $F_V \cdot U_{pr}\sqrt{2}$.
b)	CB1 open	CB2 open	Isolating the high-voltage d.c. source e_2 from the a.c. source e_1.
c)	CB1 closed	CB2 open	Reclosing on trapped charges with a rated value U_{pn} for the a.c. component.

6C.3.3.2.5 Long time constants

If $u_{s\ dc}(t)$ decays with a time constant higher than 100 ms, a realistic test arrangement is possible, as shown in Figure 6C.5.



Key

Ref. represents a high-voltage reference divider with the same voltage ratio as the low-power voltage transformer.

Diff. represents a calibrated differential amplifier with a low-pass bandwidth characteristic determined by an agreement between user and manufacturer.

Figure 6C.5 – Testing arrangement for long time constant

The waveform $e(t)$ is illustrated in Figure 6C.6.

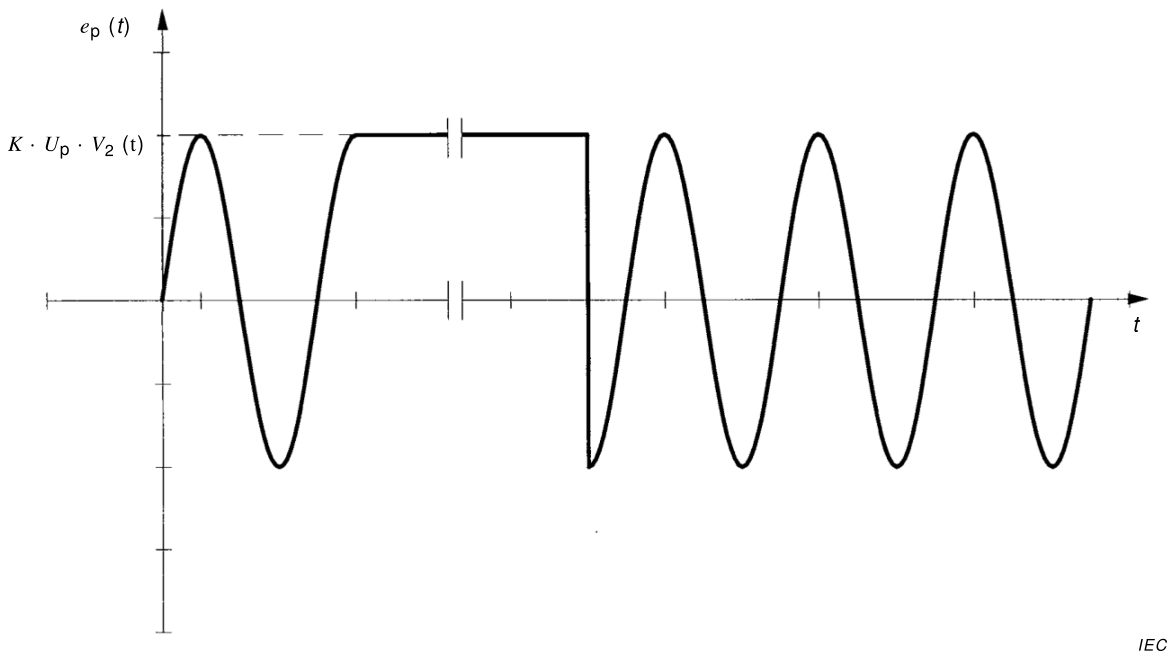


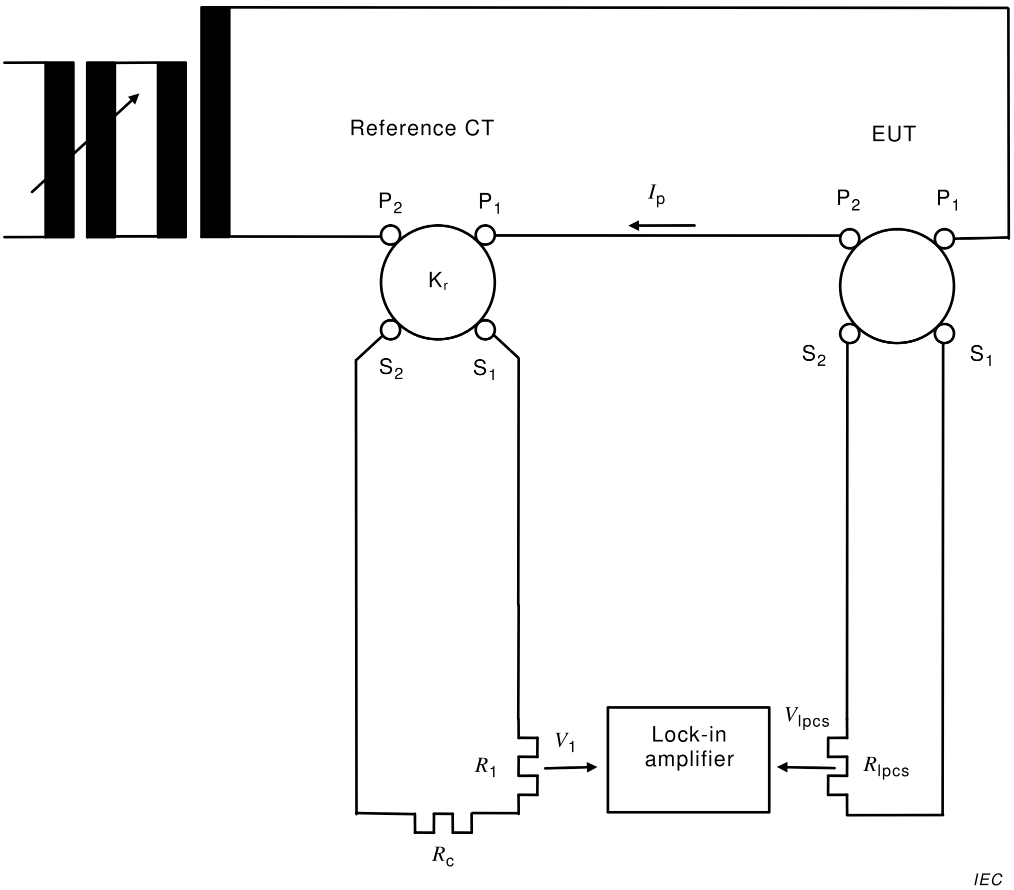
Figure 6C.6 – Typical waveform of $e(t)$ during test

Annex 6D
(informative)

Test circuits

6D.1 Test circuits for accuracy measurements in steady state for low-power current transformers

Figure 6D.1, Figure 6D.2 and Figure 6D.3 show some basic circuits for the direct measurement of a composite error for the current transformer.

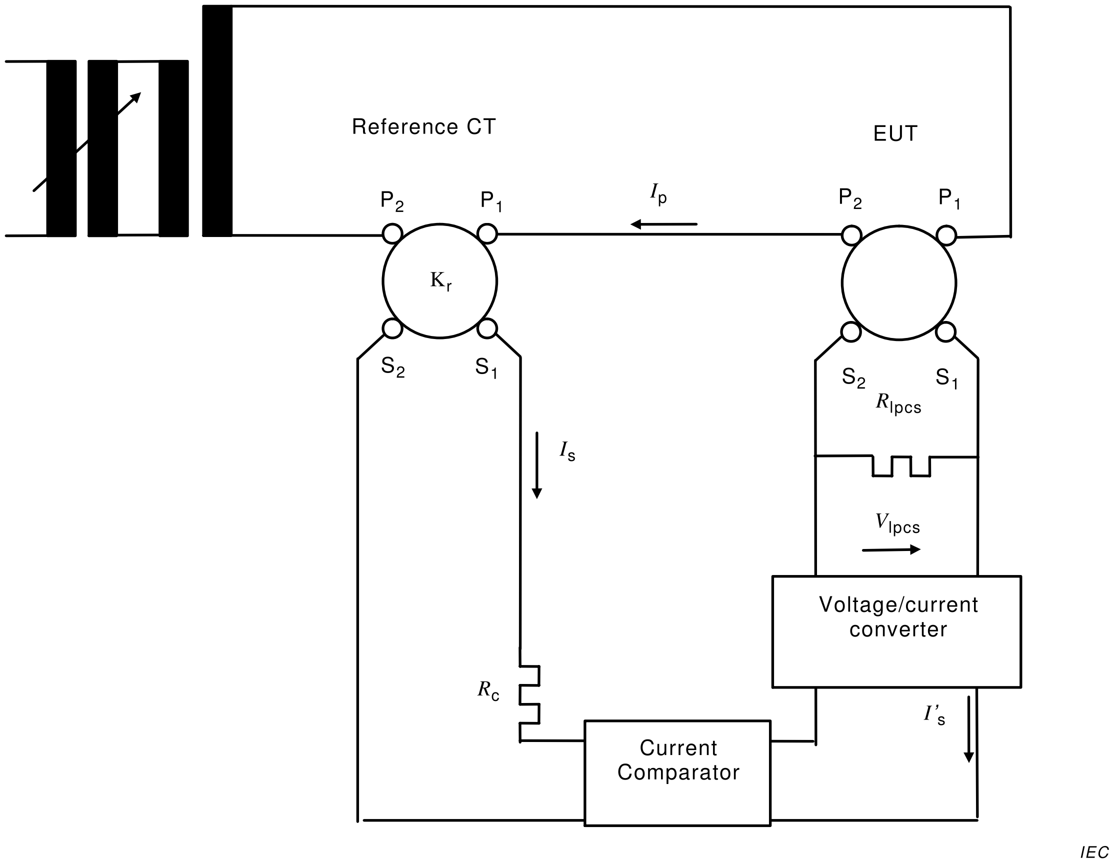


Key

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_{lpcs}	Secondary voltage for low-power current transformer
R_{lpcs}	Rated secondary burden of low-power current transformer
R_1 and R_{lpcs}	are required to be high accuracy burden

The voltage at the input of the lock-in amplifier shall be adjusted in rated conditions. This voltage shall be equal to the rated secondary voltage.

Figure 6D.1 – Test circuit for analogue accuracy measurements in steady state



Key

K_r Rated transformation ratio of reference CT

I_s Secondary current for reference CT

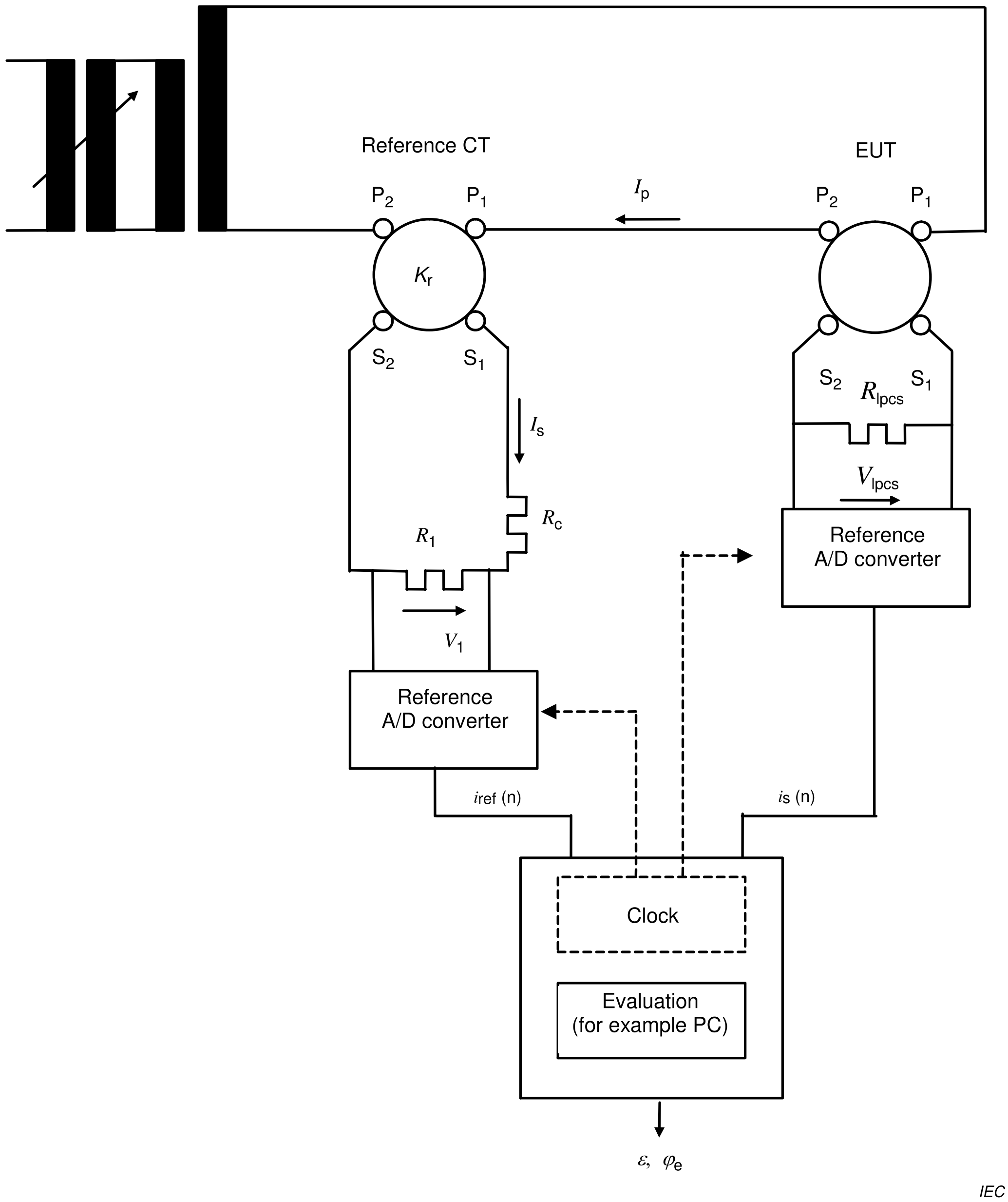
I'_s Secondary current for low-power current transformer

V_{lpcs} Secondary voltage for low-power current transformer with analogue output

R_c Rated secondary burden of reference CT

R_{lpcs} Rated secondary burden of low-power current transformer

Figure 6D.2 – Test circuit for analogue accuracy measurements in steady state (alternative solution)



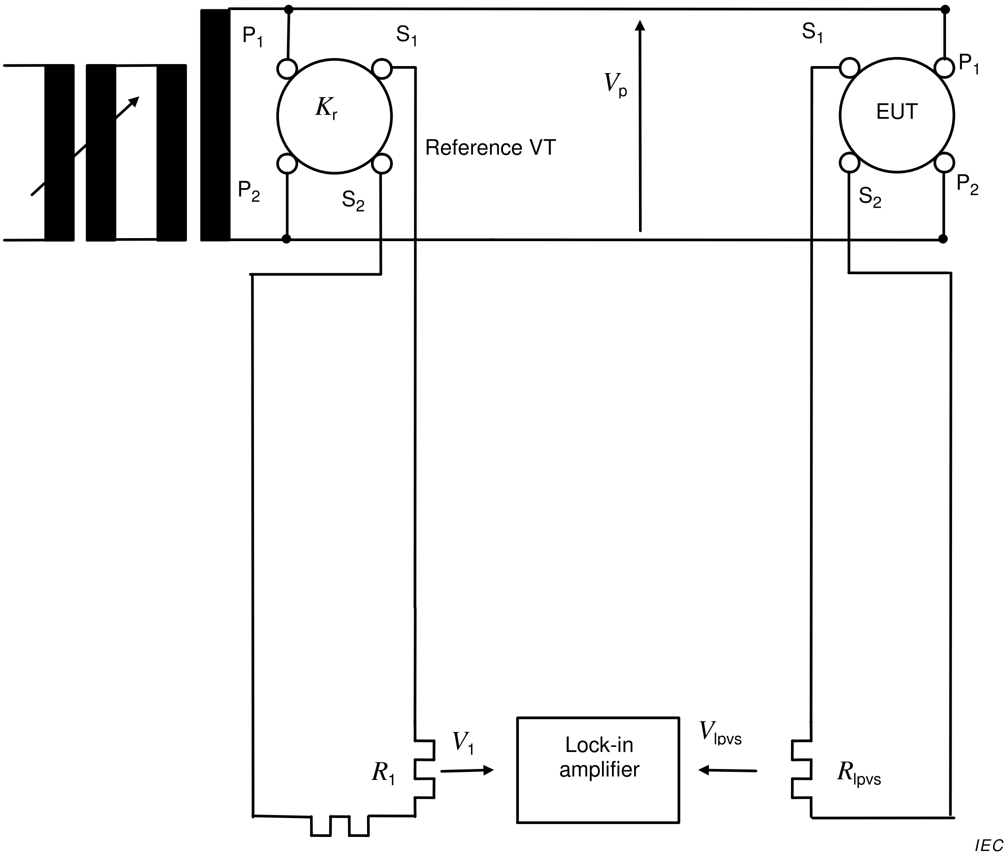
Key

K_r	Rated transformation ratio of reference CT
V_1	Voltage at the input of the reference A/D converter
V_{lpcs}	Secondary voltage for low-power current transformer with analogue output
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_{lpcs}	Rated secondary burden of low-power current transformer
R_1	is required to be a high accuracy burden

Figure 6D.3 – Test circuit for digital accuracy measurements in steady state

6D.2 Test circuits for accuracy measurements in steady state for low-power voltage transformers

Figure 6D.4, Figure 6D.5 and Figure 6D.6 show some basic circuits for the direct measurement of an error for the voltage transformer.

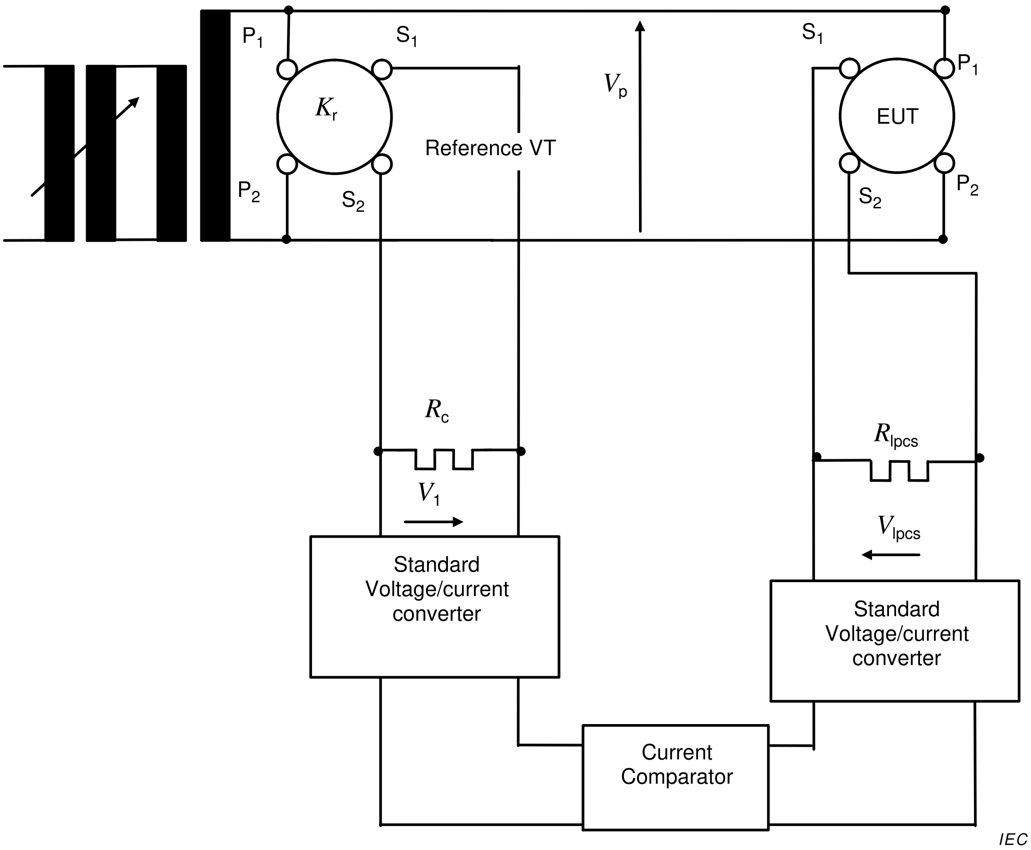


Key

K_r	Rated transformation ratio of reference VT
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 VT
V_{lpvs}	Secondary voltage for low-power voltage transformer
R_{lpvs}	Rated secondary burden of low-power voltage transformer
R_1 and R_{lpvs}	are required to be high accuracy burden

The voltage at the input of the lock-in amplifier shall be adjusted in rated conditions. This voltage shall be equal to the rated secondary voltage.

Figure 6D.4 – Test circuit for analogue accuracy measurements in steady state



Key

K_r Rated transformation ratio of reference VT

V_s Secondary voltage for reference VT

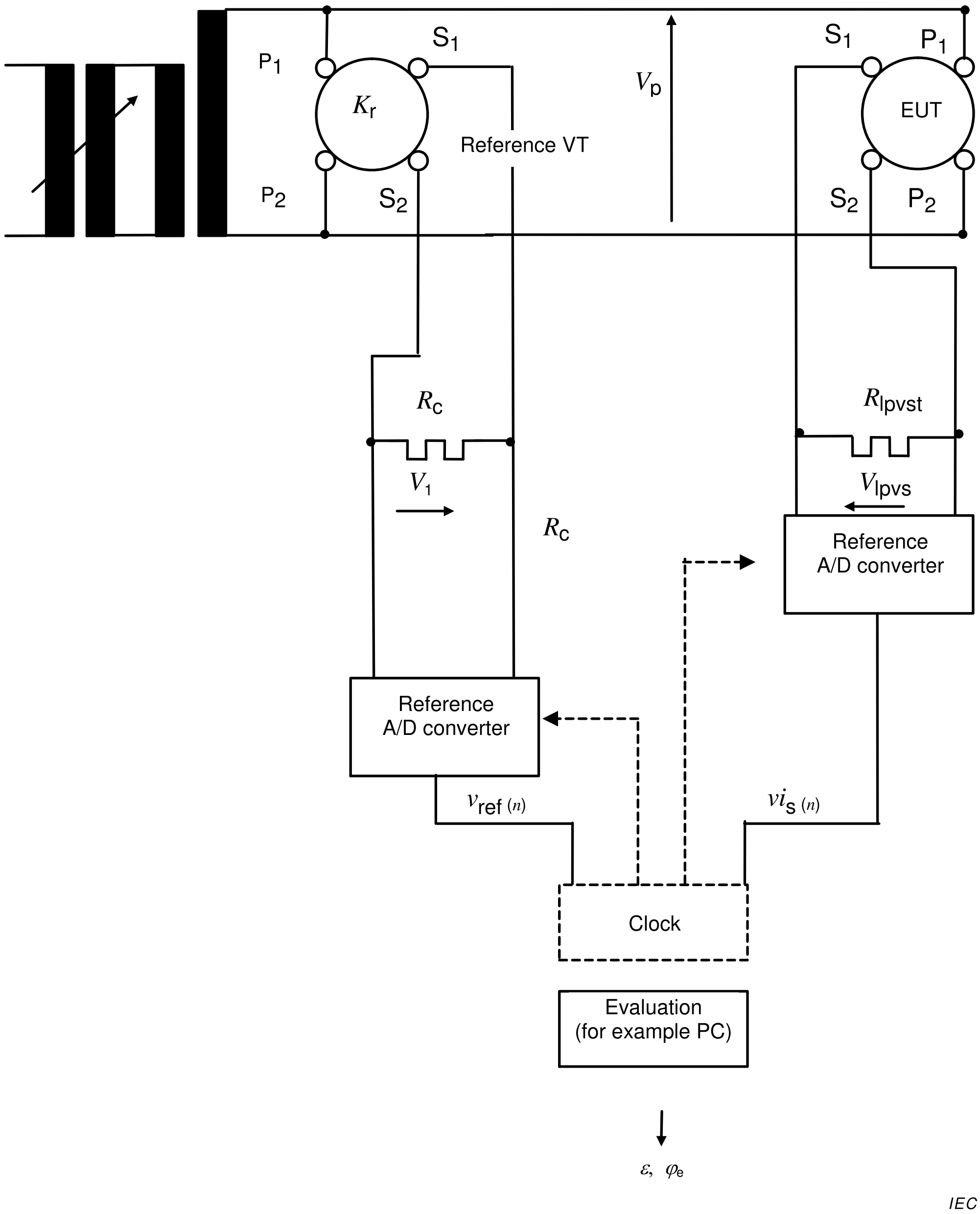
V'_s Secondary voltage for low-power voltage transformer

V_{lpcs} Secondary voltage for low-power voltage transformer with analogue output

R_c Rated secondary burden of reference VT

R_{lpcs} Rated secondary burden of low-power voltage transformer

Figure 6D.5 – Test circuit for analogue accuracy measurements in steady state (alternative solution)



Key

K_r	Rated transformation ratio of reference VT
V_1	Voltage at the input of the reference A/D converter
V_{lpvs}	Secondary voltage for low-power voltage transformer with analogue output
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 VT
R_{lpvs}	Rated secondary burden of low-power voltage transformer
R_1	is required to be a high accuracy burden

Figure 6D.6 – Test circuit for digital accuracy measurements in steady state

Annex 6E
(informative)

Graph explaining the accuracy requirements for multi-purpose low-power current transformer

The graph in Figure 6E.1 shows the accuracy limits of a multipurpose low-power current transformer (i.e. an LPIT 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.

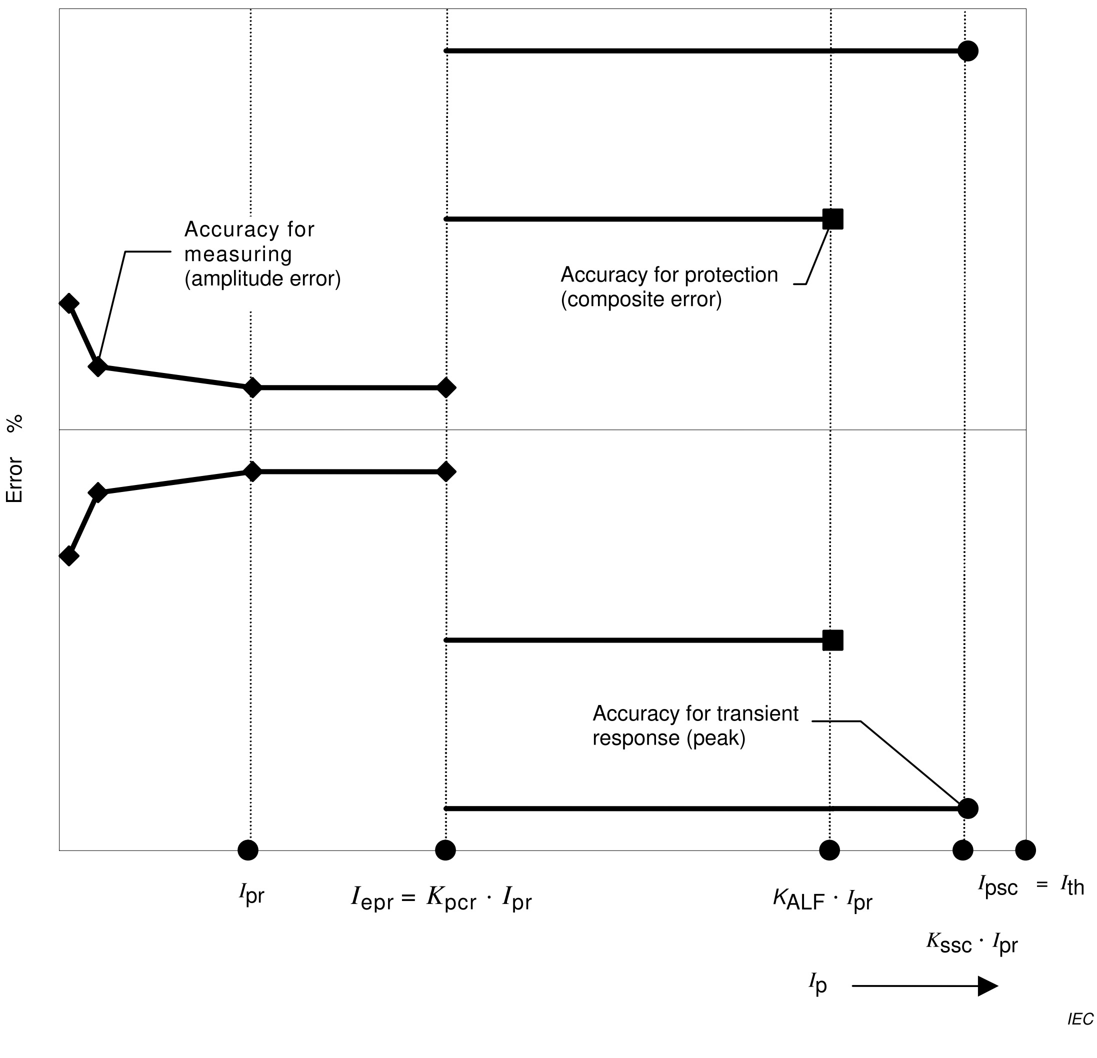


Figure 6E.1 – Accuracy limits of a multi-purpose low-power current transformer

If an application requires a small deviation between the phase and/or amplitude error between the low-power current transformers on different phases, the user shall select a set of low-power 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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[4] Under consideration.

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