BS EN 61869-2:2012

BSI Standards Publication

Instrument transformers

Part 2: Additional requirements for current transformers

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National foreword

This British Standard is the UK implementation of EN 61869-2:2012. It is identical to IEC 61869-2:2012. It supersedes BS EN 60044-1:1999 and BS EN 60044-6:1999, which are withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/38, Instrument transformers.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English version

Instrument transformers - Part 2: Additional requirements for current transformers (IEC 61869-2:2012)

Transformateurs de mesure -
Partie 2: Exigences supplémentaires concernant les transformateurs de courant
(CEI 61869-2:2012)

Messwandler -
Teil 2: Zusätzliche Anforderungen für Stromwandler
(IEC 61869-2:2012)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
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Foreword

The text of document 38/435/FDIS, future edition 1 of IEC 61869-2, prepared by IEC/TC 38, "Instrument transformers" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61869-2:2012.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2013-07-23
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2015-10-23

This document supersedes EN 60044-1:1999 + A1:2000 + A2:2003 and EN 60044-6:1999.

Additionally it introduces technical innovations in the standardization and adaptation of the requirements for current transformers for transient performance.

This Part 2 is to be used in conjunction with, and is based on, EN 61869-1:2009, *General Requirements* – however the reader is encouraged to use its most recent edition.

This Part 2 follows the structure of EN 61869-1:2009 and supplements or modifies its corresponding clauses.

When a particular clause/subclause of Part 1 is not mentioned in this Part 2, that clause/subclause applies as far as is reasonable. 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 201 are additional to those in Part 1;

– additional annexes are lettered 2A, 2B, etc.

Annex ZZ of EN 61869-1 is not applicable for this part of the series.

An overview of the planned set of standards at the date of publication of this document is given below. The updated list of standards prepared by IEC TC38 is available at the website: www.iec.ch; the updated list of standards prepared by IEC TC38 and approved by CENELEC is available at the website: www.cenelec.eu.

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<tr><th colspan="2">PRODUCT FAMILY STANDARDS</th><th>PRODUCT STANDARD</th><th>PRODUCTS</th><th>OLD STANDARD</th></tr>
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Since the publication of EN 60044-6 (*Requirements for protective current transformers for transient performance*) in 1999, the area of application of this kind of current transformers has been extended. As a consequence, the theoretical background for the dimensioning according to the electrical requirements has become much more complex. In order to keep this standard as user-friendly as possible, the explanation of the background information will be transferred to the Technical Report IEC/TR 61869-100, which is now in preparation.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

This standard covers the Principle Elements of the Safety Objectives for Electrical Equipment Designed for Use within Certain Voltage Limits (LVD - 2006/95/EC).

Endorsement notice

The text of the International Standard IEC 61869-2:2012 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Addition *to Annex ZA of EN 61869-1:2009:*

Publication	Year	Title	EN/HD	Year
IEC 61869-1 (mod)	2007	Instrument transformers - Part 1: General requirements	EN 61869-1	2009

CONTENTS

INSTRUMENT TRANSFORMERS –

Part 2: Additional requirements for Current Transformers

1 Scope

This part of IEC 61869 is applicable to newly manufactured inductive current transformers for use with electrical measuring instruments and/or electrical protective devices having rated frequencies from 15 Hz to 100 Hz.

2 Normative references

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

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

3 Terms and definitions

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

3.1 General definitions

3.1.201
current transformer
instrument transformer in which the secondary current, under normal conditions of use, is substantially proportional to the primary current and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections

[SOURCE: IEC 60050-321:1986, 321-02-01]

3.1.202
measuring current transformer
current transformer intended to transmit an information signal to measuring instruments and meters

[SOURCE: IEC 60050-321:1986, 321-02-18]

3.1.203
protective current transformer
a current transformer intended to transmit an information signal to protective and control devices

[SOURCE: IEC 60050-321: 1986, 321-02-19)

3.1.204
class P protective current transformer
protective current transformer without remanent flux limit, for which the saturation behaviour in the case of a symmetrical short-circuit is specified

3.1.205
class PR protective current transformer
protective current transformer with remanent flux limit, for which the saturation behaviour in the case of a symmetrical short-circuit is specified

3.1.206
class PX protective current transformer
protective current transformer of low-leakage reactance without remanent flux limit for which knowledge of the excitation characteristic and of the secondary winding resistance, secondary burden resistance and turns ratio, is sufficient to assess its performance in relation to the protective relay system with which it is to be used

3.1.207
class PXR protective current transformer
protective current transformer with remanent flux limit for which knowledge of the excitation characteristic and of the secondary winding resistance, secondary burden resistance and turns ratio, is sufficient to assess its performance in relation to the protective relay system with which it is to be used

Note 1 to entry: An increasingly number of situations occur where low DC currents are continuously flowing through current transformers. Therefore, in order to stop the current transformer from saturating, current transformers with air gaps, but with the same performance as Class PX, are used.

Note 2 to entry: The air gaps for remanence reduction do not necessarily lead to a high-leakage reactance current transformer (see Annex 2C).

3.1.208
class TPX protective current transformer for transient performance
protective current transformer without remanent flux limit, for which the saturation behaviour in case of a transient short-circuit current is specified by the peak value of the instantaneous error

3.1.209
class TPY protective current transformer for transient performance
protective current transformer with remanent flux limit, for which the saturation behaviour in case of a transient short-circuit current is specified by the peak value of the instantaneous error

3.1.210
class TPZ protective current transformer for transient performance
protective current transformer with a specified secondary time-constant, for which the saturation behaviour in case of a transient short-circuit current is specified by the peak value of the alternating error component

3.1.211
selectable-ratio current transformer
current transformer on which several transformation ratios are obtained by reconnecting the primary winding sections and / or by means of taps on the secondary winding

3.3 Definitions related to current ratings

3.3.201
rated primary current
I_{pr}
value of the primary current on which the performance of the transformer is based

[SOURCE: IEC 60050-321:1986, 321-01-11, modified title, synonym and definition]

3.3.202
rated secondary current
I_{sr}
value of the secondary current on which the performance of the transformer is based

[SOURCE: IEC 60050-321:1986, 321-01-15, modified title, synonym and definition]

3.3.203
rated short-time thermal current
I_{th}
maximum value of the primary current which a transformer will withstand for a specified short time without suffering harmful effects, the secondary winding being short-circuited

[SOURCE: IEC 60050-321:1986, 321-02-22]

3.3.204
rated dynamic current
I_{dyn}
maximum peak value of the primary current which a transformer will withstand, without being damaged electrically or mechanically by the resulting electromagnetic forces, the secondary winding being short-circuited

[SOURCE: IEC 60050-321:1986, 321-02-24]

3.3.205
rated continuous thermal current
I_{cth}
value of the current which can be permitted to flow continuously in the primary winding, the secondary winding being connected to the rated burden, without the temperature rise exceeding the values specified

[SOURCE: IEC 60050-321:1986, 321-02-25]

3.3.206
rated primary short-circuit current
I_{psc}
r.m.s. value of the a.c. component of a transient primary short-circuit current on which the accuracy performance of a current transformer 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}.

3.3.207
exciting current
I_e
r.m.s. value of the current taken by the secondary winding of a current transformer, when a sinusoidal voltage of rated frequency is applied to the secondary terminals, the primary and any other windings being open-circuited

[SOURCE: IEC 60050-321:1986, 321-02-32]

3.4 Definitions related to accuracy

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

Note 201 to entry: The current ratio error, expressed in per cent, is given by the formula:

$$\varepsilon = \frac{k_r I_s - I_p}{I_p} \times 100\ \%$$

where

k_r is the rated transformation ratio;
I_p is the actual primary current;
I_s is the actual secondary current when I_p is flowing, under the conditions of measurement.
An explicative vector diagram is given in 2A.1.

3.4.4
phase displacement
Δφ
The definition 3.4.4 of IEC 61869-1:2007 is applicable with the addition of the following note:

Note 1 to entry: An explicative vector diagram is given in 2A.1.

3.4.201
rated resistive burden
$\boldsymbol{R_b}$
rated value of the secondary connected resistive burden in ohms

3.4.202
secondary winding resistance
$\boldsymbol{R_{ct}}$
actual secondary winding d.c. resistance in ohms corrected to 75 ºC or such other temperature as may be specified

Note 1 to entry: R_{ct} is an actual value. It shall not be confused with the upper limit for R_{ct}, which can be specified otherwise.

3.4.203
composite error
$\boldsymbol{\varepsilon_c}$
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 current multiplied by the rated transformation ratio,

the positive signs of the primary and secondary currents corresponding to the convention for terminal markings

Note 1 to entry: The composite error ε_c is generally expressed as a percentage of the r.m.s. values of the primary current:

$$\varepsilon_c = \frac{\sqrt{\frac{1}{T}\int_0^T (k_r i_s - i_p)^2 \, dt}}{I_p} \times 100\ \%$$

where

k_r is the rated transformation ratio;
I_p is the r.m.s. value of the primary current;
i_p is the instantaneous value of the primary current;
i_s is the instantaneous value of the secondary current;
T is the duration of one cycle.

For further explanation, refer to 2A.4.

[SOURCE: IEC 60050-321:1986, 321-02-26, modified note to entry]

3.4.204
rated instrument limit primary current
$\boldsymbol{I_{PL}}$
value of the minimum primary current at which the composite error of the measuring current transformer is equal to or greater than 10 %, the secondary burden being equal to the rated burden

[SOURCE: IEC 60050-321:1986, 321-02-27]

3.4.205
instrument security factor
FS
ratio of rated instrument limit primary current to the rated primary current

Note 1 to entry: Attention should be paid to the fact that the actual instrument security factor is affected by the burden. When the burden value is significantly lower than rated one, larger current values will be produced on the secondary side in the case of short-circuit current.

Note 2 to entry: In the event of system fault currents flowing through the primary winding of a current transformer, the safety of the apparatus supplied by the transformer is at its highest when the value of the rated instrument security factor (*FS*) is at its lowest.

[SOURCE: IEC 60050-321:1986, 321-02-28, modified notes to entry]

3.4.206
secondary limiting e.m.f. for measuring current transformers
E_{FS}
product of the instrument security factor *FS*, the rated secondary current and the vectorial sum of the rated burden and the impedance of the secondary winding

Note 1 to entry: The secondary limiting e.m.f. for measuring current transformers E_{FS} is calculated as

$$E_{\mathrm{FS}} = FS \times I_{sr} \times \sqrt{(R_{ct} + R_b)^2 + X_b^2}$$

where: R_{b} is the resistive part of the rated burden;

X_{b} is the inductive part of the rated burden.

This method will give a higher value than the actual one. It was chosen in order to apply the same test method as used for protective current transformers. Refer to 7.2.6.202 and 7.2.6.203.

[SOURCE: IEC 60050-321:1986, 321-02-31, modified title, synonym and note to entry]

3.4.207
rated accuracy limit primary current
value of primary current up to which the current transformer will comply with the requirements for composite error

[SOURCE: IEC 60050-321:1986, 321-02-29]

3.4.208
accuracy limit factor
ALF
ratio of the rated accuracy limit primary current to the rated primary current

[SOURCE: IEC 60050-321:1986, 321-02-30]

3.4.209
secondary limiting e.m.f. for protective current transformers
E_{ALF}
product of the accuracy limit factor, the rated secondary current and the vectorial sum of the rated burden and the impedance of the secondary winding

Note 1 to entry: The secondary limiting e.m.f for class P and PR protective current transformers E_{ALF} is calculated as

$$E_{\mathrm{ALF}} = ALF \times I_{sr} \times \sqrt{(R_{ct} + R_b)^2 + X_b^2}$$

where: R_{b} is the resistive part of the rated burden;

X_{b} is the inductive part of the rated burden.

3.4.210
saturation flux
Ψ_{sat}
maximum value of secondary linked flux in a current transformer, which corresponds to the magnetic saturation of the core material

Note 1 to entry: The most suitable procedure for the determination of the saturation flux Ψ_{sat} is given with the d.c. saturation method described in 2B.2.3.

Note 2 to entry: In the former standard IEC 60044-6, Ψ_s was defined as a knee point value, which characterized the transition from the non-saturated to the fully saturated state of a core. This definition could not gain acceptance because the saturation value was too low, and led to misunderstandings and contradictions. Therefore, it was replaced by Ψ_{sat} , which defines the condition of complete saturation.

3.4.211
remanent flux
Ψ_r
value of secondary linked flux which would remain in the core 3 min after the interruption of a magnetizing current of sufficient magnitude to induce saturation flux (Ψ_{sat})

3.4.212
remanence factor
K_R
ratio of the remanent flux to the saturation flux, expressed as a percentage

3.4.213
secondary loop time constant
T_s
value of the time constant of the secondary loop of the current transformer obtained from the sum of the magnetizing and the leakage inductances (L_s) and the secondary loop resistance (R_s)

$$T_s = L_s / R_s$$

3.4.214
excitation characteristic
graphical or tabular presentation of the relationship between the r.m.s. value of the exciting current and a sinusoidal voltage applied to the secondary terminals of a current transformer, the primary and other windings being open-circuited, over a range of values sufficient to define the characteristics from low levels of excitation up to 1.1 times the knee point e.m.f.

3.4.215
knee point voltage
r.m.s. value of the sinusoidal voltage at rated frequency applied to the secondary terminals of the transformer, all other terminals being open-circuited, which, when increased by 10 %, causes the r.m.s. value of the exciting current to increase by 50 %

[SOURCE: IEC 60050-321:1986, 321-02-34]

3.4.216
knee point e.m.f.
e.m.f. of a current transformer at rated frequency, which, when increased by 10 %, causes the r.m.s. value of the exciting current to increase by 50 %

Note 1 to entry: While the knee point voltage can be applied to the secondary terminals of a current transformer, the knee point e.m.f. is not directly accessible. The values of the knee point voltage and of the knee point e.m.f. are deemed as equal, due to the minor influence of the voltage drop across the secondary winding resistance.

3.4.217
rated knee point e.m.f.
E_k
lower limit of the knee point e.m.f.

Note 1 to entry: The rated knee point e.m.f. appears in the specifications of class PX and PXR protective current transformers. It may be calculated as

$$E_k = K_x \times (R_{ct} + R_b) \times I_{sr}$$

3.4.218
rated turns ratio
specified ratio of the number of primary turns to the number of secondary turns

EXAMPLE 1 1/600 (meaning 1 primary turn to 600 secondary turns)

EXAMPLE 2 2/1200 (meaning 2 primary turns to 1200 secondary turns)

Note 1 to entry: The rated turns ratio appears in the specifications of class PX and PXR protective current transformers.

Note 2 to entry: Rated turns ratio and rated transformation ratio are both defined as primary to secondary entities. If they shall be compared, the value of the rated turns ratio has to be inverted.

3.4.219
turns ratio error
difference between the actual turns ratio and the rated turns ratio, expressed as a percentage of the rated turns ratio

3.4.220
dimensioning factor
K_x
factor to indicate the multiple of rated secondary current (I_{sr}) occurring under power system fault conditions, inclusive of safety margins, up to which the transformer is required to meet performance requirements

Note 1 to entry: See formula under 3.4.217.

3.4.221
instantaneous error current
i_ε
difference between the instantaneous values of the secondary current (i_s) multiplied by the rated transformation ratio (k_r) and the primary current (i_p):

$$i_\varepsilon = k_r \times i_s - i_p$$

Note 1 to entry: When both alternating current components (i_{sac} , i_{pac}) and direct current components (i_{sdc} , i_{pdc}) are present, the constituent components ($i_{\varepsilon ac}$, $i_{\varepsilon dc}$) are separately identified as follows:

$$i_\varepsilon = i_{\varepsilon ac} + i_{\varepsilon dc} = (k_r \times i_{sac} - i_{pac}) + (k_r \times i_{sdc} - i_{pdc})$$

3.4.222
peak instantaneous error
$\hat{\varepsilon}$
peak value ($\hat{i}_\varepsilon$) of instantaneous error current (see 3.4.221) for the specified duty cycle, expressed as a percentage of the peak value of the rated primary short-circuit current:

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

3.4.223
peak alternating error component
$\hat{\varepsilon}_{ac}$
peak value $\hat{i}_{\varepsilon ac}$ of the alternating component of the instantaneous error current, expressed as a percentage of the peak value of the rated primary short-circuit current:

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

3.4.224
specified duty cycle (C-O and / or 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 (see Figure 201)

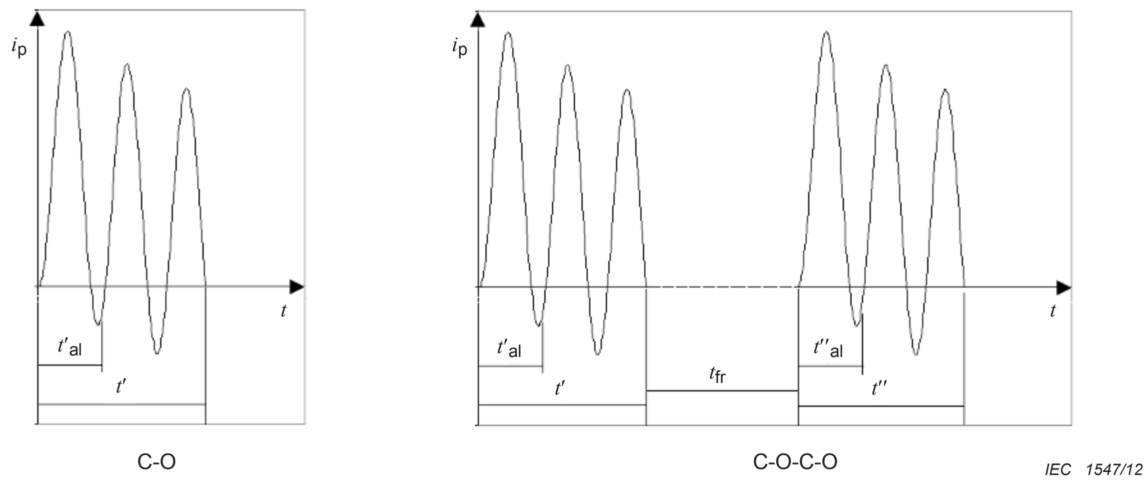


Figure 201 – Duty cycles

3.4.225
Specified primary time constant
T_P
that specified value of the time constant of the d.c. component of the primary short-circuit current on which the transient performance of the current transformer is based (see Figure 202)

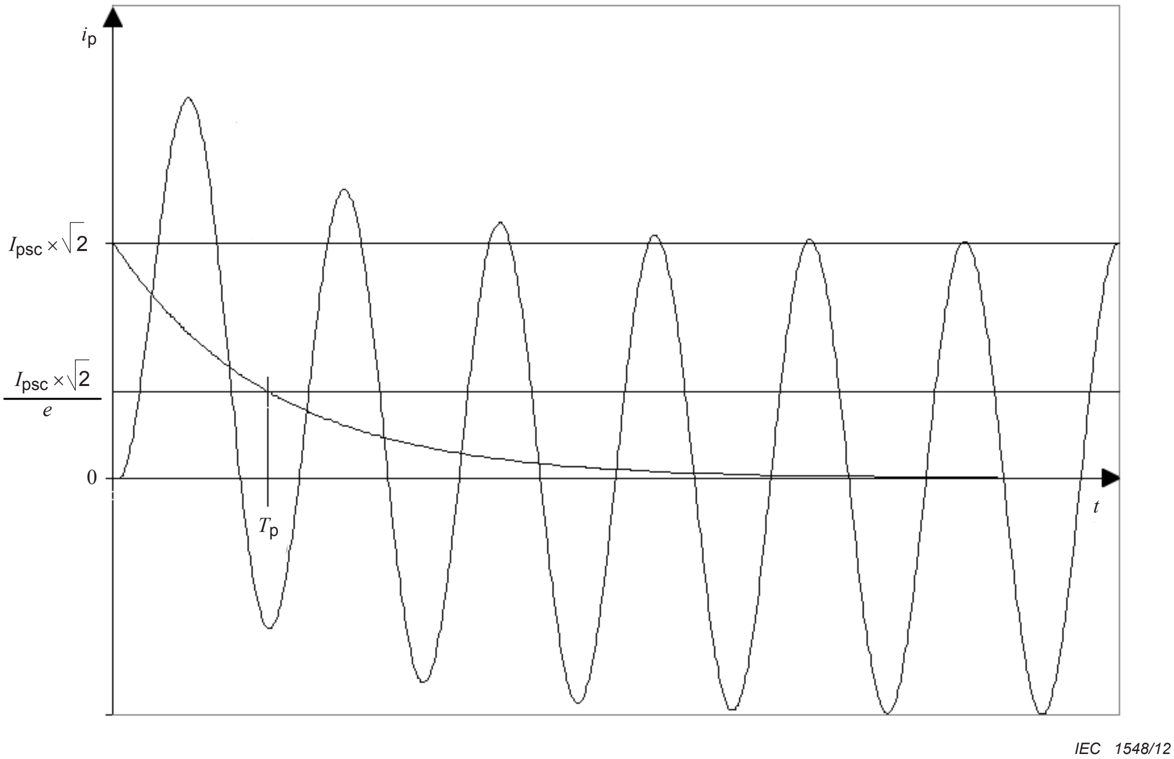


Figure 202 – Primary time constant T_P

3.4.226
duration of the first fault
t'
duration of the fault in a C-O duty cycle, or of the first fault in a C-O-C-O duty cycle

Note 1 to entry: See Figure 201.

3.4.227
duration of the second fault
t''
duration of the second fault in a C-O-C-O duty cycle

Note 1 to entry: See Figure 201.

3.4.228
specified time to accuracy limit in the first fault
t'_{al}
time in a C-O duty cycle, or in the first energization of a C-O-C-O duty cycle, during which the specified accuracy has to be maintained

Note 1 to entry: See Figure 201. This time interval is usually defined by the critical measuring time of the associated protection scheme.

3.4.229
specified time to accuracy limit in the second fault
t''_{al}
time in the second energization of a C-O-C-O duty cycle during which the specified accuracy has to be maintained

Note 1 to entry: See Figure 201. This time interval is usually defined by the critical measuring time of the associated protection scheme.

3.4.230
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

Note 1 to entry: See Figure 201.

3.4.231
secondary loop resistance
R_s
total resistance of the secondary circuit

$$R_s = R_b + R_{ct}$$

3.4.232
rated symmetrical short-circuit current factor
K_{ssc}
ratio of the rated primary short circuit current to the rated primary current

$$K_{ssc} = \frac{I_{psc}}{I_{pr}}$$

3.4.233
transient factor
K_{tf}
ratio of the secondary linked flux at a specified point of time in a duty cycle to the peak value of its a.c. component

Note 1 to entry: K_{tf} is calculated analytically with different formulae depending on T_P, T_S, on the duty cycle and on the fault inception angle. A determination of K_{tf} is given in Annex 2B.1.

Note 2 to entry: Figure 203 shows possible courses of the secondary linked flux for different fault inception angles γ.

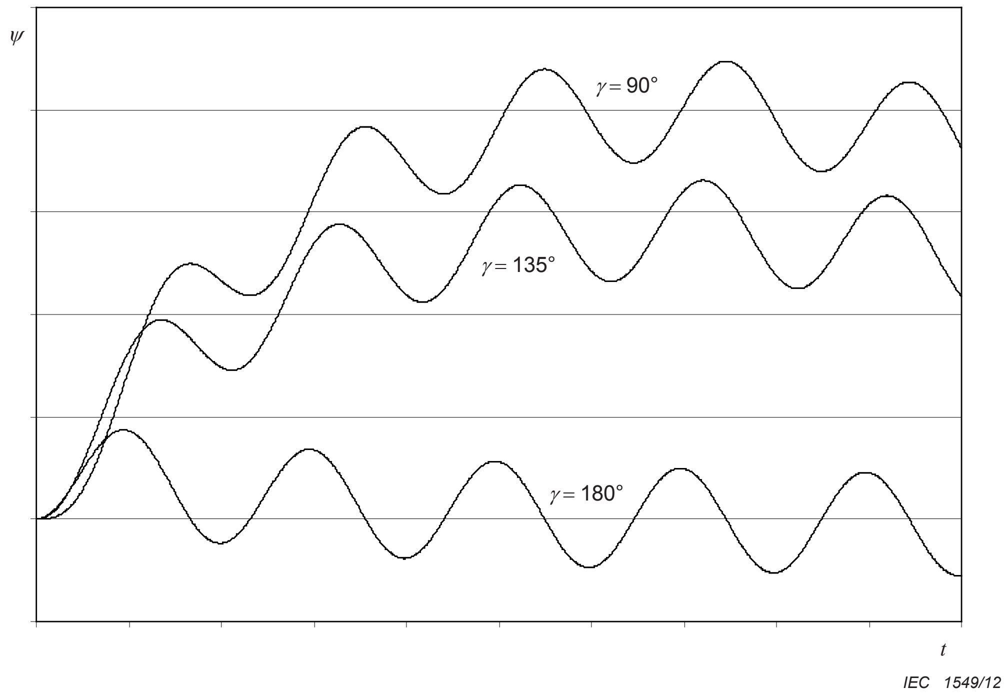


Figure 203 – Secondary linked flux for different fault inception angles γ

3.4.234
transient dimensioning factor
K_{td}
dimensioning factor to consider the increase of the secondary linked flux due to a d.c. component of the primary short circuit current

Note 1 to entry: While K_{tf} is defined as a function of time, K_{td} is the definitive dimensioning parameter. K_{td} is derived from current transformer requirements given by the relay manufacturer (gained from relay stability type tests) or from worst-case considerations based on the K_{tf} curves (see 2B.1).

3.4.235
Low-leakage reactance current transformer
current transformer for which measurements made at the secondary terminals (while primary open-circuited) are sufficient for an assessment of its protection performance up to the required accuracy limit

3.4.236
high-leakage reactance current transformer
current transformer which does not satisfy the requirements of 3.4.235, and for which an additional allowance is made by the manufacturer to take account of influencing effects which result in additional leakage flux

3.4.237
rated equivalent limiting secondary e.m.f.
E_{al}
that r.m.s. value of the equivalent secondary circuit e.m.f. at rated frequency necessary to meet the requirements of the specified duty cycle:

$$E_{al} = K_{ssc} \times K_{td} \times (R_{ct} + R_b) \times I_{sr}$$

3.4.238
peak value of the exciting secondary current at E_{al}
$\hat{I}_{al}$
peak value of the exciting current when a voltage corresponding to E_{al} is applied to the secondary terminals while the primary winding is open

3.4.239
factor of construction
F_c
factor reflecting the possible differences in measuring results at limiting conditions between direct test and indirect test methods

Note 1 to entry: The measuring procedure is given in 2B.3.3.

3.7 Index of abbreviations

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

AIS	Air-Insulated Switchgear
ALF	Accuracy limit factor
CT	Current Transformer
CVT	Capacitive Voltage Transformer
E_{al}	rated equivalent limiting secondary e.m.f.
E_{ALF}	secondary limiting e.m.f. for class P and PR protective current transformers
E_{FS}	secondary limiting e.m.f for measuring current transformers
E_k	rated knee point e.m.f.

F	mechanical load
F_c	factor of construction
f_R	rated frequency
F_{rel}	relative leakage rate
FS	instrument security factor
GIS	Gas-Insulated Switchgear
$\hat{I}_{al}$	peak value of the exciting secondary current at E_{al}
I_{cth}	rated continuous thermal current
I_{dyn}	rated dynamic current
I_e	exciting current
I_{PL}	rated instrument limit primary current
I_{pr}	rated primary current
I_{psc}	rated primary short-circuit current
I_{sr}	rated secondary current
IT	Instrument Transformer
I_{th}	rated short-time thermal current
i_ε	instantaneous error current
k	actual transformation ratio
k_r	rated transformation ratio
K_R	remanence factor
K_{ssc}	rated symmetrical short-circuit current factor
K_{td}	transient dimensioning factor
K_{tf}	transient factor
K_x	dimensioning factor
L_m	magnetizing inductance
R_b	rated resistive burden
R_{ct}	secondary winding resistance
R_s	secondary loop resistance
S_r	rated output
t'	duration of the first fault
t''	duration of the second fault
t'_{al}	specified time to accuracy limit in the first fault
t''_{al}	specified time to accuracy limit in the second fault
t_{fr}	fault repetition time
T_p	specified primary time constant
T_s	secondary loop time constant
U_m	highest voltage for equipment
U_{sys}	highest voltage for system
VT	Voltage Transformer
$\Delta\varphi$	phase displacement
ε	ratio error

ε_c	composite error
$\hat{\varepsilon}$	peak value of instananeous error
$\hat{\varepsilon}_{ac}$	peak value of alternating error component
Ψ_r	remanent flux
Ψ_{sat}	saturation flux

5 Ratings

5.3 Rated insulation levels

5.3.2 Rated primary terminal insulation level

Clause 5.3.2 of IEC 61869-1:2007 is applicable with the addition of the following:

For a current transformer without primary winding and without primary insulation of its own, the value U_m = 0,72 kV is assumed.

5.3.5 Insulation requirements for secondary terminals

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

The secondary winding insulation of class PX and class PXR current transformers having a rated knee point e.m.f. $E_k \geq 2$ kV shall be capable of withstanding a rated power frequency withstand voltage of 5 kV r.m.s. for 60 s.

5.3.201 Inter-turn insulation requirements

The rated withstand voltage for inter-turn insulation shall be 4,5 kV peak.

For class PX and class PXR current transformers having a rated knee point e.m.f. of greater than 450 V, the rated withstand voltage for the inter-turn insulation shall be a peak voltage of 10 times the r.m.s. value of the specified knee point e.m.f., or 10 kV peak, whichever is the lower.

NOTE 1 Due to the test procedure, the wave shape can be highly distorted.

NOTE 2 In accordance with the test procedure 7.3.204, lower voltage values may result.

5.5 Rated output

5.5.201 Rated output values

The standard values of rated output for measuring classes, class P and class PR are:

2,5 – 5,0 – 10 – 15 and 30 VA.

Values above 30 VA may be selected to suit the application.

NOTE For a given transformer, provided one of the values of rated output is standard and associated with a standard accuracy class, the declaration of other rated outputs, which may be non-standard values, but associated with other standard accuracy classes, is not precluded.

5.5.202 Rated resistive burden values

Standard values for rated resistive burden in Ω for class TPX, TPY and TPZ current transformers are:

0,5 – $\underline{1}$ – 2 – $\underline{5}$ Ω

The preferred values are underlined. The values are based on a rated secondary current of 1 A. For current transformers having a rated secondary current other than 1 A, the above values shall be adjusted in inverse ratio to the square of the current.

NOTE For a given transformer, provided one of the values of rated resistive burden is standard and associated with a standard accuracy class, the declaration of other rated resistive burdens, which may be non-standard values, but associated with other standard accuracy classes, is not precluded.

5.6 Rated accuracy class

5.6.201 Measuring current transformers

5.6.201.1 Accuracy class designation for measuring current transformers

For measuring current transformers, the accuracy class is designated by the highest permissible percentage of the ratio error (ε) at rated primary current and rated output.

5.6.201.2 Standard accuracy classes

The standard accuracy classes for measuring current transformers are:

0,1 – 0,2 – 0,2S – 0,5 – 0,5S – 1 – 3 – 5

5.6.201.3 Limits of ratio error (ε) and phase displacement for measuring current transformers

For classes 0,1 – 0,2 – 0,5 and 1, the ratio error and phase displacement at rated frequency shall not exceed the values given in Table 201 where the burden can assume any value from 25 % to 100 % of the rated output.

For classes 0,2S and 0,5S the ratio error and phase displacement at the rated frequency shall not exceed the values given in Table 202 where the burden can assume any value from 25 % and 100 % of the rated output.

For class 3 and class 5, the ratio error at rated frequency shall not exceed the values given in Table 203 where the burden can assume any value from 50 % to 100 % of the rated output. There are no specified limits of phase displacement for class 3 and class 5.

For all classes, the burden shall have a power-factor of 0,8 lagging except that, when the burden is less than 5 VA, a power-factor of 1,0 shall be used, with a minimum value of 1 VA.

NOTE In general the prescribed limits of ratio error and phase displacement are valid for any given position of an external conductor spaced at a distance in air not less than that required for insulation in air at the highest voltage for equipment (U_m).

Table 201 – Limits of ratio error and phase displacement for measuring current transformers (classes 0,1 to 1)

Accuracy class	Ratio error				Phase displacement							
	± %				± Minutes				± Centiradians			
	at current (% of rated)				at current (% of rated)				at current (% of rated)			
	5	20	100	120	5	20	100	120	5	20	100	120
0,1	0,4	0,2	0,1	0,1	15	8	5	5	0,45	0,24	0,15	0,15
0,2	0,75	0,35	0,2	0,2	30	15	10	10	0,9	0,45	0,3	0,3
0,5	1,5	0,75	0,5	0,5	90	45	30	30	2,7	1,35	0,9	0,9
1	3,0	1,5	1,0	1,0	180	90	60	60	5,4	2,7	1,8	1,8

Table 202 – Limits of ratio error and phase displacement for measuring current transformers (classes 0,2S and 0,5S)

Accuracy class	Ratio error ± %					Phase displacement ± Minutes					Phase displacement ± Centiradians				
	at current (% of rated)					at current (% of rated)					at current (% of rated)				
	1	5	20	100	120	1	5	20	100	120	1	5	20	100	120
0,2 S	0,75	0,35	0,2	0,2	0,2	30	15	10	10	10	0,9	0,45	0,3	0,3	0,3
0,5 S	1,5	0,75	0,5	0,5	0,5	90	45	30	30	30	2,7	1,35	0,9	0,9	0,9

Table 203 – Limits of ratio error for measuring current transformers (classes 3 and 5)

Class	Ratio error ± %	
	at current (% of rated)	
	50	120
3	3	3
5	5	5

5.6.201.4 Extended burden range

For all measuring classes, an extended burden range can be specified. The ratio error and phase displacement shall not exceed the limits of the appropriate class given in Table 201, Table 202 and Table 203 for the range of secondary burden from 1 VA up to rated output. The power factor shall be 1,0 over the full burden range. The maximum rated output is limited to 15 VA.

5.6.201.5 Extended current ratings

Current transformers of accuracy classes 0.1 to 1 may be marked as having an extended current rating provided they comply with the following two requirements:

a) the rated continuous thermal current shall be the rated extended primary current.

b) the limits of ratio error and phase displacement prescribed for 120 % of rated primary current in Table 201 shall be retained up to the rated extended primary current.

The rated extended primary current shall be expressed as a percentage of the rated primary current.

5.6.201.6 Instrument security factor

An instrument security factor may be specified.

Standard values are: FS 5 and FS 10

5.6.202 Protective current transformers

5.6.202.1 General

Three different approaches are designated to define protective current transformers (see Table 204). In practice, each of the three definitions may result in the same physical realization.

Table 204 – Characterisation of protective classes

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

[a)] Although there is no limit of remanent flux, air gaps are allowed, e.g. in split core current transformers.

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

5.6.202.2 Class P protective current transformers

5.6.202.2.1 Standard accuracy limit factors (*ALF*)

The standard *ALF* values are:

5 – 10 – 15 – 20 – 30

5.6.202.2.2 Accuracy class designation

The accuracy class is designated using the highest permissible percentage of the composite error, followed by the letter "P" (standing for "protection") and the *ALF* value.

5.6.202.2.3 Standard accuracy classes

The standard accuracy classes for protective current transformers are:

5P and 10P

5.6.202.2.4 Error limits for class P protective current transformers

At rated frequency and with rated burden connected, the ratio error, phase displacement and composite error shall not exceed the limits given in Table 205.

The rated burden shall have a power-factor of 0,8 inductive except that, when the rated output is less than 5 VA a power-factor of 1,0 shall be used.

Table 205 – Error limits for protective current transformers class P and PR

Accuracy class	Ratio error at rated primary current	Phase displacement at rated primary current		Composite error at rated accuracy limit primary current
	± %	± Minutes	± Centiradians	%
5P and 5PR	1	60	1,8	5
10P and 10PR	3	–	–	10

5.6.202.3 Class PR protective current transformers

5.6.202.3.1 Standard accuracy limit factors (*ALF*)

The standard *ALF* values are:

5 – 10 – 15 – 20 – 30

5.6.202.3.2 Accuracy class designation

The accuracy class is designated by the highest permissible percentage of the composite error, followed by the letters "PR" (indicating protection low remanence) and the *ALF* value.

5.6.202.3.3 Standard accuracy classes

The standard accuracy classes for low remanence protective current transformers are:

5PR and 10PR

5.6.202.3.4 Error limits for class PR protective current transformers

At rated frequency and with rated burden connected, the ratio error, phase displacement and composite error shall not exceed the limits given in Table 205.

The rated burden shall have a power-factor of 0,8 inductive except that, when the rated output is less than 5 VA a power-factor of 1,0 shall be used.

5.6.202.3.5 Remanence factor (K_R)

The remanence factor (K_R) shall not exceed 10 %.

NOTE The insertion of one or more air gaps in the core is a method for limiting the remanence factor.

5.6.202.3.6 Secondary loop time constant (T_s)

The secondary loop time constant may be specified.

5.6.202.3.7 Secondary winding resistance (R_{ct})

The upper limit of the secondary winding resistance may be specified.

5.6.202.4 Class PX and class PXR protective current transformers

The performance of class PX protective current transformers shall be specified in terms of the following:

- rated primary current (I_{pr});
- rated secondary current (I_{sr});
- rated turns ratio;
- rated knee point e.m.f. (E_k);
- upper limit of exciting current (I_e) at the rated knee point e.m.f. and/or at a stated percentage thereof;
- upper limit of secondary winding resistance (R_{ct}).

Instead of specifying the rated knee point e.m.f. (E_k) explicitly, E_k may be calculated as follows:

$$E_{\mathrm{k}} = K_{\mathrm{x}} \times (R_{\mathrm{ct}} + R_{\mathrm{b}}) \times I_{\mathrm{sr}}$$

In this case, the rated resistive burden (R_b) and the dimensioning factor (K_x) shall be specified, and the choice of R_{ct} is left to the manufacturer.

For class PX, the turns ratio error shall not exceed ±0,25 %.

For class PXR, the turns ratio error shall not exceed ±1 %.

For class PXR, the remanence factor shall not exceed 10 %.

NOTE 201 To ensure a remanence factor <= 10 %, class PXR current transformers may comprise air gaps.

NOTE 202 For large class PXR cores with low ampere-turns, it may be difficult to meet the remanence factor requirement. In such cases, a remanence factor higher than 10 % may be agreed.

5.6.202.5 Protective current transformers for transient performance

5.6.202.5.1 Error limits for TPX, TPY and TPZ current transformers

With rated resistive burden connected to the current transformer, the ratio error and the phase displacement at rated frequency shall not exceed the error limits given in Table 206.

When the specified duty cycle (or a duty cycle corresponding to the specified transient dimensioning factor K_{td}) is applied to the current transformer connected to the rated resistive burden, the transient errors $\hat{\varepsilon}$ (for TPX and TPY) or $\hat{\varepsilon}_{ac}$ (for TPZ) shall not exceed the limits given in Table 206.

All error limits are based on a secondary winding temperature of 75°C.

Table 206 – Error limits for TPX, TPY and TPZ current transformers

Class	At rated primary current			Transient error limits under specified duty cycle conditions
	Ratio error ±%	Phase displacement		
		Minutes	Centiradians	
TPX	0,5	±30	±0,9	$\hat{\varepsilon}$ =10 %
TPY	1,0	±60	±1,8	$\hat{\varepsilon}$ =10 %
TPZ	1,0	180±18	5,3±0,6	$\hat{\varepsilon}_{ac}$ =10 %

NOTE 1 In some cases, the absolute value of the phase displacement may be of less importance than achieving minimal deviation from the average value of a given production series.

NOTE 2 For TPY cores, the following formula can be used under the condition that the appropriate E_{al} value does not exceed the linear part of the magnetizing curve:

$$\hat{\varepsilon} = \frac{K_{\mathrm{td}}}{2\pi f_{\mathrm{R}} \times T_{\mathrm{s}}} \times 100\,\%$$

5.6.202.5.2 Limits for remanence factor (K_R)

TPX: no limit

TPY: $K_{\mathrm{R}} \leq 10\,\%$

TPZ: $K_{\mathrm{R}} \leq 10\,\%$

NOTE For TPZ cores, a remanence factor << 10 % is given by the design. Therefore, the remanent flux can be neglected.

5.6.202.5.3 Specification Methods

The two specification methods are illustrated in Table 207.

In some cases, the choice of one specific duty cycle cannot describe all protection requirements. Therefore, the alternative definition offers the possibility to specify "overall requirements", which cover the requirements of different duty cycles. The specifications shall not be mixed, otherwise the current transformer may be over-determined.

Table 207 – Specification Methods for TPX, TPY and TPZ current transformers

Standard specification	Alternative specification
Class designation (TPX, TPY or TPZ)	Class designation (TPX, TPY or TPZ)
Rated symmetrical short-circuit current factor K_{ssc}	Rated symmetrical short-circuit current factor K_{ssc}
Duty cycle, consisting of for C-O cycle: t'_{al} for C-O-C-O cycle: t'_{al}, t', t_{fr}, t''_{al}	Rated value of transient dimensioning factor K_{td} Rated value of secondary loop time constant T_S (for TPY cores only)
Rated primary time constant T_p	
Rated resistive burden R_b	Rated resistive burden R_b

NOTE 1 For current transformers with tapped secondary windings, the given accuracy requirements can be fulfilled for one ratio only.

Note 2 For current transformers with primary reconnection, the accuracy requirements may be fulfilled for different ratios. In this case, attention should be paid to the factor of construction F_c which may be influenced by the configuration of the primary conductors.

NOTE 3 In the alternative specification, K_{td} is usually given by the supplier of the protection devices. T_S has also to be specified, because it is the only parameter of the current transformer which is used in the calculation of K_{td}.

5.6.203 Class assignments for selectable-ratio current transformers

5.6.203.1 Accuracy performance for current transformers with primary reconnection

For all accuracy classes, the accuracy requirements refer to all specified reconnections.

5.6.203.2 Accuracy performance for current transformers with tapped secondary windings

For all accuracy classes, the accuracy requirements refer to the highest transformation ratio, unless specified otherwise.

When required by the purchaser, the manufacturer shall give information about the accuracy performance at lower ratios.

5.201 Standard values for rated primary current

The standard values for rated primary current are:

10 – 12,5 – 15 – 20 – 25 – 30 – 40 – 50 – 60 – 75 A,

and their decimal multiples or fractions.

The preferred values are those underlined.

5.202 Standard values for rated secondary current

The standard values for rated secondary current are 1 A and 5 A.

For protective current transformers for transient performance, the standard value of the rated secondary current is 1 A.

5.203 Standard values for rated continuous thermal current

The standard value for rated continuous thermal current is the rated primary current.

When a rated continuous thermal current greater than the rated primary current is specified, the preferred values are 120 %, 150 % and 200 % of rated primary current.

5.204 Short-time current ratings

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

A rated short-time thermal current (I_{th}) shall be assigned to the transformer.

The standard value for the duration of the rated short-time thermal current is 1 s.

5.204.2 Rated dynamic current (I_{dyn})

The standard value of the rated dynamic current (I_{dyn}) is 2,5 times the rated short-time thermal current (I_{th}).

6 Design and construction

6.4 Requirements for temperature rise of parts and components

6.4.1 General

This clause of IEC 61869-1:2007 is applicable with the addition of the following:

The temperature rise in a current transformer when carrying a primary current equal to the rated continuous thermal current, with a unity power-factor burden corresponding to the rated output, shall not exceed the appropriate value given in Table 5 of IEC 61869-1:2007. These values are based on the service conditions given in Clause 4.

6.13 Markings

6.13.201 Terminal markings

6.13.201.1 General rules

The terminal markings shall identify:

a) the primary and secondary windings;
b) the winding sections, if any;
c) the relative polarities of windings and winding sections;

d) the intermediate taps, if any.

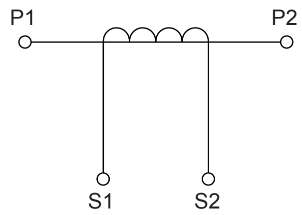
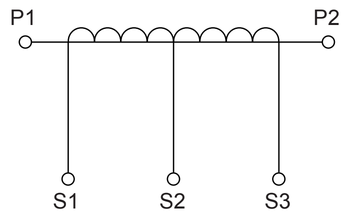
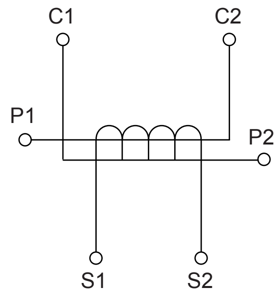
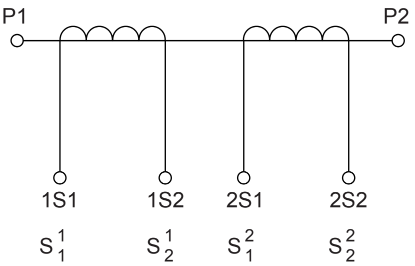
6.13.201.2 Method of marking

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

6.13.201.3 Markings to be used

The markings of current transformer terminals shall be as indicated in Table 208.

Table 208 – Marking of terminals

Primary terminals Secondary terminals	 Single-ratio transformer	 Transformer with an intermediate tapping on secondary winding
Primary terminals Secondary terminals	 Transformer with primary winding in 2 sections intended for connections either in series or in parallel	 Transformer with 2 secondary windings; each with its own magnetic core (two alternative markings for the secondary terminals)

6.13.201.4 Indication of relative polarities

All the terminals marked P1, S1 and C1 shall have the same polarity at the same instant.

6.13.202 Rating plate markings

6.13.202.1 General

In addition to those markings defined in IEC 61869-1:2007, Clause 6.13, all current transformers shall carry the general rating plate markings as defined in this clause. The markings related to the particular accuracy classes are given in Subclauses 6.13.202.2 to 6.13.202.6.

a) the rated primary and secondary current (e.g. 100/1 A);

b) the rated short-time thermal current (I_{th}), (e.g. Ith = 40 kA);

c) the rated dynamic current (I_{dyn}) if it differs from 2,5 × I_{th} (e.g. I_{dyn} = 85 kA);

d) on current transformers with two or more secondary windings, the use of each winding and its corresponding terminals;

e) the rated continuous thermal current if different from the rated primary current.

EXAMPLE 1
For single core current transformer with secondary taps: I_{cth} = 150 %
(meaning 150 % of the rated primary current for each tap)

EXAMPLE 2
For current transformers with several cores of different ratios
(e.g. 300/5 A and 4000/1 A): I_{cth} = 450 A
(meaning 450 A as the maximum continuous thermal current through all cores of the current transformer)

EXAMPLE 3
For current transformers with primary reconnection (4x300/1 A): I_{cth} = 4×450 A
(meaning continuous thermal current of 450, 900 or 1800 A, depending on the primary reconnection)

A current transformer satisfying the requirements of several combinations of output and accuracy class may be marked according to all of them.

EXAMPLE 4 5 VA cl. 0,5; 10 VA cl. 5P20

EXAMPLE 5 15 VA cl. 1; 7 VA cl. 0,5

EXAMPLE 6 5 VA cl.1 & 5P20

6.13.202.2 Specific marking of the rating plate of a measuring current transformer

The accuracy class and instrument security factor (if any) shall be indicated following the indication of the corresponding rated output.

EXAMPLE 1 15 VA cl. 0,5

EXAMPLE 2 15 VA cl. 0,5 FS 10

Current transformers having an extended current rating (see 5.6.201.5) shall have this rating indicated immediately following the class designation.

EXAMPLE 3 15 VA cl. 0,5 ext.150 % FS 10

For current transformers having an extended burden range (see 5.6.201.4), this rating shall directly precede the class indication.

EXAMPLE 4 1-10 VA class 0,2 (meaning burden range from 1 to 10 VA at class 0,2)

NOTE The rating plate may contain information concerning several combinations of ratios, burdens and accuracy classes that the transformer can satisfy at the same ratio. In this case, non-standard values of burden may be used.

EXAMPLE 15 VA class 1; 7 VA class 0,5

6.13.202.3 Specific marking of the rating plate of a class P protective current transformer

The rated accuracy limit factor shall be indicated following the corresponding rated output and accuracy class.

EXAMPLE 30 VA class 5P10

6.13.202.4 Specific marking of the rating plate of class PR protective current transformers

The rated accuracy limit factor shall be indicated following the corresponding rated output and accuracy class.

EXAMPLE 1 10 VA class 5PR10

If specified, the following parameters shall also be indicated:

– the secondary loop time constant (T_s);
– the upper limit of the secondary winding resistance (R_{ct});

EXAMPLE 2 10 VA class 5PR10, Ts = 200 ms, Rct <= 2,4 Ω

6.13.202.5 Specific marking of the rating plate of class PX and PXR protective current transformers

The class requirements may be indicated as follows:

- the rated turns ratio
- the rated knee point e.m.f. (E_k);
- the upper limit of exciting current (I_e) at the rated knee point e.m.f. and/or at the stated percentage thereof;
- the upper limit of secondary winding resistance (R_{ct}).

EXAMPLE 1 class PX, Ek = 200 V, Ie <= 0,2A, Rct <= 2,0 Ω

If specified, the following parameters shall also be indicated:

- the dimensioning factor (K_x);
- the rated resistive burden (R_b).

EXAMPLE 2 Ek = 200 V, Ie <= 0,2 A, Rct <= 2,0 Ω, Kx = 40, Rb = 3,0 Ω

6.13.202.6 Specific marking of the rating plate of current transformers for transient performance

The class marking consists of the following 2 elements:

a) Definition part (compulsory)
The definition part contains the essential information which is necessary to determine whether the current transformer fulfils given requirements (consisting of duty cycle and T_p).

EXAMPLE 1 applying K_{ssc}= 20 and K_{td} = 12,5:

Rb = 5Ω, class TPX 20x12,5, Rct <= 2,8Ω

Rb = 5Ω, class TPY 20x12,5, Rct <= 2,8Ω, Ts = 900 ms

Rb = 5Ω, class TPZ 20x12,5, Rct <= 2,8Ω

NOTE For R_{ct}, its maximum value within the batch may be stated.

b) Complementary part (compulsory only if a duty cycle is specified by the customer)
The complementary part represents one of many possible duty cycles which lead to the K_{td} value specified in a).

EXAMPLE 2

Cycle 100 ms, T_p = 100 ms	meaning t'_{al} =100 ms, T_p =100 ms
Cycle (40-100)-300-40 ms, T_p = 100 ms	meaning t'_{al}=40 ms, t'=100 ms, t_{fr}=300 ms, t''_{al}=40 ms, T_p=100 ms
Cycle (100-100)-300-40 ms, T_p = 75 ms	meaning t' = t'_{al}=100 ms, t_{fr}=300 ms, t''_{al}=40 ms, T_p= 75 ms

7 Tests

7.1 General

7.1.2 Lists of tests

Table 10 of IEC 61869-1:2007 is replaced by new Table 10.

Table 10 – List of tests

Tests	Subclause
Type tests	**7.2**
Temperature-rise test	7.2.2
Impulse voltage withstand test on primary terminals	7.2.3
Wet test for outdoor type transformers	7.2.4
Electromagnetic Compatibility tests	7.2.5
Tests 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
Short-time current tests	7.2.201
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
Tests 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
Determination of the secondary winding resistance	7.3.201
Determination of the secondary loop time constant	7.3.202
Test for rated knee point e.m.f. and exciting current at rated knee point e.m.f.	7.3.203
Inter-turn overvoltage test	7.3.204
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
Fire hazard test	7.4.10
Sample Tests	**7.5**
Determination of the remanence factor	7.5.1
Determination of the instrument security factor (FS) of measuring current transformers	7.5.2

Table 11 of IEC 61869-1:2007 is applicable with the addition of the following text:

For GIS current transformers, the accuracy tests may be performed without insulating gas.

7.2 Type tests

7.2.2 Temperature-rise test

IEC 61869-1:2007, 7.2.2 is applicable with the following additions:

7.2.2.201 Test set up

The current transformer shall be mounted in a manner representative of the mounting in service and the secondary windings shall be loaded with the burdens according to 6.4.1. However, because the position of the current transformer in each switchgear installation can be different, the test setup arrangement is left to the manufacturer.

For current transformers in three phase gas-insulated metal enclosed switchgear, all three phases have to be tested at the same time.

7.2.2.202 Measurement of the ambient temperature

The sensors to measure the ambient temperature shall be distributed around the current transformer, at an appropriate distance according to the current transformer ratings and at about half-height of the transformer, protected from direct heat radiation.

To minimise the effects of variation of cooling-air temperature, particularly during the last test period, appropriate means should be used for the temperature sensors such as heat sinks with a time-constant approximately equal to that of the transformer.

The average readings of two sensors shall be used for the test.

7.2.2.203 Duration of test

The test can be stopped when both of the following conditions are met:

– the test duration is at least equal to three times the current transformer thermal time constant;
– the rate of temperature rise of the windings (and of the top oil of oil-immersed current transformers) does not exceed 1 K per hour during three consecutive temperature rise readings.

The manufacturer shall estimate the thermal time constant by one of the following methods:

– before the test, based on the results of previous tests on a similar design. The thermal time constant shall be confirmed during the temperature rise test.
– during the test, from the temperature rise curve(s) or temperature decrease curve(s) recorded during the course of the test and calculated according to Annex 2D.
– during the test, as the point of intersection between the tangent to the temperature rise curve originating at 0 and the maximum estimated temperature rise.
– during the test, as the time elapsed until 63 % of maximum estimated temperature rise.

7.2.2.204 Temperatures and temperature rises

The purpose of the test is to determine the average temperature rise of the windings and, for oil-immersed transformers, the temperature rise of the top oil, in steady state when the losses resulting from the specified service conditions are generated in the current transformer.

The average temperature of the windings shall, when practicable, be determined by the resistance variation method, but for windings of very low resistance, thermometers, thermocouples or other appropriate temperature sensors may be employed.

Thermometers or thermocouples shall measure the temperature rise of parts other than windings. The top-oil temperature shall be measured by sensors applied to the top of metallic head directly in contact with the oil.

The temperature rises shall be determined by the difference with respect to the ambient temperature measured as indicated in 7.2.2.202.

7.2.2.205 Test modalities for current transformers having U_m <550 kV

The test shall be performed by applying the rated continuous thermal current to the primary winding.

NOTE Subject to an agreement between manufacturer and purchaser the test current may also be applied by energizing one or more secondary windings, if the voltages at the secondary terminals of the energizing cores are at least as high as if connected to rated burden, with the primary winding short-circuited and the non-supplied secondary winding(s) connected to the rated burden(s).

7.2.2.206 Test modalities for oil-immersed current transformers having $U_m \geq$ 550 kV

The test shall be performed by simultaneously applying the following to the current transformer:

- the rated continuous thermal current to the primary winding;

  The test current may also be applied by energizing one or more secondary windings, if the voltages at the secondary terminals of the energizing cores are at least as high as if connected to rated burden, with the primary winding short-circuited and the non-supplied secondary winding(s) connected to the rated burden(s).
- the highest voltage of the equipment divided by √3 between the primary winding and earth. One terminal of each secondary winding shall be connected to earth.

7.2.3 Impulse voltage withstand test on primary terminals

7.2.3.1 General

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

The test voltage shall be applied between the terminals of the primary winding (connected together) and earth. The frame, case (if any), and core (if intended to be earthed) and all terminals of the secondary winding(s) shall be connected to earth.

For three-phase current transformers for gas insulated substations, each phase shall be tested, one by one. During the test on each phase, the other phases shall be earthed.

For the acceptance criteria of gas-insulated metal enclosed transformers, refer to IEC 62271-203:2011, Clause 6.2.4.

7.2.6 Tests for accuracy

7.2.6.201 Test for ratio error and phase displacement of measuring current transformers

To prove compliance with 5.6.201.3, 5.6.201.4 and 5.6.201.5, accuracy measurements shall be made at each value of current given in Table 201, Table 202 and Table 203 respectively, at the highest and at the lowest value of the specified burden range.

Transformers having an extended current rating shall be tested at the rated extended primary current instead of 120 % of rated current.

7.2.6.202 Determination of the instrument security factor (*FS*) of measuring current transformers

This test may be performed using the following indirect test method:

With the primary winding open-circuited, the secondary winding is energized at rated frequency by a substantially sinusoidal voltage. The voltage shall be increased until the exciting current I_e reaches $I_{sr} \times FS \times 10\ \%$.

The r.m.s. value of the obtained terminal voltage shall be less than the secondary limiting e.m.f. E_{FS} (see 3.4.206).

The exciting voltage shall be measured with an instrument which has a response proportional to the average of the rectified signal, but calibrated in r.m.s.. The exciting current shall be measured using an r.m.s measuring instrument having a minimum crest factor of 3.

If the measurement result should be put to question, a further measurement shall be performed with the direct test (see 2A.5, 2A.6). Then the result of the direct test is the reference.

NOTE The great advantage of the indirect test is that high currents are not necessary (for instance 30 000 A at a primary rated current 3 000 A and an instrument security factor 10) and also that no burdens have to be made available for 50 A. The effect of the return primary conductors is not physically effective during the indirect test. Under service conditions the effect can only increase the composite error, which is desirable for the safety of the apparatus supplied by the measuring current transformer.

7.2.6.203 Test for composite error of class P and PR protective current transformers

The following two test procedures are given:

a) Compliance with the limits of composite error given in Table 205 shall be demonstrated by a direct test in which a substantially sinusoidal current equal to the rated accuracy limit primary current is passed through the primary winding with the secondary winding connected to a burden of magnitude equal to the rated burden but having, at the discretion of the manufacturer, a power factor between 0,8 inductive and unity (see 2A.4, 2A.5, 2A.6, 2A.7.

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

   As far as very high primary currents and single-bar primary winding current transformers are concerned, the distance between the return primary conductor and the current transformer should be taken into account from the point of view of reproducing service conditions.

b) For low-leakage reactance current transformers according to Annex 2C, the direct test may be replaced by the following indirect test.

   With the primary winding open-circuited, the secondary winding is energized at rated frequency by a substantially sinusoidal voltage having an r.m.s. value equal to the secondary limiting e.m.f. E_{ALF}.

   The resulting exciting current, expressed as a percentage of $I_{sr} \times ALF$ shall not exceed the composite error limit given in Table 205.

   The exciting voltage shall be measured with an instrument which has a response proportional to the average of the rectified signal, but calibrated in r.m.s.. The exciting current shall be measured using an r.m.s measuring instrument having a minimum crest factor of 3.

   In determining the composite error by the indirect method, a possible correction of the turns ratio need not be taken into account.

7.2.6.204 Test for error at limiting conditions for class TPX, TPY and TPZ protective current transformers

The purpose of the type test is to prove the compliance with the requirements at limiting conditions. For test methods refer to Annex 2B.

If the current transformer is a low-leakage reactance type according to Annex 2C, an indirect type test may be performed according to 2B.2, otherwise a direct test shall be performed according to 2B.3.

The test can be performed on a full-scale model of the active part of the current transformer assembly inclusive of all metal housings but without insulation.

7.2.6.205 Test of low-leakage reactance type for class PX and PXR protective current transformers

The proof of low-leakage reactance shall be made according to Annex 2C.

7.2.6.206 Determination of the remanence factor class PR, TPY, and PXR protective current transformers

To prove compliance with

5.6.202.3.5 for class PR,

5.6.202.5.2 for class TPY,

5.6.202.4 for class PXR,

the remanence factor (K_R) shall be determined. For test methods, refer to 2B.2.

7.2.201 Short-time current tests

To verify the requirements of rated short-time thermal current and of rated dynamic current given in 5.204, the two following tests are specified.

The thermal test shall be made with the secondary winding(s) short-circuited, and at a current I' for a time t', so that

$$I'^2 \times t' \geq I_{th}^2 \times t$$

where t is the specified duration of the short-time thermal current.

t' shall have a value between 0,5 s and 5 s.

The dynamic test shall be made with the secondary winding(s) short-circuited, and with a primary current the peak value of which is not less than the rated dynamic current (I_{dyn}) for at least one peak.

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

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

a) it is not visibly damaged;
b) its errors after demagnetization do not differ from those recorded before the tests by more than half the limits of error appropriate to its accuracy class;
c) it withstands the dielectric tests specified in 7.3.1, 7.3.2, 7.3.3 and 7.3.4 but with the test voltages or currents reduced to 90 % of those given;
d) on examination, the insulation next to the surface of the conductor does not show significant deterioration (e.g. carbonization).

The examination d) is not required if the current density in the primary winding, corresponding to the rated short-time thermal current (I_{th}), does not exceed:

– 180 A/mm^2 where the winding is of copper of conductivity not less than 97 % of the value given in IEC 60028;
– 120 A/mm^2 where the winding is of aluminium of conductivity not less than 97 % of the value given in IEC 60121.

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

7.3 Routine tests

7.3.1 Power-frequency voltage withstand tests on primary terminals

This clause of IEC 61689-1 is applicable with the addition of the following:

The test voltage shall be applied between the short-circuited primary winding and earth. The short-circuited secondary winding(s), the frame, case (if any) and core (if there is a special earth terminal) shall be connected to earth.

7.3.5 Tests for accuracy

7.3.5.201 Tests for ratio error and phase displacement of measuring current transformers

The routine test for accuracy is in principle the same as the type test in 7.2.6.201, but routine tests at a reduced number of currents and/or burdens are permissible provided it has been shown by type tests on a similar transformer that such a reduced number of tests are sufficient to prove compliance with 5.6.201.3.

7.3.5.202 Tests for ratio error and phase displacement of class P and PR protective current transformers

Tests shall be made at rated primary current and rated burden to prove compliance with 5.6.202.2 and 5.6.202.3 respectively, with respect of ratio error and phase displacement.

7.3.5.203 Test for composite error of class P and PR protective current transformers

For low-leakage reactance current transformers (see Annex 2C), the routine test is the same as the indirect type test described in item b) of 7.2.6.203.

For other transformers, the indirect test described in item b) of 7.2.6.203 may be used, but a correction factor for the exciting current shall be applied to the results. This factor is obtained from a comparison between the results of direct and indirect tests applied to a transformer of the same type as the one under consideration, the accuracy limit factor and the conditions of loading being the same. In such cases, the manufacturer should hold test reports available.

NOTE 1 The correction factor is equal to the ratio of the composite error obtained by the direct method, and the exciting current expressed as a percentage of I_{sr} x ALF, as determined by the indirect method.

NOTE 2 The expression "transformer of the same type" implies that the ampere turns are similar irrespective of ratio, and that the materials and the geometrical arrangements of the iron core and the secondary windings are identical.

7.3.5.204 Test for ratio error and phase displacement for class TPX, TPY and TPZ protective current transformers

The ratio error and the phase displacement shall be measured at rated current to prove compliance with 5.6.202.5.1.

The results shall correspond to a secondary winding temperature of 75 °C.

Therefore, the actual value of the secondary winding temperature shall be measured and the difference to its value corrected to 75 °C shall be determined. The error measurement shall be made with the burden R_b increased by the above mentioned difference of winding resistance.

Alternatively, for TPY and TPZ cores the phase displacement at 75 °C ($\Delta\varphi_{75}$) may be determined by measuring at ambient temperature ($\Delta\varphi_{amb}$) and calculating as follows:

$$\Delta\varphi_{75} = \Delta\varphi_{amb} \frac{R_{ct} + R_b}{R_{ct\,amb} + R_b}$$

where $R_{ct\,amb}$ is the winding resistance at the ambient temperature. The influence of this resistance correction on the ratio error can be neglected.

For type and routine testing, a direct test method (using a primary current source and a reference current transformer) has to be applied. For low-leakage reactance current transformers, an indirect test method is given in Annex 2E. It may be applied for on-site measurements and for monitoring purposes.

7.3.5.205 Test for error at limiting conditions for class TPX, TPY and TPZ protective current transformers

The purpose of the routine test is to prove compliance with the requirements at limiting conditions.

If the current transformer is a low-leakage reactance type according to Annex 2C, an indirect test shall be performed according to 2B.2.

If compliance with the requirements of low-leakage reactance design cannot be established, but a type test report of a current transformer of the same type is available, an indirect test shall be performed according to 2B.2. In this case, a possibly available factor of construction F_c shall be considered if the factor is greater than 1,1. If such a type test is not available, one unit of the batch shall be type-tested and used as reference for the indirect testing of the remaining units.

NOTE 1 When determining the factor of construction F_C, laboratories have to cope with a high measuring uncertainty due to the necessity of integrating the e.m.f. and due to nonlinear parameters at accuracy limiting conditions. Furthermore, only few laboratories are in the position to provide the required duty cycles, and these with limited precision only. As a consequence, the results of direct and indirect tests usually do not match nicely, and unreliable F_C values may result. Therefore, little experience exists in this field.

NOTE 2 The expression “transformer of the same type” implies that the ampere turns are similar irrespective of ratio, and that the materials and the geometrical arrangements of the iron core and the secondary windings are identical.

7.3.5.206 Test for turns ratio error for class PX and PXR protective current transformers

For class PX and class PXR, the turns ratio error shall be determined in accordance with Annex 2F.

The test may be substituted by performing the measurement of the ratio error with a zero-Ω burden connected, subject to an agreement between manufacturer and purchaser.

The turns ratio error shall not exceed the limits given in 5.6.202.4.

7.3.201 Determination of the secondary winding resistance (R_{ct})

The secondary winding resistance (R_{ct}) shall be measured for current transformers of the following classes, to prove compliance with the appropriate clauses:

class PR:	clauses 5.6.202.3.7 and 6.13.202.4 (if parameter specified)
class PX, PXR:	clauses 5.6.202.4 and 6.13.202.5
class TPX, TPY, TPZ:	clause 6.13.202.6

An appropriate correction shall be made to meet 75°C or other such temperature as may have been specified.

For classes PR, PX and PXR, the value obtained when corrected to 75 °C shall not exceed the specified upper limit (if any).

7.3.202 Determination of the secondary loop time constant (T_s)

The secondary loop time constant (T_s) shall be determined at current transformers with the following classes, to prove compliance with the appropriate clauses:

class PR:	clause 5.6.202.3.6 (if parameter specified)
class TPY	clause 5.6.202.5.3

The measured value shall not differ from any specified value by more than ±30 %.

For the determination of T_s, the following formula shall be used (For the determination of L_m: see 2B.2):

$$T_S = \frac{L_m}{(R_{ct} + R_b)}$$

In cases where the burden is defined as rated output, given in VA, R_b is taken as being equal to the resistive part of the burden.

Alternatively, T_s may be determined according to the following equation:

$$T_S = \frac{1}{2\pi f_R \times \tan(\Delta\varphi)}$$

If the phase displacement $\Delta\varphi$ is expressed in minutes, the following approximate formula may be applied:

$$T_S[\mathrm{s}] = \frac{3438}{2\pi f_R \times \Delta\varphi\ [\mathrm{min}]}$$

NOTE 1 The method using Δφ may cause difficulties for current transformers with high transformation ratio and small phase displacement due to uncertainty of the measurement of low phase displacement.

NOTE 2 For class TPZ cores, T_s has not to be stated explicitly. The accuracy requirement of Δφ = (180 ± 18) min is verified as routine test. T_s is then provided by the above mentioned formula.

7.3.203 Test for rated knee point e.m.f. (E_k) and exciting current at E_k

The rated knee point e.m.f. shall be verified and the exciting current I_e at rated knee point e.m.f. E_k shall be measured for current transformers with the following classes, to prove compliance with the appropriate clause:

class PX, PXR: clause 5.6.202.4

A suitable sinusoidal exciting voltage with rated frequency shall be applied to the secondary terminals of the full winding of the transformer, all other terminals being open-circuited, and the exciting current shall be measured.

The exciting voltage shall be measured with an instrument which has a response proportional to the average of the rectified signal, but calibrated in r.m.s.. The exciting current shall be measured using an r.m.s measuring instrument having a minimum crest factor of 3.

The excitation characteristic shall be plotted at least up to a voltage equal to 1.1 x E_k.

At a voltage equal to E_k, the knee point condition according to 3.4.215 shall be fulfilled.

The exciting current I_e at a voltage equal to E_k (or at any stated percentage), shall not exceed the specified limit.

NOTE 1 For selectable-ratio current transformers with tapped secondary windings, the excitation characteristic for other than the maximum ratio may be calculated. For every measuring point, the following equations can be applied:

$$E_2 = E_1 \times \frac{k_{r2}}{k_{r1}}$$

$$I_{e2} = I_{e1} \times \frac{k_{r1}}{k_{r2}}$$

where k_{r1}, k_{r2} are the two rated transformation ratios;
E_1, E_2 are the two appropriate secondary e.m.f values;
I_{e1}, I_{e2} are the two appropriate exciting current values.

NOTE 2 The number of measurement points may be agreed between the manufacturer and the purchaser.

NOTE 3 Usually, the actual knee point e.m.f. is determined, which must be higher than the rated knee point e.m.f E_k.

7.3.204 Inter-turn overvoltage test

Tests shall be performed to demonstrate compliance with 5.3.201.

The inter-turn overvoltage test shall be performed at the full winding in accordance with one of the following procedures. If not otherwise agreed, the choice of the procedure is left to the manufacturer.

Procedure A: with the secondary windings open-circuited (or connected to a high impedance device which reads peak voltage), a substantially sinusoidal current at a frequency between 40 Hz and 60 Hz and of r.m.s. value equal to the rated primary current (or rated extended primary current if specified) shall be applied for 60 s to the primary winding.

The applied current shall be limited if the test voltage given in 5.3.201 is obtained before reaching the rated primary current (or rated extended primary current).

If the test voltage given in 5.3.201 is not reached at maximum primary current, the obtained voltage shall be regarded as the test voltage.

Procedure B: with the primary winding open-circuited, the test voltage given in 5.3.201 (at some suitable test frequency) shall be applied for 60 s to the terminals of each secondary winding.

The r.m.s. value of the secondary current shall not exceed the rated secondary current (or the appropriate extended value if specified).

The test frequency shall be chosen in order to reach the test voltage, but it shall not exceed 400 Hz.

If the test voltage given in 5.3.201 is not reached at maximum secondary current and maximum test frequency, the obtained voltage shall be regarded as the test voltage.

When the test frequency exceeds twice the rated frequency, the duration of the test t shall be reduced as below:

$$t = 120\,\mathrm{s} \times \frac{f_\mathrm{R}}{f_\mathrm{T}}$$

where

f_R is the rated frequency;

f_T is the test frequency;

with a minimum t of 15 s.

NOTE The inter-turn overvoltage test is not a test carried out to verify the suitability of a current transformer to operate with the secondary winding open-circuited. Current transformers should not be operated with the secondary winding open-circuited because of the potentially dangerous overvoltage and overheating which can occur.

7.4 Special tests

7.4.3 Measurement of capacitance and dielectric dissipation factor

This clause of IEC 61869-1:2007 is applicable with the addition of the following:

The test voltage shall be applied between the short-circuited primary winding terminals and earth. Generally, the short-circuited secondary winding(s), any screen, and the insulated metal casing shall be connected to the measuring device. If the current transformer has a special terminal suitable for this measurement, the other low-voltage terminals shall be short-circuited and connected together with the metal casing to the earth or the screen of the measuring device.

The test shall be performed with the current transformer at ambient temperature, the value of which shall be recorded.

7.4.6 Internal arc fault test

This clause of IEC 61869-1:2007 is applicable with the addition of the following note:

NOTE For top-core oil-immersed current transformers, the area in which in-service failure occurs, the incept is, in many cases, located in the upper part of the main insulation. For hair-pin oil-immersed current transformers this area is generally located in the bottom part of the main insulation.

7.5 Sample tests

7.5.1 Determination of the remanence factor

Usually, as sample test for each production series, the type test given in 7.2.6.206 is repeated.

7.5.2 Determination of the instrument security factor (FS) of measuring current transformers

Usually, as sample test for each production series, the type test given in 7.2.6.202 is repeated using the indirect method.

Annex 2A
(normative)

Protective current transformers classes P, PR

2A.1 Vector diagram

If consideration is given to a current transformer which is assumed to contain only linear electric and magnetic components in itself and in its burden, then, under the further assumption of sinusoidal primary current, all the currents, voltages and magnetic fluxes will be sinusoidal, and the performance can be illustrated by a vector diagram as shown in Figure 2A.1.

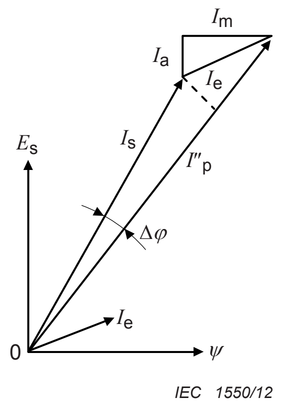


Figure 2A.1 – Vector Diagram

In Figure 2A.1, I_s represents the secondary current. It flows through the impedance of the secondary winding and the burden which determines the magnitude and direction of the necessary induced e.m.f. E_s and of the secondary linked flux ψ which is perpendicular to the e.m.f. vector. This flux is maintained by the exciting current I_e, having a magnetizing component I_m parallel to the secondary linked flux ψ, and a loss (or active) component I_a parallel to the e.m.f.. The vector sum of the secondary current I_s and the exciting current I_e is the vector I''_p representing the primary current multiplied by the actual turns ratio (number of primary turns to number of secondary turns).

Thus, for a current transformer with the inverse of the actual turns ratio equal to the rated transformation ratio, the difference in the lengths of the vectors I_s and I''_p, related to the length of I''_p, is the ratio error (ε) according to the definition of 3.4.3, and the angular difference $\Delta\varphi$ is the phase displacement according to 3.4.4.

2A.2 Turns correction

When the inverse of the actual turns ratio is different from (usually less than) the rated transformation ratio, the current transformer is said to have turns correction. Thus, in evaluating performance, it is necessary to distinguish between I''_p, the primary current multiplied by the actual turns ratio, and I'_p, the primary current divided by the rated transformation ratio. Absence of turns correction means $I'_p = I''_p$. If turns correction is present, I'_p is different from I''_p, and since I''_p is used in the vector diagram and I'_p is used for the determination of the ratio error (ε), it can be seen that turns correction has an influence on the ratio error (ε) (and may be used deliberately for that purpose). However, the vectors I'_p and I''_p have the same direction, so turns correction has no influence on phase displacement.

It will also be apparent that the influence of turns correction on composite error is less than its influence on ratio error (ε).

2A.3 The error triangle

In Figure 2A.2, the upper part of Figure 2A.1 is re-drawn to a larger scale and under the further assumption that the phase displacement is so small that for practical purposes the two vectors I_s and I''_p can be considered to be parallel. Assuming again that there is no turns correction, it will be seen by projecting I_e to I_p that to a good approximation the in-phase component (ΔI) of I_e can be used instead of the arithmetic difference between I''_p and I_s to obtain the ratio error (ε). Similarly, the quadrature component (ΔI_q) *of* I_e can be used to express the phase displacement.

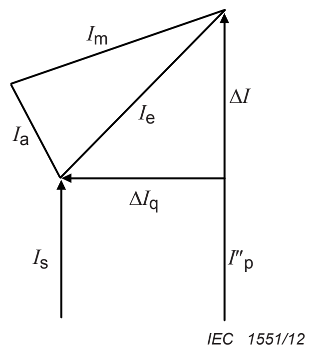


Figure 2A.2 – Error triangle

It can further be seen that under the given assumptions the exciting current I_e divided by I''_p is equal to the composite error according to 3.4.203.

Thus, for a current transformer without turns correction and under conditions where a vector representation is justifiable, the ratio error (ε), phase displacement and composite error form a right-angled triangle.

In this triangle, the hypotenuse representing the composite error is dependent on the magnitude of the total burden impedance consisting of burden and secondary winding, while the division between ratio error (ε) and phase displacement depends on the power factors of the total burden impedance and of the exciting current. Zero phase displacement will result when these two power factors are equal, i.e. when I_s and I_e are in phase.

2A.4 Composite error

The most important application, however, of the concept of composite error is under conditions where a vector representation cannot be justified because non-linear conditions introduce higher harmonics in the exciting current and in the secondary current (see Figure 2A.3).

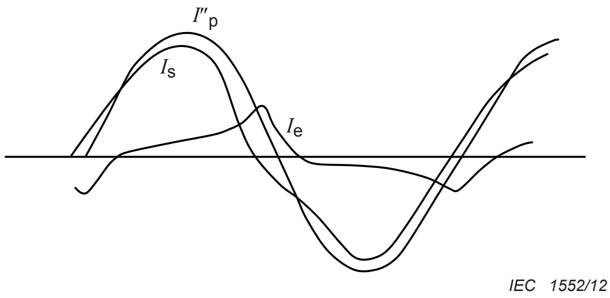


Figure 2A.3 – Typical current waveforms

It is for this reason that the composite error is defined as in 3.4.203 and not in the far simpler way as the vector sum of ratio error (ε) and phase displacement as shown in Figure 2A.2.

Thus, in the general case, the composite error also represents the deviations from the ideal current transformer that are caused by the presence in the secondary winding of higher harmonics which do not exist in the primary. (The primary current is always considered sinusoidal for the purposes of this standard.)

2A.5 Direct test for composite error

The standard method is given by recording and digitizing the waveforms of the primary current and of the secondary current, and by calculating the composite error using numerical integration according to its definition in 3.4.203.

Nevertheless, in this annex, the traditional methods for the determination of the composite error with analogue instruments are described.

Figure 2A.4 shows a current transformer having a turns ratio of 1:1. It is connected to a source of primary (sinusoidal) current, a secondary burden Z_B with linear characteristics and to an ammeter in such a manner that both the primary and secondary currents pass through the ammeter but in opposite directions. In this manner, the resultant current through the ammeter will be equal to the exciting current under the prevailing conditions of sinusoidal primary current, and the r.m.s. value of that current related to the r.m.s. value of the primary current is the composite error according to 3.4.203, the relation being expressed as a percentage.

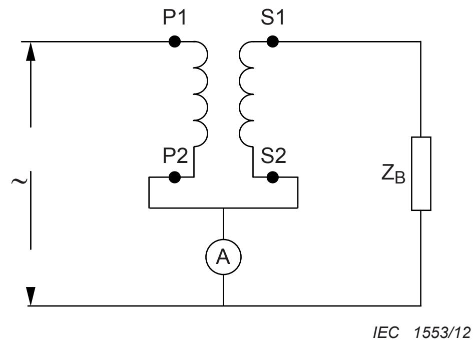


Figure 2A.4 – Basic circuit for 1:1 current transformer

Figure 2A.4 therefore represents the basic circuit for the direct measurement of composite error.

Figure 2A.5 represents the basic circuit for the direct measurement of composite error for current transformers having rated transformation ratios differing from unity. It shows two current transformers of the same rated transformation ratio. The current transformer marked N is assumed to have negligible composite error under the prevailing conditions (minimum burden), while the current transformer under test and marked X is connected to its rated burden.

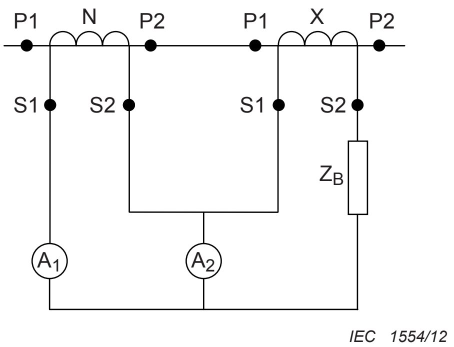


Figure 2A.5 – Basic circuit for current transformer with any ratio

They are both fed from the same source of primary sinusoidal current, and an ammeter is connected to measure the difference between the two secondary currents. Under these conditions, the r.m.s. value of the current in the ammeter A_2 related to the r.m.s. value of the current in ammeter A_1 is the composite error of transformer X, the relation being expressed as a percentage.

With this method, it is necessary that the composite error of transformer N is truly negligible under the conditions of use. It is not sufficient that transformer N has a known composite error since, because of the highly complicated nature of composite error (distorted waveform), any composite error of the reference transformer N cannot be used to correct the test results.

2A.6 Alternative method for the direct measurement of composite error

Alternative means may be used for the measurement of composite error and one method is shown in Figure 2A.6.

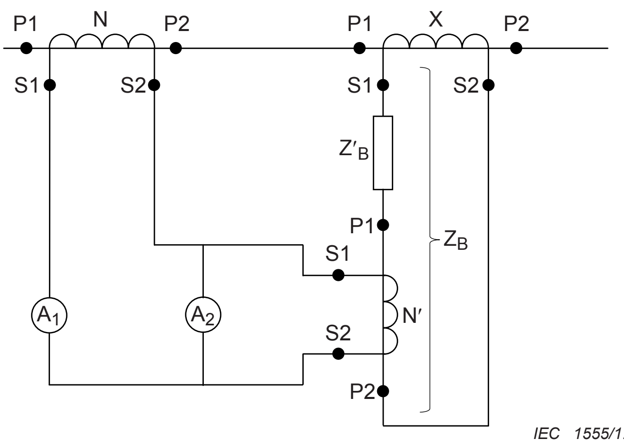


Figure 2A.6 – Alternative test circuit

Whilst the method shown in Figure 2A.5 requires a “special” reference transformer N of the same rated transformation ratio as the transformer X and having negligible composite error at the accuracy limit primary current, the method shown in Figure 2A.6, enables standard reference current transformers N and N′ to be used at or around their rated primary currents. It is still essential, however, for these reference transformers to have negligible composite errors but the requirement is easier to satisfy.

In Figure 2A.6, X is the transformer under test. N is a standard reference transformer with a rated primary current of the same order of magnitude as the rated accuracy limit primary current of transformer X (the current at which the test is to be made). N′ is a standard reference transformer having a rated primary current of the order of magnitude of the secondary current corresponding to the rated accuracy limit primary current of transformer X. It should be noted that the transformer N′ constitutes a part of the burden Z_B of transformer X and must therefore be taken into account in determining the value of the burden Z_B. A_1 and A_2 are two ammeters and care must be taken that A_2 measures the difference between the secondary currents of transformers N and N′.

If the rated transformation ratio of transformer N is k_r, of transformer X is k_{rx} and of transformer N′ is k'_r, the ratio k_r must equal the product of k'_r and k_{rx}:

$$k_r = k'_r \times k_{rx}$$

Under these conditions, the r.m.s. value of the current in ammeter A_2, related to the current in ammeter A_1, is the composite error of transformer X, the relation being expressed as a percentage.

NOTE When using the methods shown in Figure 2A.5 and Figure 2A.6, care should be taken to use a low impedance instrument for A_2 since the voltage across this ammeter (divided by the ratio of transformer N′ in the case of Figure 2A.6) constitutes part of the burden voltage of transformer X and tends to reduce the burden on this transformer. Similarly, this ammeter voltage increases the burden on transformer N.

2A.7 Use of composite error

The numeric value of the composite error will never be less than the vector sum of the ratio error (ε) and the phase displacement (the latter being expressed in centiradians).

Consequently, the composite error always indicates the highest possible value of ratio error (ε) or phase displacement.

The ratio error (ε) is of particular interest in the operation of overcurrent relays, and the phase displacement in the operation of phase sensitive relays (e.g. directional relays).

In the case of differential relays, it is the combination of the composite errors of the current transformers involved, which must be considered.

An additional advantage of a limitation of composite error is the resulting limitation of the harmonic content of the secondary current, which is necessary for the correct operation of certain types of relays.

Annex 2B
(normative)

Protective current transformer classes for transient performance

2B.1 Basic theoretical equations for transient dimensioning

2B.1.1 Short-circuit

The following equations refer to a C-O duty cycle. C-O-C-O duty cycles are treated in 2B.1.3.

The general expression for the instantaneous value of a short-circuit current may be defined:

$$i_{k}(t) = \sqrt{2}\, I_{psc}\left[e^{-t/T_p} \cos(\gamma - \varphi) - \cos(\omega\, t + \gamma - \varphi)\right] \quad (2B.1)$$

where

I_{psc}	is the r.m.s. value of primary symmetrical short-circuit current $I_{psc} = K_{ssc} \times I_{pr}$;
$T_p = \dfrac{L_p}{R_p}$	is the primary time constant;
γ	is the switching or fault inception angle;
$\varphi = \arctan\dfrac{X_p}{R_p} = \arctan(\omega\, T_p)$	is the phase angle of the system short-circuit impedance;
ω	is the angular frequency $2\pi f_R$;

when the equivalent voltage source in the short-circuit with R_p and X_p is

$$u(t) = -U_{max} \cos(\omega\, t + \gamma) \quad (2B.2)$$

For simplification purposes the fault inception angle and system impedance angle can be summed up to one single angle which makes the calculation easier to understand from the mathematical point of view.

$$\theta = \gamma - \varphi \quad (2B.3)$$

$$i_{k}(t) = \sqrt{2}\, I_{psc}\left[e^{-t/T_p} \cos(\theta) - \cos(\omega\, t + \theta)\right] \quad (2B.4)$$

The angles θ and γ both describe the possibility of varying the fault inception angle and therefore can be applied alternatively as suitable but according to their definition.

Figure 2B.1 shows two typical primary short-circuit currents. The first one occurs with a fault inception angle of $\gamma = 90°$ which leads to the highest peak current and the highest peak of secondary linked flux for long t'_{al} (Figure 2B.2) whereas the second one occurs with $\gamma = 140°$, which leads to a lower asymmetry. Cases like the latter one are important for short t'_{al}, because, during the first half cycle, the current and flux are temporarily higher than in the case of $\gamma = 90°$.

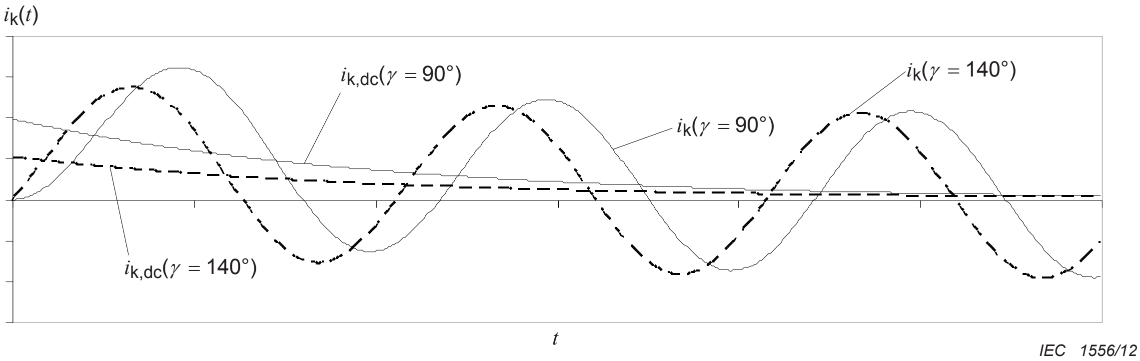


Figure 2B.1 – Short-circuit current for two different fault inception angles

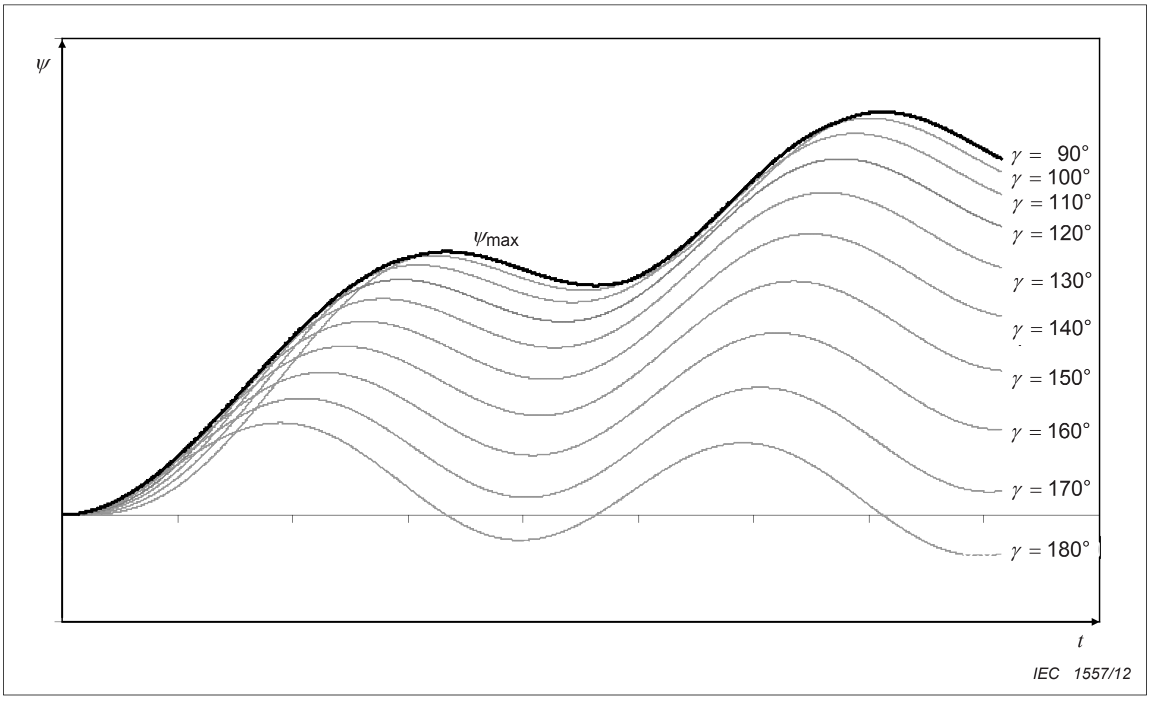


Figure 2B.2 – $\psi_{max}(t)$ as the curve of the highest flux values, considering all relevant fault inception angles γ

A possibly reduced range of fault inception angle can be used to define a reduced asymmetry which may lead to a reduced factor K_{td} in some special cases.

NOTE The possibility of restricting the current inception angle is not covered in this standard, but will be discussed in the Technical Report IEC 61869-100.

2B.1.2 Transient dimensioning factor K_{td}

The transient dimensioning factor K_{td} is the final parameter for the core dimensioning and is given on the rating plate. It can be calculated from different functions of the transient factor K_{tf} as given in the equations below and as shown in Figure 2B.3.

In some cases, the protection system may require a t'_{al} value which is not constant and depends on various parameters of the short-circuit current. Therefore the transient dimensioning factor K_{td} can also be obtained from relay stability type tests and given by the manufacturer of the protection system.

The transient factor K_{tf} given in this section is derived from the differential equation of the equivalent circuit with a constant inductivity of the current transformer core, with an ohmic burden and without consideration of remanence. In this annex, the solutions of the differential equation are given either as curve diagrams or as simplified formulas.

NOTE The differential equation and the exact solution is given in the Technical Report IEC 61869-100 TR.

K_{tf} and the secondary linked flux depend likewise on time and, in the end, on the time to accuracy limit t'_{al} required by the protection system. By calculating with the linear inductivity, the solution is only valid up to the first saturation of the current transformer.

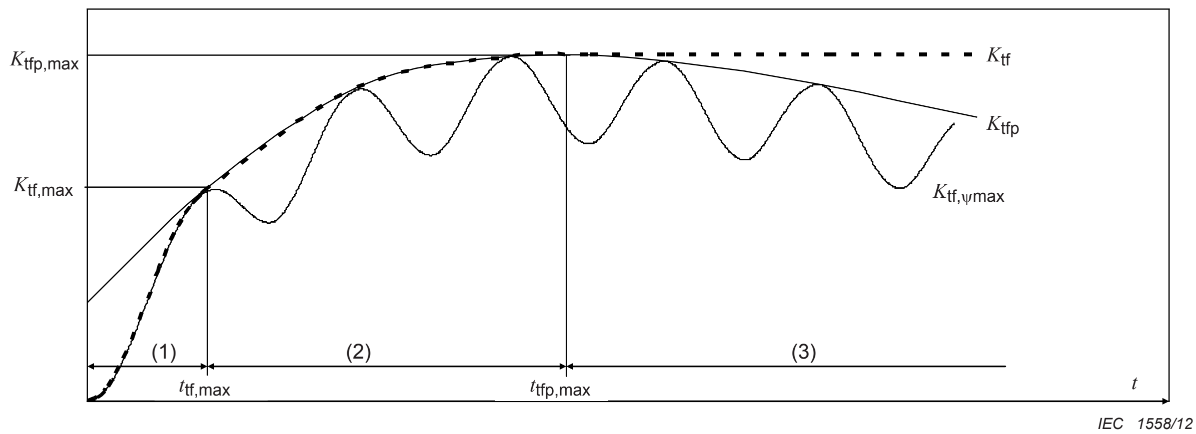


Figure 2B.3 – Relevant time ranges for calculation of transient factor

In Figure 2B.3, the curve $K_{tf,\psi max}$ is built as follows:

For every time point of the ψ_{max} curve (Figure 2B.2), the K_{tf} value is calculated according its definition in 3.4.233. K_{tfp} is the appropriate envelope curve. Three ranges have to be distinguished, defined by three functions of K_{tf}:

Range 1: $0 \le t_{al} < t_{tf,max}$:

In the first time range, the K_{tf} curve follows the $K_{tf,\psi max}$ curve. The time range begins at zero time and ends when the curve of $K_{tf,\psi max}$ touches its envelope curve of peaks K_{tfp} at the time

$$t_{tf,max} = \frac{\pi + \varphi}{\omega} \quad (2B.5)$$

Eqn (2B.5) is simplified with $\gamma = 90°$ from a more general formula, but it is suitable for practical application.

Within this time range, $K_{tf,\psi max}$ considers the worst-case switching angle $\theta(t'_{al})$ which leads to the highest flux at the time to accuracy limit t'_{al}. Figure 2B.4 to Figure 2B.6 show the K_{tf} curves versus the primary time constant T_p for different values of t'_{al}. A high secondary time constant T_s was chosen in the calculation. Lower T_s values lead to slightly lower K_{tf} values.

NOTE A larger variety of curves is given in the Technical Report IEC 61869-100 TR.

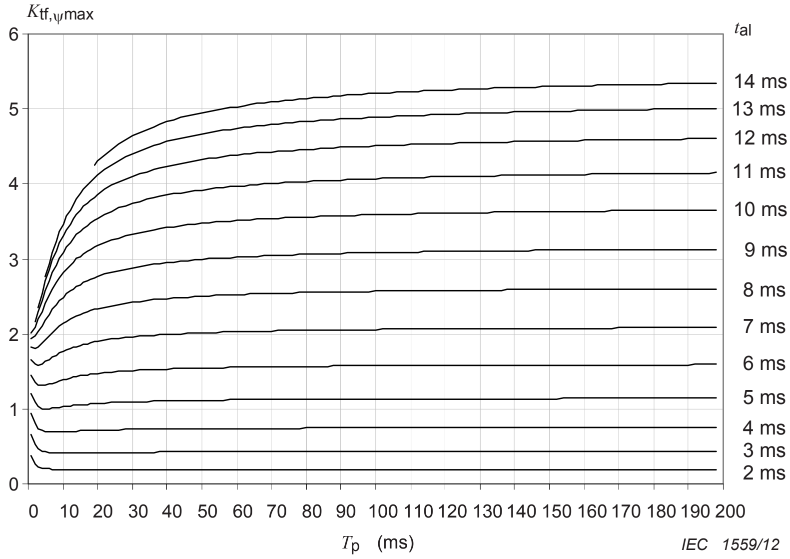


Figure 2B.4 – Determination of K_{tf} in time range 1 at 50 Hz for T_s = 1,8 s

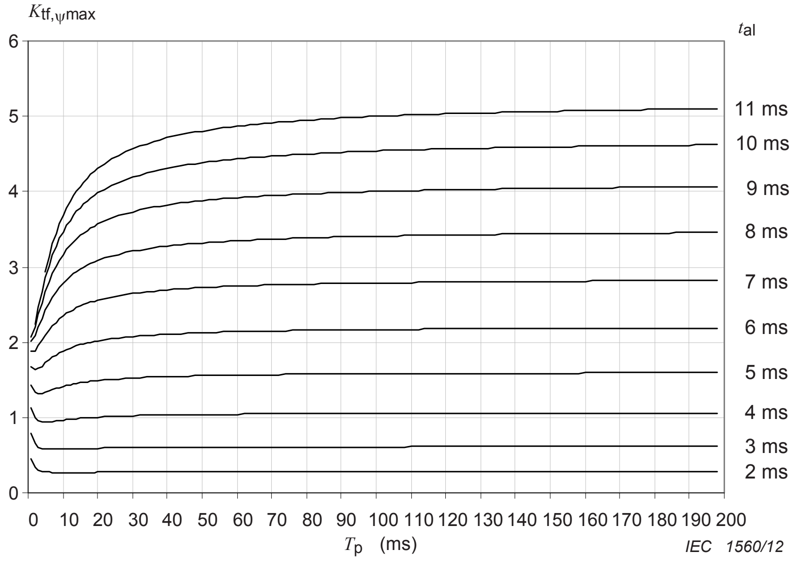


Figure 2B.5 – Determination of K_{tf} in time range 1 at 60 Hz for T_s = 1,5 s

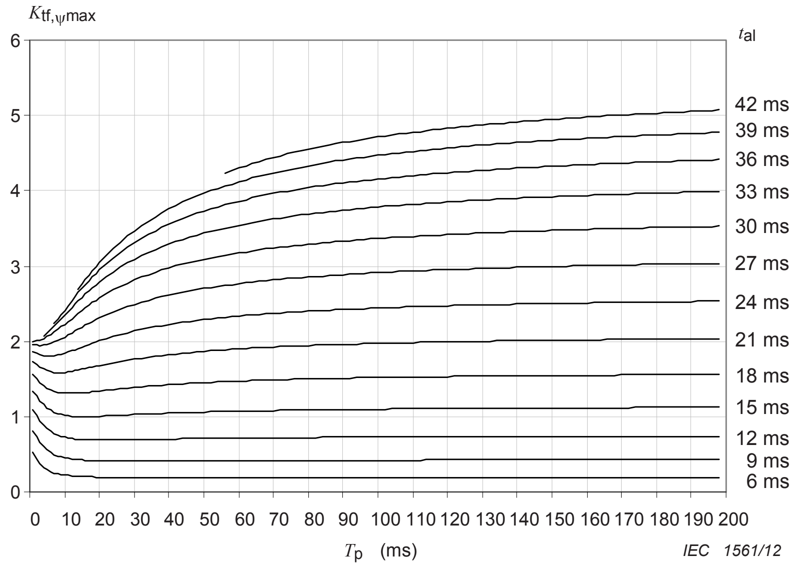


Figure 2B.6 – Determination of K_{tf} in time range 1 at 16,7 Hz for T_s = 5,5 s

Range 2: $t_{\text{tf,max}} \leq t_{\text{al}} < t_{\text{tfp,max}}$

In the second time range, the K_{tf} curve follows the envelope curve K_{tfp} for $\gamma = 90°$, which leads to the highest peak flux, therefore $\theta = 90° - \varphi$.

$$K_{\text{tfp}} = \frac{\omega T_{\text{s}} T_{\text{p}}}{T_{\text{p}} - T_{\text{s}}} \cos(\theta) \left(e^{-t_{\text{al}}/T_{\text{p}}} - e^{-t_{\text{al}}/T_{\text{s}}} \right) + \sin(\theta) e^{-t_{\text{al}}/T_{\text{s}}} + 1 \tag{2B.6}$$

The time range ends at the maximum of the K_{tfp} curve at the time

$$t_{\text{tfp,max}} = \frac{T_{\text{p}} T_{\text{s}}}{T_{\text{p}} - T_{\text{s}}} \ln \frac{\frac{T_{\text{p}}}{T_{\text{s}}} \cos(\theta) + \frac{T_{\text{s}} - T_{\text{p}}}{\omega T_{\text{s}}^2} \sin(\theta)}{\cos(\theta)} \tag{2B.7}$$

Range 3: $t_{\text{tfp,max}} \leq t_{\text{al}}$

In the third time range, K_{tf} assumes the constant value $K_{\text{tfp,max}}$, given in eqn. (2B.8). It is defined as the maximum value of the K_{tfp} curve.

$$K_{\text{tfp,max}} = \left(\omega T_{\text{p}} \cos(\theta) + \frac{T_{\text{p}} + T_{\text{s}}}{T_{\text{s}}} \sin(\theta) \right) \times \left[\frac{\frac{T_{\text{p}}}{T_{\text{s}}} \cos(\theta) + \frac{T_{\text{s}} - T_{\text{p}}}{\omega T_{\text{s}}^2} \sin(\theta)}{\cos(\theta)} \right]^{\frac{T_{\text{p}}}{T_{\text{s}} - T_{\text{p}}}} + 1 \tag{2B.8}$$

2B.1.3 C-O-C-O duty cycles

The transient dimensioning for auto-reclosure duty cycles has to be done separately for each cycle according to the equations given above.

For cores having a high secondary time constant (typically TPX cores), there is no significant flux declination after t'.

$$K_{\text{td,(C-O-C-O)}} = K_{\text{td}}(t') + K_{\text{td}}(t''_{\text{al}}) \tag{2B.9}$$

For cores having a low secondary time constant (typically TPY and TPZ cores), the secondary linked flux declines exponentially with the secondary time constant T_{S} during the fault repetition time t_{fr}. In this case, no analytical formula exists for the time argument t in the term for the first cycle, and several case differentiations may be necessary.

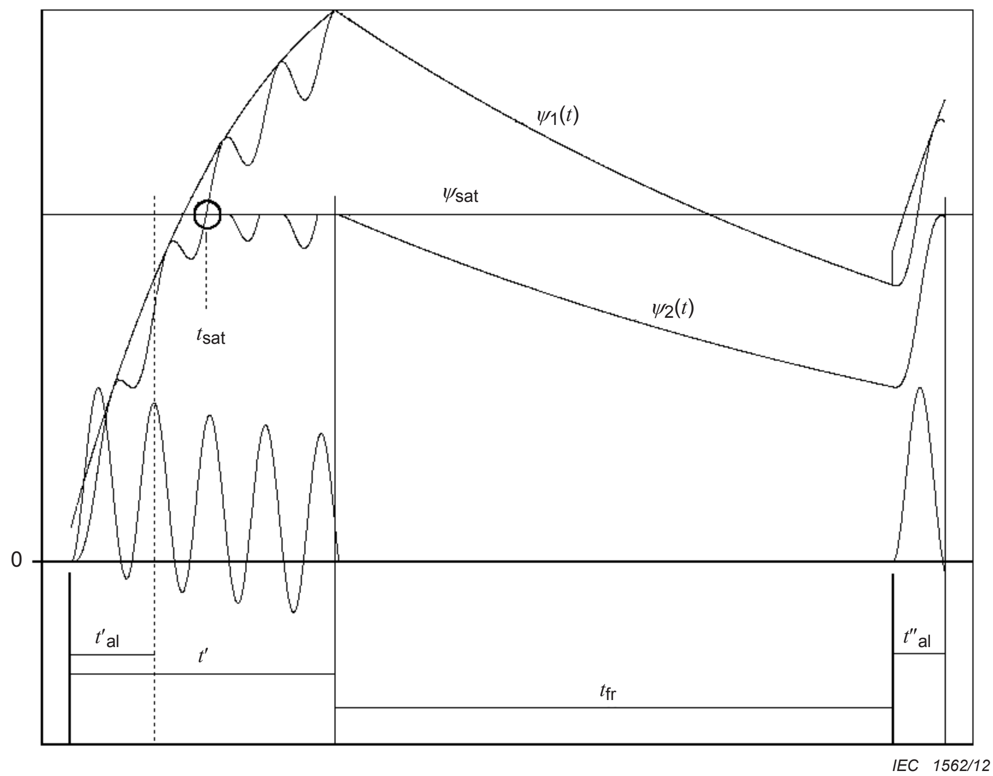


Figure 2B.7 – Limiting the magnetic flux by considering core saturation

Fig. 2B.7 shows a typical case where saturation is reached after t'_{al}. The flux (ψ_2(t)) is limited to saturation flux(ψ_{sat}) before t' is reached. During t_{fr}, it declines to a value which is low enough to remain below saturation up to t''_{al}. Ignoring saturation (shoved by curve ψ_1(t)), the declined flux starts from a higher level at the beginning of the second cycle. This example demonstrates the interdependency between the core dimensioning in the first and in the second cycle, and the determination of K_{td}.

NOTE 1 The formula for the C-O-C-O-cycle, which was given in the preceding standard IEC 60044-6, ignores saturation within the first cycle and leads in many cases to unnecessarily high K_{td} values. See Fig. 2B.7.

It is therefore recommended to draw a graph similar to the one in Fig. 2B.7, in order to make oneself familiar with the actual situation. The following equation provides an upper limit for K_{td}:

$$K_{td,(C-O-C-O)max} = \max \left\{ K_{td}(t'_{al}),\ K_{td}(t')e^{-(t_{fr}+t''_{al})/T_s} + K_{td}(t''_{al}) \right\} \tag{2B.10}$$

NOTE 2 In Technical Report IEC 61869-100 TR calculation methods are given which may be used to determine the K_{td} value.

2B.2 Measurement of the core magnetization characteristic

2B.2.1 General

Measuring the core magnetization characteristic implies

- the measurement of the magnetizing inductance L_m;
- the measurement of the remanence factor K_R;
- the determination of the error at limiting conditions using an indirect method.

All of these are based on the following relationship. If an arbitrary voltage $u(t)$ is applied to the secondary terminals (see Figure 2B.8), the flux $\psi(t)$ linked through the secondary winding at time t is related to this voltage through the equation:

$$\psi(t) = \int_0^t (u(t) - R_{\mathrm{ct}} \times i_{\mathrm{m}}(t))dt \qquad (2B.11)$$

where i_{m} is the instantaneous value of the magnetizing current.

NOTE As the term "exciting current" is reserved for the r.m.s. value using a.c. quantities (see 3.3.207), i_{m} and the term "magnetizing current" are used for instantaneous values in the d.c. method and capacitor discharge method.

The methods described in the following clauses take advantage of this relationship.

The effect of the voltage drop across the secondary winding resistance shall be estimated. If it exceeds 2 %, this drop shall be deduced from the voltage measured.

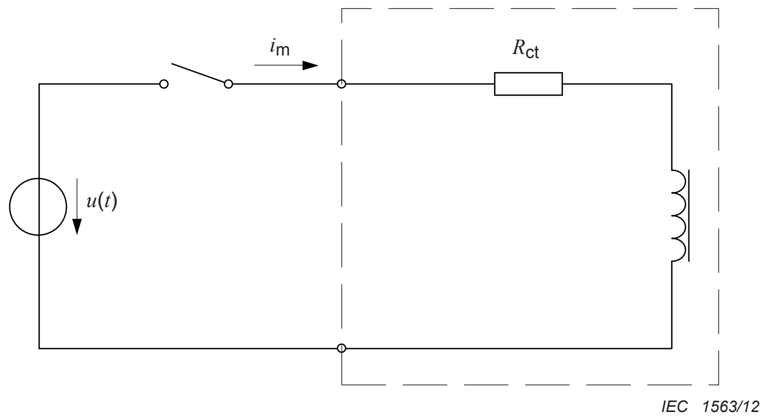


Figure 2B.8 – Basic circuit

For TPX current transformers, it is necessary to demagnetize the core before each test, because of the high remanence factor. For TPY current transformers the remanent flux is often so low that it can be neglected. Demagnetization requires additional means by which the core can be subjected to slowly decreasing hysteresis loops starting from saturation. A direct current source will normally be provided when the d.c. test method has to be used.

Either of the three methods (a.c. method, d.c. method, capacitor discharge method) may be applied.

2B.2.2 A.C. method

2B.2.2.1 Determination of the magnetizing inductance L_{m}

A substantially sinusoidal a.c. voltage is applied to the secondary terminals and the corresponding value of the exciting current is measured. The test may be performed at reduced frequency f' to avoid unacceptable voltage stressing of the winding and secondary terminals. Effects of undue eddy current losses in the core and capacitive currents between the winding layers will be less likely to cause false readings at lower frequencies. The result shall be shown as a saturation curve.

The exciting voltage shall be measured with an instrument whose response is proportional to the average of the rectified signal, but calibrated in r.m.s. The exciting current shall be measured using a peak reading instrument.

The peak value of the secondary linked flux ψ may be derived from the measured r.m.s. value of the applied voltage U at the frequency f' as follows:

$$\hat{\psi} = \frac{\sqrt{2}\,U}{2\pi f'}$$

Accordingly, the saturation voltage U_{sat} corresponds with the saturation flux ψ_{sat} as follows:

$$\hat{\psi}_{sat} = \frac{\sqrt{2}\,U_{sat}}{2\pi f'}$$

NOTE 201 U_{sat} shall be estimated as the voltage value where the curve is practically horizontal. The influence of the uncertainty in the determination of U_{sat} on L_m is practically negligible.

Considering this equation, the curve gives the required relationship between the peak value of the exciting current and the peak value of the secondary linked flux ψ. The magnetizing inductance L_m is defined as the mean slope of this curve between 20 % and 70 % of the saturation flux ψ_{sat}. It is calculated as

$$L_m = \frac{0{,}5 \times U_{sat} \times \sqrt{2}}{(\hat{i}_{70} - \hat{i}_{20}) \times 2\pi f'}$$

where

$\hat{i}_{20}$ is the peak value of the exciting current at 20 % U_{sat};

$\hat{i}_{70}$ is the peak value of the exciting current at 70 % U_{sat}.

NOTE 202 This formula differs slightly from the formula given in the preceding standard IEC 60044-6 (B4) due to the improved definition of saturation.

2B.2.2.2 Determination of the error at limiting conditions

The test arrangement of 2B.2.2.1 shall be used.

The voltage shall be increased up to the voltage equal to E_{al} given as

$$E_{al} = K_{ssc} \times K_{td} \times (R_{ct} + R_b) \times I_{sr}$$

The appropriate exciting current $\hat{I}_{al}$ shall not exceed the following limits:

For classes TPX and TPY: $\hat{I}_{al} \le \sqrt{2} \times I_{sr} \times K_{ssc} \times \hat{\varepsilon}$

For class TPZ: $\hat{I}_{al} \le \sqrt{2} \times I_{sr} \times K_{ssc} \times \left(\frac{K_{td} - 1}{2\pi f_R \times T_S} + \hat{\varepsilon}_{ac} \right)$

NOTE For TPZ current transformers, the accuracy is specified only for the a.c. component while, in the determination of the permissible value of I_{al} during indirect tests, it is also necessary to take the d.c. component of the exciting current into account. In the above equation, the d.c. component is represented by (K_{td} – 1).

2B.2.2.3 Determination of the remanence factor K_R

Other than in 2B.2.2.1 and 2B.2.2.2, the waveforms of the a.c. signals have to be detected.

In determining the remanence factor K_R by the a.c. test method, it is necessary to integrate the exciting voltage according to equation (1) given in 2B.2.1. The integrated voltage with the corresponding current i_e will display a hysteresis loop, showing the saturation flux ψ_{sat}. The secondary linked flux value at zero crossing of current is deemed to represent the remanent flux ψ_r. See Figure 2B.9. The remanence factor K_R is then calculated as

$$K_R = \frac{\psi_r}{\psi_{sat}} \qquad (2B.12)$$

At lower frequencies, effects of undue eddy current losses in the core and capacitive currents between the winding layers will be less likely to cause false readings.

NOTE ψ_{sat} shall be estimated as the secondary linked flux value where the curve is practically horizontal.

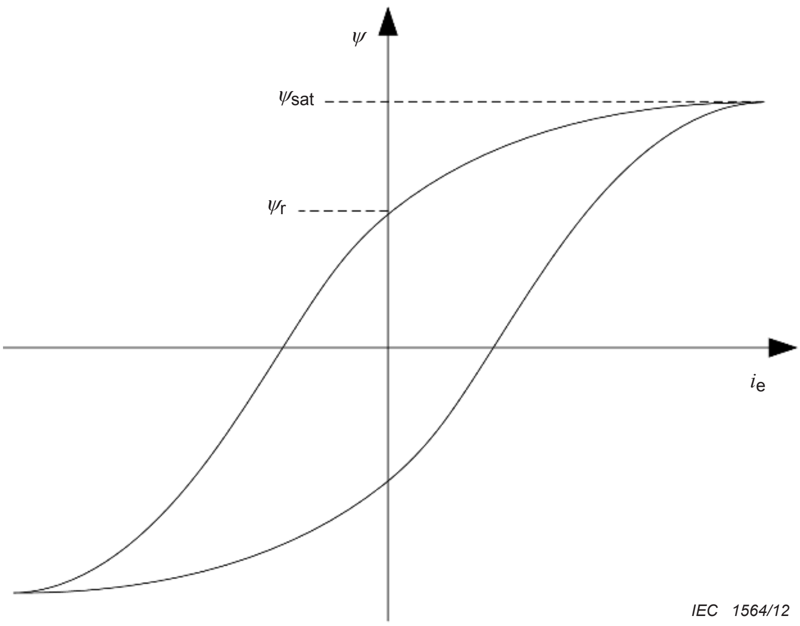


Figure 2B.9 – Determination of remanence factor by hysteresis loop

2B.2.3 D.C. method

2B.2.3.1 General

The d.c. saturation method applies a d.c. voltage u(t) of such duration that saturation flux is reached. The flux measurement is derived according to equation (2B.11) given in 2B.2.1, where u(t) is the voltage across the terminals. See Figure 2B.10.

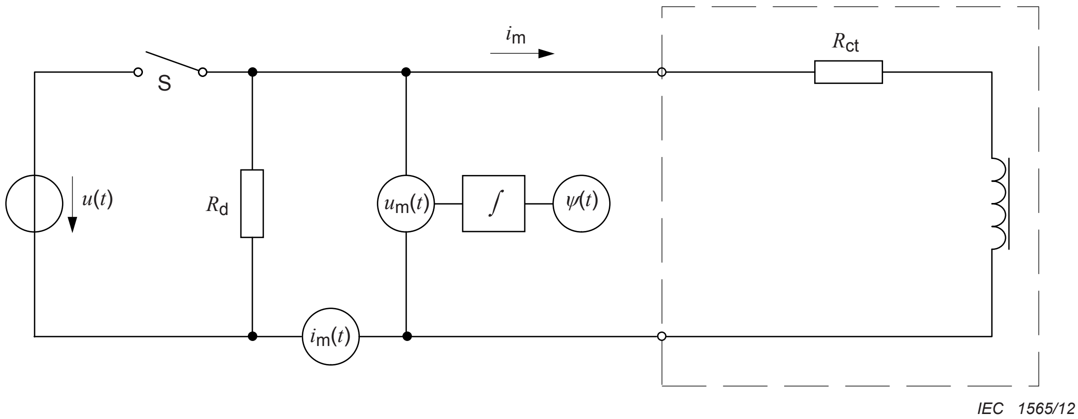


Figure 2B.10 – Circuit for d.c. method

The applied voltage source shall be suitable to drive the current transformer into saturation.

The discharge resistor R_d shall be connected; otherwise the magnetizing inductance of the core may cause very high overvoltage when switch S is opened and the inductive current interrupted.

2B.2.3.2 Determination of the remanence factor K_R

The test circuit according to 2B.2.3.1 shall be used.

Sometime after the switch S has been closed, the magnetizing current will be deemed to have reached its maximum value ($\hat{i}_m$) at which the secondary linked flux would remain constant. Before reaching the constant value, the i_m curve must show a significant increase of the gradient, indicating saturation. The d.c. source shall be able to drive the transformer core into saturation without influencing the test results due to its limitations. This condition is fulfilled if the secondary linked flux achieves a stable value earlier than the magnetizing current.

The rising values of the magnetizing current and of the flux shall be recorded up to the time at which the values become constant, then the switch S will be opened.

Typical test records of the flux ψ and of the magnetizing current i_m are shown in Figure 2B.11.

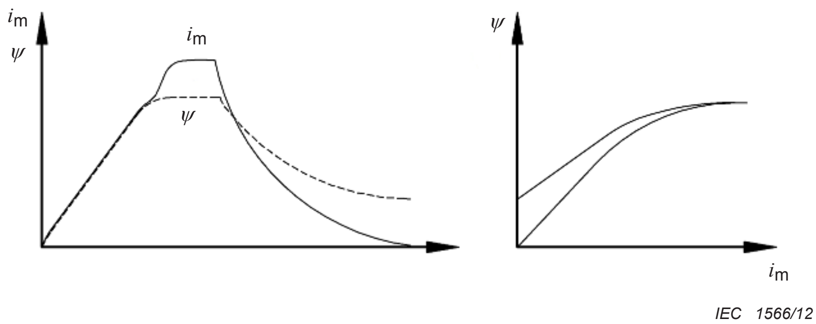


Figure 2B.11 – Time-amplitude and flux-current diagrams

At the opening of switch S, a decreasing current flows through the secondary winding and the discharging resistor R_d . The corresponding flux value decreases, but may not fall to zero.

When a suitable magnetizing current i_m has been chosen to achieve the saturation flux ψ_{sat}, the remaining flux value at the zero current shall be deemed to be the remanent flux ψ_r.

For a current transformer whose core has not been demagnetized before, the saturation flux and the remanent flux may be determined by an additional test in which the secondary terminals have been interchanged. The curve of secondary linked flux obtained hereby contains an offset of half of the apparently measured remanent flux value. Therefore, the zero line has to be shifted correspondingly, leading to corrected values of saturation flux and remanent flux. See figure 2B.12.

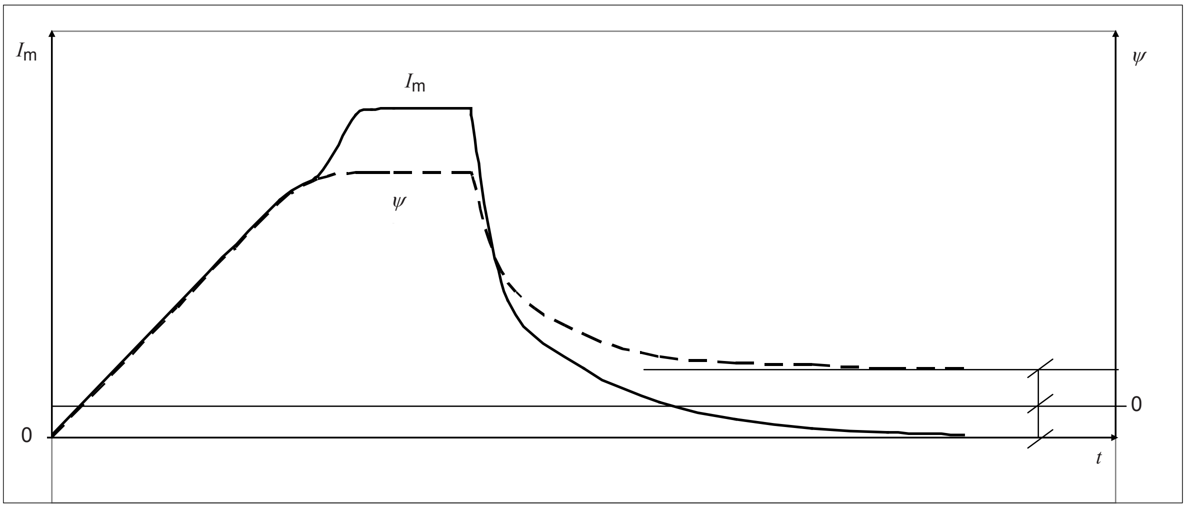


Figure 2B.12 – Recordings with shifted flux base line

The remanence factor K_R is determined

$$K_R = \frac{\psi_r}{\psi_{sat}}$$

2B.2.3.3 Determination of the magnetizing inductance L_m

The test procedure of 2B.2.3.2 shall be used.

The magnetizing inductance (L_m) may be deduced according to the following equation:

$$L_m = \frac{0{,}5 \times \psi_{sat}}{i_{70} - i_{20}}$$

where

i_{20} is the peak value of the magnetizing current at 20 % ψ_{sat};

i_{70} is the peak value of the magnetizing current at 70 % ψ_{sat}.

NOTE This formula differs slightly from the definition given in the preceding standard IEC 60044-6 (B4) due to the improved definition of saturation.

2B.2.3.4 Determination of the error at limiting conditions

The test circuit according to 2B.2.3.1 shall be used.

For determination of the error at limiting conditions, the magnetizing current i_m at the secondary linked flux ψ_{al} shall be measured while increasing the flux.

ψ_{al} is given as

$$\psi_{al} = \frac{\sqrt{2} \times E_{al}}{2\pi f_R} = \frac{\sqrt{2} \times K_{td} \times K_{ssc} \times I_{sr} \times (R_b + R_{ct})}{2\pi f_R}$$

The magnetizing current i_m shall not exceed the following limits:

For classes TPX and TPY: $i_m \le \sqrt{2} \times I_{sr} \times K_{ssc} \times \hat{\varepsilon}$

For class TPZ: $i_m \le \sqrt{2} \times I_{sr} \times K_{ssc} \times \left(\frac{K_{td} - 1}{2\pi f_R \times T_S} + \hat{\varepsilon}_{ac} \right)$

NOTE For TPZ current transformers, the accuracy is specified only for the a.c. component while, in the determination of the permissible value of i_m during indirect tests, it is also necessary to take the d.c. component of the exciting current into account. In the above equation, the d.c. component is represented by $(K_{td} - 1)$.

2B.2.4 Capacitor discharge method

The capacitor discharge method uses the charge of a capacitor for energizing the current transformer core from the secondary. The flux measurement is derived according to equation (1) given in 2B.2.1, where u(t) is the voltage across the terminals. See Figure 2B.13.

The capacitor is charged with a voltage sufficiently high to produce a secondary linked flux equal to or greater than the flux ψ_{al} corresponding to E_{al}. See Figure 2B.13 and Figure 2B.14.

$$\psi_{al} = \frac{\sqrt{2} \times E_{al}}{2\pi f_R}$$

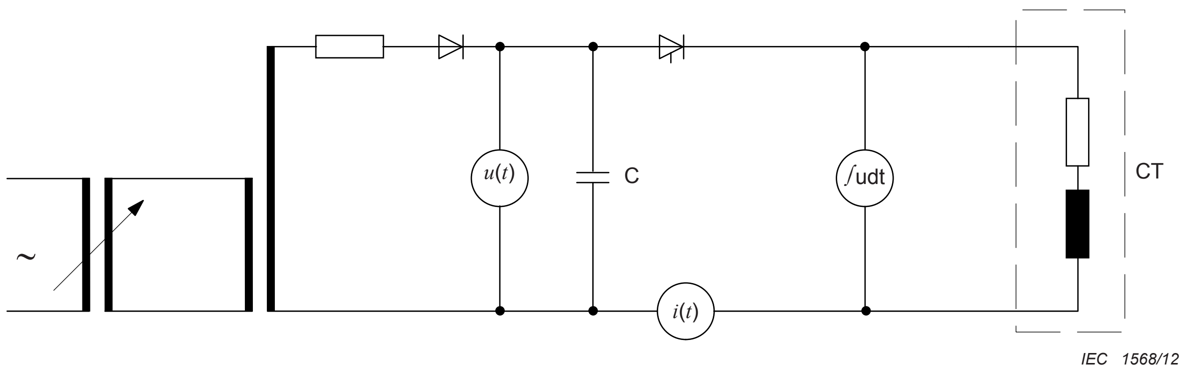


Figure 2B.13 – Circuit for capacitor discharge method

At the time when ψ_{al} is reached, the peak value of the secondary exciting current i_m shall be measured and shall not exceed the peak value of the exciting secondary current $\hat{I}_{al}$.

The secondary time constant T_s shall be determined by applying a voltage with a voltage-time integral corresponding to 90 % of E_{al}. The corresponding exciting current i'_m is measured and the secondary time constant calculated as follows:

$$T_s = \frac{\sqrt{2} \times 0{,}9 \times E_{al}}{2\pi f_R \times (R_{ct} + R_b) \times i'_m}$$

NOTE This definition of T_s does not conform with the definition in the above mentioned d.c. and a.c. methods.

In determining the remanence factor K_R, the integrated voltage with the corresponding current will determine a hysteresis loop. If the exciting current has been such that the saturation flux is reached, the flux value at zero crossing of the current is deemed to represent the remanent flux ψ_r .

The remanence factor K_R is determined:

$$K_R = \frac{\psi_r}{\psi_{sat}}$$

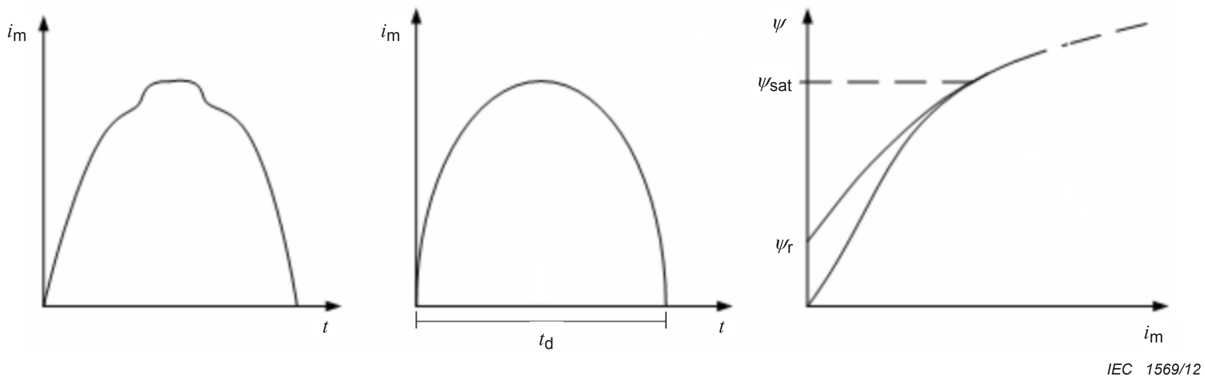


Figure 2B.14 – Typical records for capacitor discharge method

2B.3 Direct test for determination of the error at limiting conditions

2B.3.1 General

The instantaneous error current can be measured in different ways. In all cases, the errors of the measuring system shall not exceed 10 % of the error limit corresponding to the class of the tested current transformer during the whole of the duty cycle.

2B.3.2 Direct test

Class TPX current transformers shall be demagnetized before the direct test because of the high remanence factor. It may be necessary to demagnetize class TPY current transformers if the remanence factor K_R is not negligible.

Two direct tests shall be performed at rated frequency and with rated secondary burden:

a) The rated primary short-circuit current at rated frequency is applied without any offset. The a.c. component of the instantaneous error is measured and shall be in accordance with the theoretical value $1/\omega T_s$.

b) To verify that the current transformer meets the accuracy requirements of the specified duty cycle, the following test shall be performed:

   The rated primary short-circuit current at rated frequency is applied with the required offset. For specified values of primary time constant up to 80 ms, the test is performed in the specified accuracy limiting condition (specified duty cycle). The primary time constant shall not deviate by more than 10 % from the specified value.

For specified values of primary time constant above 80 ms, the tests can be performed in equivalent accuracy limiting conditions (by modifying duty cycle and/or burden), subjected to agreement between manufacturer and purchaser.

During the energization period, the first peak of the primary current shall be not less than the value corresponding to the specified conditions.

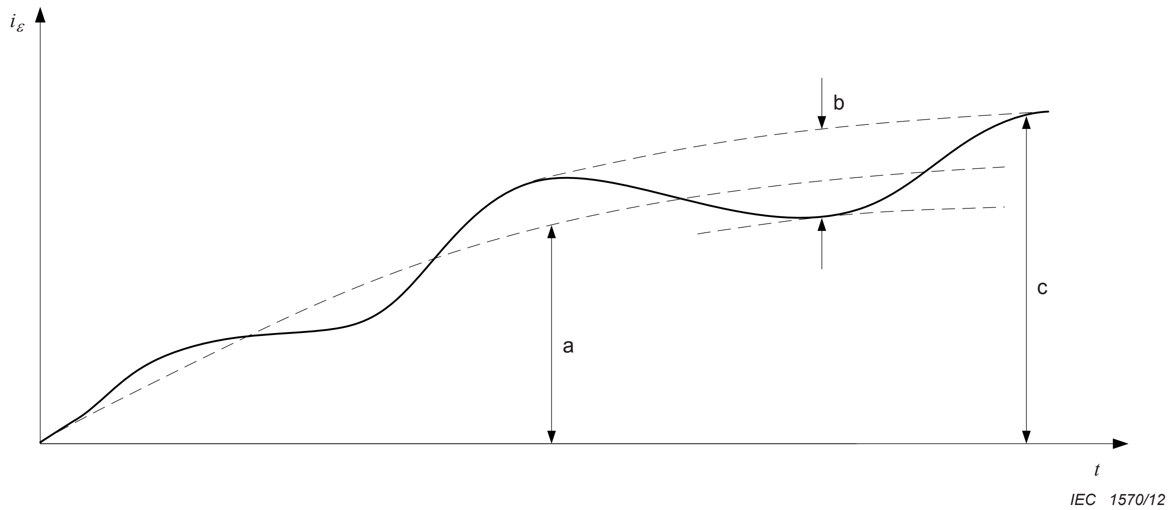
In laboratory practice, it may be difficult to reproduce the exact duty cycle specification. In this case, the calculated K_{td} value of the applied duty cycle shall not be less than the calculated K_{td} value of the specified duty cycle. To meet this requirement, the duration of the energization(s) and/or the secondary burden may be adjusted.

NOTE As the calculation of K_{td} is based on worst-case formulas (formula 6 in 2B.1.2 may deliver K_{td} values which are 30 % higher than necessary), the current transformer may satisfy the duty cycle without reaching the flux corresponding to the calculated K_{td} value.

For class TPX and TPY current transformers, the instantaneous error current i_ε is measured as $i_\varepsilon = i_s \times k_r - i_p$. The error value $\hat{\varepsilon}$ according to 3.4.222 shall be determined. Its value shall not exceed the limit given in Table 206.

For class TPZ current transformers, the a.c. component of the error current is measured as one half of the peak-to-peak value (see Figure 2B.15). The error value $\hat{\varepsilon}_{ac}$ according to 3.4.223 shall be determined. Its value shall not exceed the limit given in Table 206.

NOTE It is possible that the class definition does not contain a duty cycle. In this case, for test purposes, a duty cycle leading to the given K_{td} value shall be agreed between manufacturer and purchaser.



Where:

a= $\hat{i}_{\varepsilon dc}$

b= $2\hat{i}_{\varepsilon ac}$

c= $\hat{i}_{\varepsilon ac} + \hat{i}_{\varepsilon dc}$

for TPY: $\hat{i}_\varepsilon = c$

for TPZ: $\hat{i}_\varepsilon = \hat{i}_{\varepsilon ac} = \dfrac{b}{2}$

Figure 2B.15 – Measurement of error currents

If the real K_{td} value of the current transformer has to be determined, the duration of the energization and/or secondary burden shall be increased so that the measured instantaneous error current reaches the limiting value for the accuracy class concerned (Table 206). For class TPZ, linear interpolation is used to determine the instant at which the limiting value of the a.c. component of the error current is reached.

The secondary linked flux ψ_{dir} shall be determined as

$$\psi(t) = \frac{R_{ct} + R_{b}}{R_{b}} \times \int_{0}^{t} R_{b} \times i_{s}(t)dt$$

where t is the time point when the error limit $\hat{\varepsilon}$ or $\hat{\varepsilon}_{ac}$ is reached.

The total dimensioning factor K_{td} of the current transformer is the ratio of ψdir to the peak value of the a.c. component of ψ under steady-state conditions. This a.c. component can be derived from a secondary linked flux measurement in the test a), which has to be related to the exact (theoretical) value of the short circuit current K_{ssc} x I_{sr}. The measurement shall be made using the abovementioned formula.

The error in flux measurement shall not exceed 5 %.

2B.3.3 Determination of the factor of construction

If compliance with the requirements of low-leakage reactance design cannot be established to the mutual satisfaction of the manufacturer and purchaser by reference to drawings, then the factor of construction F_c shall be determined as follows:

The secondary linked flux values in both a direct test and an indirect test have to be determined, in both cases for the magnetizing current at accuracy limiting conditions. If a transient performance class is specified by the alternative definition, the appropriate duty cycle and burden shall be chosen in order to achieve the specified K_{ssc} x K_{td} value.

The secondary linked flux ψ_{dir}, which is obtained in the direct test according to 2B.3.2, shall be determined.

In the indirect test, the secondary linked flux $\hat{\psi}_{ind}$ shall be determined with one of the following methods:

<u>a.c. method:</u>

The test arrangement according to 2B.2.2.1 shall be applied.

The voltage shall be increased until the appropriate limit of the exciting current $\hat{I}_{al}$ given in 2B.2.2.2 is reached. The voltage U obtained hereby shall be noted. The secondary linked flux $\hat{\psi}_{ind}$ is given by

$$\hat{\psi}_{ind} = \frac{\sqrt{2} \times U}{2\pi f}$$

where f is the applied frequency.

<u>d.c. or capacitor discharge method:</u>

The test circuit according to 2B.2.3.1 (d.c. method) or 2B.2.4 (capacitor discharge method) shall be used.

The flux $\hat{\psi}_{\mathrm{ind}}$ is the secondary linked flux which corresponds to the limit of the magnetizing current i_{m} given in 2B.2.3.4.

F_{c} is then calculated as

$$F_{\mathrm{c}} = \frac{\hat{\psi}_{\mathrm{ind}}}{\hat{\psi}_{\mathrm{dir}}}$$

In the tests, the error in flux measurement shall not exceed 5 %.

If F_{c} is greater than 1,1, it shall be considered when dimensioning the core.

NOTE The value of primary current required to perform direct tests on certain transformer types may be beyond the capability of facilities normally provided by manufacturers. Tests at lower levels of primary current may be agreed between the manufacturer and purchaser.

Annex 2C
(normative)

Proof of low-leakage reactance type

It shall be demonstrated that:

– the current transformer has a substantially continuous ring core, with air gaps uniformly distributed, if any;
– the current transformer has uniformly distributed secondary winding;
– the current transformer has a primary conductor symmetrical with respect to rotation;
– the influences of conductors of the adjacent phase outside of the current transformer housing and of the neighbouring phases are negligible.

If compliance with the requirements of low-leakage reactance design cannot be established to the mutual satisfaction of manufacturer and purchaser by reference to drawings, then the results of a direct test and of an indirect test shall be compared as follows:

For class TPX, TPY and TPZ current transformers, the factor of construction F_c shall be determined according to 2B.3.3. If F_c is less than 1,1, the current transformer shall be regarded as low-leakage reactance current transformer.

For all other protection classes, the composite errors of the full winding obtained with a direct test method and with the indirect test method shall be compared.

For the direct test, either of the methods given in 2A.5 and 2A.6 may be applied. The primary test current shall be:

ALF x I_{pr} for class P and class PR;
K_x x I_{pr} for class PX and class PXR.

For the indirect test, the method given in 7.2.6.203 b) shall be applied. The voltage applied to the secondary terminals shall be equal to:

E_{ALF} for class P and class PR;
E_k for class PX and class PXR.

Proof of low-leakage reactance design shall be considered to have been established if the value of composite error from the direct method is less than 1,1 times that deduced from the indirect method.

NOTE According to its definition (3.4.235), the term “low-leakage reactance current transformer” is not universal, but related to its protection performance, e.g. protection class.

Annex 2D
(informative)

Technique used in temperature rise test of oil-immersed transformers to determine the thermal constant by an experimental estimation

List of symbols:

θ	Temperature in °C
$\theta(t)$	Oil temperature, varying with time (this may be the temperature of the oil at the top, or average oil temperature)
θ_a	External cooling medium temperature (ambient air or water) assumed to be constant
$\Delta\theta$	Oil temperature rise above θ_a
θ_u, $\Delta\theta_u$	Ultimate values in steady state
$\varepsilon(t)$	Remaining deviation from steady-state value θ_u
T_o	Time constant for exponential variation of bulk oil temperature rise
h	Time interval between readings
θ_1, θ_2, θ_3	Three successive temperature readings with time interval h between them.

In principle, the test should continue until the steady-state temperature rise (of the oil) is ascertained.

$$\theta_u = \theta_a + \Delta\theta_u \qquad (2D.1)$$

$$\theta(t) = \theta_a + \Delta\theta_u\,(1 - e^{-t/T_o}) \qquad (2D.2)$$

The remaining deviation from steady state is then:

$$\varepsilon(t) = \theta_u - \theta(t) = \Delta\theta_u \times e^{-t/T_o} \qquad (2D.3)$$

It is considered that:

- the ambient temperature is kept as constant as possible;
- the oil temperature $\theta(t)$ will approach an ultimate value θu along an exponential function with a time constant of T_o;
- the equation (2D.2) is a good approximation of the temperature curve (see Figure 2D.1).

Given three successive readings $\Delta\theta_1$, $\Delta\theta_2$ and $\Delta\theta_3$, the exponential relation of equation (2D.2), is a good approximation of the temperature curve, then the increments will have the following relation:

$$\frac{\Delta\theta_2 - \Delta\theta_1}{\Delta\theta_3 - \Delta\theta_2} = e^{h/T_o}$$

$$T_o = \frac{h}{ln\dfrac{\Delta\theta_2 - \Delta\theta_1}{\Delta\theta_3 - \Delta\theta_2}} \qquad (2D.4)$$

The readings also permit a prediction of the final temperature rise:

$$\Delta\theta_u = \frac{(\Delta\theta_2)^2 - \Delta\theta_1\Delta\theta_3}{2\Delta\theta_2 - \Delta\theta_1 - \Delta\theta_3} \quad (2D.5)$$

Successive estimates are to be made and they should converge. In order to avoid large random numerical errors the time interval h should be approximately T_o and $\Delta\theta_3/\Delta\theta_u$ should be not less than 0,95.

A more accurate value of steady-rate temperature rise is obtained by a least square method of extrapolation of all measured points above approximately 60 % of $\Delta\theta_u$ ($\Delta\theta_u$ estimated by the three point method).

A different numerical formulation is:

$$\Delta\theta_u = \Delta\theta_2 + \frac{\sqrt{(\Delta\theta_2 - \Delta\theta_1) - (\Delta\theta_3 - \Delta\theta_2)}}{\ln\dfrac{\Delta\theta_2 - \Delta\theta_1}{\Delta\theta_3 - \Delta\theta_2}} \quad (2D.6)$$

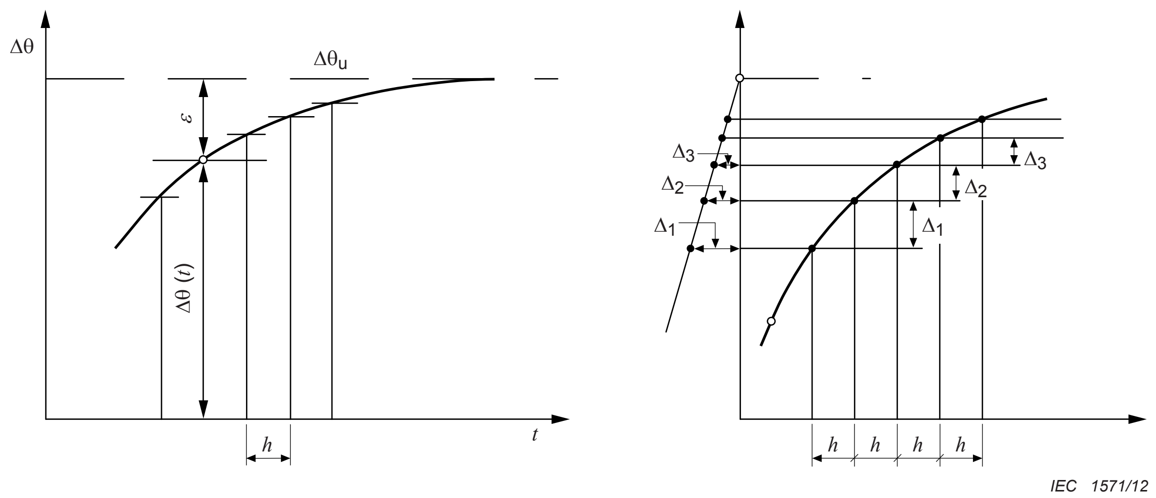


Figure 2D.1 – Graphical extrapolation to ultimate temperature rise

Annex 2E
(informative)

Alternative measurement of the ratio error (ε)

For low-leakage reactance current transformers, the following indirect test will lead to results which are very close to the results obtained in the direct test.

Nevertheless, routine tests for ratio error determination shall always be performed as a direct test, as this method gives the highest evidence of the “low-leakage reactance property” of a core, including magnetic homogeneity of the iron core. On the other hand, the alternative method is suitable for on-site measurements, and for monitoring purposes.

In this case, it shall be noted that this method never considers the influence of current flow in the neighborhood of the current transformer.

For the determination of the ratio error, the simplified equivalent circuit diagram shown in Figure 2E.1 is used:

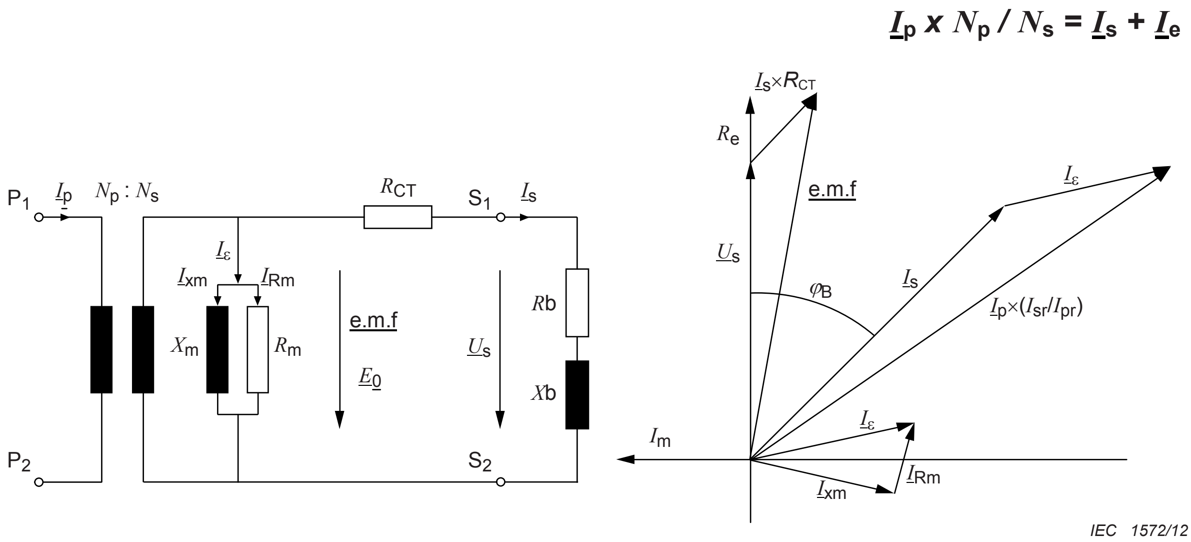


Figure 2E.1 – Simplified equivalent circuit of the current transformer

A substantially sinusoidal voltage is applied to the secondary terminals $S_1 - S_2$ of the current transformer. The test voltage across the terminals $\underline{U}_{s\ Test}$ and the current $\underline{I}_{s\ Test}$ are measured. The injected voltage should generate an e.m.f. across the main inductivity with the same amplitude as during operation with a certain current and the actual burden. The e.m.f. can be calculated from the test results by subtracting the voltage drop across the winding resistance R_{ct} from the test voltage $U_{s\ Test}$ across the $S_1 - S_2$ terminals. This subtraction has to be done in the complex plane. The measured current $I_{s\ Test}$ is equal the error current I_ε.

The ratio error can be expressed as:

$$\varepsilon = \frac{\underline{I}_s - \underline{I}_p \frac{I_{sr}}{I_{pr}}}{\underline{I}_p \frac{I_{sr}}{I_{pr}}} = \frac{\underline{I}_s I_{pr}}{\underline{I}_p I_{sr}} - 1 \qquad (2E.1)$$

with:

$$\frac{\underline{I}_p N_p}{N_s} = \underline{I}_e + \underline{I}_s \Rightarrow \underline{I}_p = \frac{(\underline{I}_e + \underline{I}_s) N_s}{N_p} \tag{2E.2}$$

the ratio error can be expressed as:

$$\varepsilon = \frac{\underline{I}_s \times N_p \times I_{pr}}{(\underline{I}_e + \underline{I}_s) \times N_s \times I_{sr}} - 1 \tag{2E.3}$$

To determine the ratio error for a certain secondary current I_s the following test procedure is proposed:

- Calculation of the secondary voltage across $S_1 - S_2$:

$$\underline{U}_s = \underline{I}_s \times (R_b + jX_b)$$

- Measurement of the secondary winding resistance R (value at the actual temperature)
- Calculation of the corresponding e.m.f.

$$\underline{E}_0 = \underline{I}_s R + \underline{U}_s$$

- Injection of

$$\underline{U}_{s\,Test} = \underline{E}_0 + \underline{I}_{s\,Test} R \qquad (\text{ with } I_{s\,Test} = I_s)$$

  into the secondary terminals $S_1 - S_2$
- Measurement of the voltage $U_{p\,Test}$ across P_1 - P_2
- Calculation of the turns ratio

$$\frac{N_p}{N_s} = \frac{U_{p\,Test}}{|\underline{E}_0|}$$

- Calculation of the corresponding I_p

$$\underline{I}_P = \frac{(\underline{I}_s + \underline{I}_{s\,Test}) N_s}{N_p}$$

  The ratio error can be calculated as:

$$\varepsilon = \frac{\underline{I}_s N_p I_{pr}}{(\underline{I}_{s\,Test} + \underline{I}_s) \times I_{sr}} - 1$$

Annex 2F
(normative)

Determination of the turns ratio error

The actual transformation ratio is affected by errors from three sources:

a) the difference between the inverse of the turns ratio and the rated transformation ratio;

b) the core exciting current (I_e);

c) the currents which flow in the stray capacitances associated with the windings.

In most cases, it is reasonable to assume that for a given secondary winding induced e.m.f. (E_s), the error currents due to stray capacitances and core magnetization will maintain a constant value irrespective of the value of the primary energizing current. E_s can theoretically be maintained at a constant value for a range of energizing currents, provided that the secondary loop impedance can be appropriately adjusted. For current transformers designed to be of the low-leakage reactance type, the secondary leakage reactance can be ignored and only the secondary winding resistance has to be considered. Thus, for any two currents I'_s and I''_s the basic equation defining the test requirement is

given by

$$I'_S(R + R'_b) = E_S = I''_S(R + R''_b)$$

where R is the actual resistance of the secondary winding.

Assuming that the measured ratio errors are ε'_c and ε''_c, the turns ratio error is denoted as ε_t, and the combined magnetization and stray currents are given by I_x. The respective error currents will be given by:

$$(\varepsilon'_c - \varepsilon_t) \times k_r I'_s = I_x = (\varepsilon''_c - \varepsilon_t) \times k_r I''_s$$

whence:

$$\varepsilon_t = \frac{\varepsilon'_c \times I'_s - \varepsilon''_c \times I''_s}{I'_s - I''_s}$$

If $I'_S = 2I''_S$, the turns ratio error is given by 2 $\varepsilon'_c - \varepsilon''_c$.

A test at rated current with minimum secondary connected burden, followed by a test at half rated current and suitable increase in secondary loop resistance, will usually give satisfactory results.

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