IEC 60076-1

Edition 3.0 2011-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Power transformers –
Part 1: General

Transformateurs de puissance –
Partie 1: Généralités

IEC 60076-1:2011

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 1: General

FOREWORD

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International Standard IEC 60076-1 has been prepared by IEC technical committee 14: Power transformers.

This third edition cancels and replaces the second edition published in 1993, and its Amendment 1(1999). It is a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– addition of a definition of harmonic content;
– addition of a subclause on transport;
– addition of functional method of specification;
– addition of connection symbols for single phase transformers;
– addition of safety and environmental requirements;
– addition of requirements for liquid preservation systems;

– addition of a clause on DC currents;
– addition of vacuum, pressure and leak tests on tanks;
– the requirements formerly in Annex A are now incorporated in the text and Annex A is now an informative checklist;
– informative annexes have been added on facilities for condition monitoring and environmental and safety considerations.

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

FDIS	Report on voting
14/675/FDIS	14/682/RVD

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

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

A list of all parts of the IEC 60076 series can be found, under the general title *Power transformers*, on the IEC website.

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

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- withdrawn,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

POWER TRANSFORMERS –

Part 1: General

1 Scope

This part of IEC 60076 applies to three-phase and single-phase power transformers (including auto-transformers) with the exception of certain categories of small and special transformers such as:

– single-phase transformers with rated power less than 1 kVA and three-phase transformers less than 5 kVA;
– transformers, which have no windings with rated voltage higher than 1 000 V;
– instrument transformers;
– traction transformers mounted on rolling stock;
– starting transformers;
– testing transformers;
– welding transformers;
– explosion-proof and mining transformers;
– transformers for deep water (submerged) applications.

When IEC standards do not exist for such categories of transformers (in particular transformer having no winding exceeding 1000 V for industrial applications), this part of IEC 60076 may still be applicable either as a whole or in part.

This standard does not address the requirements that would make a transformer suitable for mounting in a position accessible to the general public.

For those categories of power transformers and reactors which have their own IEC standards, this part is applicable only to the extent in which it is specifically called up by cross-reference in the other standard. Such standards exist for:

– reactors in general (IEC 60076-6);
– dry-type transformers (IEC 60076-11);
– self-protected transformers (IEC 60076-13);
– gas-filled power transformers (IEC 60076-15);
– transformers for wind turbine applications (IEC 60076-16);
– traction transformers and traction reactors (IEC 60310);
– converter transformers for industrial applications (IEC 61378-1);
– converter transformers for HVDC applications (IEC 61378-2).

At several places in this part it is specified or recommended that an 'agreement' should be reached concerning alternative or additional technical solutions or procedures. Such agreement is made between the manufacturer and the purchaser. The matters should preferably be raised at an early stage and the agreements included in the contract specification.

2 Normative references

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

IEC 60076-2, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-3:2000, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

IEC 60076-5:2006, *Power transformers – Part 5: Ability to withstand short circuit*

IEC 60076-10:2001, *Power transformers – Part 10: Determination of sound levels*

IEC 60076-11:2004, *Power transformers – Part 11: Dry-type transformers*

IEC 60137:2008, *Insulated bushings for alternating voltages above 1 000 V*

IEC 60214-1:2003, *Tap-changers – Part 1: Performance requirements and test methods*

IEC 60296:2003, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

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

ISO 9001:2008, *Quality management systems – Requirements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE Other terms use the meanings ascribed to them in the International Electrotechnical Vocabulary (IEV).

3.1 General

3.1.1
power transformer
a static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power

[IEC 60050-421:1990, 421-01-01, modified]

3.1.2
auto-transformer
a transformer in which at least two windings have a common part

[IEC 60050-421:1990, 421-01-11]

NOTE Where there is a need to express that a transformer is not auto-connected, use is made of terms such as separate winding transformer, or double-wound transformer (see IEC 60050-421:1990, 421-01-13).

3.1.3
series transformer
a transformer, other than an autotransformer, of which one winding is intended to be connected in series with a circuit in order to alter its voltage and/or shift its phase. The other winding is an energizing winding

[IEC 60050-421:1990, 421-01-12, modified]

NOTE Series transformers were called booster transformers in earlier editions of this standard.

3.1.4
liquid-immersed type transformer
a transformer in which the magnetic circuit and windings are immersed in liquid

3.1.5
dry-type transformer
a transformer in which the magnetic circuit and windings are not immersed in an insulating liquid

[IEC 60050-421:1990, 421-01-16]

3.1.6
liquid preservation system
system in a liquid-filled transformer by which the thermal expansion of the liquid is accommodated.

NOTE Contact between the liquid and external air may sometimes be diminished or prevented.

3.1.7
specified value
the value specified by the purchaser at the time of order

3.1.8
design value
the expected value given by the number of turns in the design in the case of turns ratio or calculated from the design in the case of impedance, no-load current or other parameters

3.1.9
highest voltage for equipment U_m applicable to a transformer winding
the highest r.m.s. phase-to-phase voltage in a three-phase system for which a transformer winding is designed in respect of its insulation

3.2 Terminals and neutral point

3.2.1
terminal
a conducting element intended for connecting a winding to external conductors

3.2.2
line terminal
a terminal intended for connection to a line conductor of a network

[IEC 60050-421:1990, 421-02-01]

3.2.3
neutral terminal
a) for three-phase transformers and three-phase banks of single-phase transformers:

   the terminal or terminals connected to the common point (the neutral point) of a star-connected or zigzag connected winding

b) for single-phase transformers:

the terminal intended for connection to a neutral point of a network

[IEC 60050-421:1990, 421-02-02, modified]

3.2.4
neutral point
the point of a symmetrical system of voltages which is normally at zero potential

3.2.5
corresponding terminals
terminals of different windings of a transformer, marked with the same letter or corresponding symbol

[IEC 60050-421:1990, 421-02-03]

3.3 Windings

3.3.1
winding
the assembly of turns forming an electrical circuit associated with one of the voltages assigned to the transformer

[IEC 60050-421:1990, 421-03-01, modified]

NOTE For a three-phase transformer, the 'winding' is the combination of the phase windings (see 3.3.3).

3.3.2
tapped winding
a winding in which the effective number of turns can be changed in steps

3.3.3
phase winding
the assembly of turns forming one phase of a three-phase winding

[IEC 60050-421:1990, 421-03-02, modified]

NOTE The term 'phase winding' should not be used for identifying the assembly of all coils on a specific leg.

3.3.4
high-voltage winding
HV winding*
the winding having the highest rated voltage

[IEC 60050-421:1990, 421-03-03]

3.3.5
low-voltage winding
LV winding*
the winding having the lowest rated voltage

[IEC 60050-421:1990, 421-03-04]

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* The winding which receives active power from the supply source in service is referred to as a 'primary winding', and that which delivers active power to a load as a 'secondary winding'. These terms have no significance as to which of the windings has the higher rated voltage and should not be used except in the context of direction of active power flow (see IEC 60050-421:1990, 421-03-06 and 07). A further winding in the transformer, usually with lower value of rated power than the secondary winding, is then often referred to as 'tertiary winding', see also definition 3.3.8.

NOTE For a series transformer, the winding having the lower rated voltage may be that having the higher insulation level.

3.3.6
intermediate-voltage winding*
a winding of a multi-winding transformer having a rated voltage intermediate between the highest and lowest winding rated voltages

[IEC 60050-421:1990, 421-03-05]

3.3.7
auxiliary winding
a winding intended only for a small load compared with the rated power of the transformer

[IEC 60050-421:1990, 421-03-08]

3.3.8
stabilizing winding
a supplementary delta-connected winding provided in a star-star-connected or star-zigzag-connected transformer to decrease its zero-sequence impedance, see 3.7.3

[IEC 60050-421:1990, 421-03-09, modified]

NOTE A winding is referred to as a stabilizing winding only if it is not intended for three-phase connection to an external circuit.

3.3.9
common winding
the common part of the windings of an auto-transformer

[IEC 60050-421:1990, 421-03-10]

3.3.10
series winding
the part of the winding of an auto-transformer or the winding of a series transformer which is intended to be connected in series with a circuit

[IEC 60050-421:1990, 421-03-11, modified]

3.3.11
energizing winding (of a series transformer)
the winding of a series transformer which is intended to supply power to the series winding

[IEC 60050-421:1990, 421-03-12, modified]

3.3.12
auto-connected windings
the series and common windings of an auto-transformer

3.4 Rating

3.4.1
rating
those numerical values assigned to the quantities which define the operation of the transformer in the conditions specified in this part of IEC 60076 and on which the manufacturer's guarantees and the tests are based

3.4.2
rated quantities
quantities (voltage, current, etc.), the numerical values of which define the rating

NOTE 1 For transformers having tappings, rated quantities are related to the principal tapping (see 3.5.2), unless otherwise specified. Corresponding quantities with analogous meaning, related to other specific tappings, are called tapping quantities (see 3.5.9).

NOTE 2 Voltages and currents are always expressed by their r.m.s. values, unless otherwise specified.

3.4.3
rated voltage of a winding
U_r
the voltage assigned to be applied, or developed at no-load, between the terminals of an untapped winding, or of a tapped winding connected on the principal tapping (see 3.5.2), for a three-phase winding it is the voltage between line terminals

[IEC 60050-421:1990, 421-04-01, modified]

NOTE 1 The rated voltages of all windings appear simultaneously at no-load when the voltage applied to one of them has its rated value.

NOTE 2 For single-phase transformers intended to be connected in star to form a three-phase bank or to be connected between the line and the neutral of a three phase system, the rated voltage is indicated as the phase-to-phase voltage, divided by $\sqrt{3}$ for example $400/\sqrt{3}$ kV.

NOTE 3 For single phase transformers intended to be connected between phases of a network, the rated voltage is indicated as the phase-to-phase voltage.

NOTE 4 For the series winding of a three-phase series transformer, which is designed as an open winding (see 3.10.5), the rated voltage is indicated as if the windings were connected in star.

3.4.4
rated voltage ratio
the ratio of the rated voltage of a winding to the rated voltage of another winding associated with a lower or equal rated voltage

[IEC 60050-421:1990, 421-04-02, modified]

3.4.5
rated frequency
f_r
the frequency at which the transformer is designed to operate

[IEC 60050-421:1990, 421-04-03, modified]

3.4.6
rated power
S_r
conventional value of apparent power assigned to a winding which, together with the rated voltage of the winding, determines its rated current

NOTE Both windings of a two-winding transformer have the same rated power which by definition is the rated power of the whole transformer.

3.4.7
rated current
I_r
the current flowing through a line terminal of a winding which is derived from rated power S_r and rated voltage U_r for the winding

[IEC 60050-421:1990, 421-04-05, modified]

NOTE 1 For a three-phase winding the rated current I_r is given by:

$$I_r = \frac{S_r}{\sqrt{3} \times U_r}$$

NOTE 2 For single-phase transformer windings intended to be connected in delta to form a three-phase bank, the rated current is indicated as line current divided by $\sqrt{3}$,

$$I_r = \frac{I_{line}}{\sqrt{3}}$$

NOTE 3 For a single phase transformer not intended to be connected to form a three phase bank, the rated current is

$$I_r = \frac{S_r}{U_r}$$

NOTE 4 For open windings (see 3.10.5) of a transformer, the rated current of the open windings is the rated power divided by the number of phases and by the rated voltage of the open winding:

$$I_r = \frac{S_r}{\text{No. of phases} \times U_r}$$

3.5 Tappings

3.5.1
tapping
in a transformer having a tapped winding, a specific connection of that winding, representing a definite effective number of turns in the tapped winding and, consequently, a definite turns ratio between this winding and any other winding with a fixed number of turns

NOTE One of the tappings is the principal tapping, and other tappings are described in relation to the principal tapping by their respective tapping factors. See definitions of these terms below.

3.5.2
principal tapping
the tapping to which the rated quantities are related

[IEC 60050-421:1990, 421-05-02]

3.5.3
tapping factor (corresponding to a given tapping)
the ratio:

$$\frac{U_d}{U_r} \text{(tapping factor)} \quad \text{or} \quad 100\,\frac{U_d}{U_r} \text{(tapping factor expressed as a percentage)}$$

where

U_r is the rated voltage of the winding (see 3.4.3);

U_d is the voltage which would be developed at no-load at the terminals of the winding, at the tapping concerned, by applying rated voltage to an untapped winding

NOTE For series transformers, the tapping factor is the ratio of the voltage of the series winding corresponding to a given tapping to U_r.

[IEC 60050-421:1990, 421-05-03, modified]

3.5.4
plus tapping
a tapping whose tapping factor is higher than 1

[IEC 60050-421:1990, 421-05-04]

3.5.5
minus tapping
a tapping whose tapping factor is lower than 1

[IEC 60050-421:1990, 421-05-05]

3.5.6
tapping step
the difference between the tapping factors, expressed as a percentage, of two adjacent tappings

[IEC 60050-421:1990, 421-05-06]

3.5.7
tapping range
the variation range of the tapping factor, expressed as a percentage, compared with the value '100'

NOTE If this factor ranges from 100 + a to 100 – b, the tapping range is said to be: +a %, –b % or ±a %, if a = b.
[IEC 60050-421:1990, 421-05-07]

3.5.8
tapping voltage ratio (of a pair of windings)
the ratio which is equal to the rated voltage ratio:

– multiplied by the tapping factor of the tapped winding if this is the high-voltage winding;
– divided by the tapping factor of the tapped winding if this is the low-voltage winding

[IEC 60050-421:1990, 421-05-08]

NOTE While the rated voltage ratio is, by definition, at least equal to 1, the tapping voltage ratio can be lower than 1 for certain tappings when the rated voltage ratio is close to 1.

3.5.9
tapping quantities
those quantities the numerical values of which define the duty of a particular tapping (other than the principal tapping)

NOTE Tapping quantities exist for any winding in the transformer, not only for the tapped winding (see 6.2 and 6.3).

The tapping quantities are:

– tapping voltage (analogous to rated voltage, 3.4.3);
– tapping power (analogous to rated power, 3.4.6);
– tapping current (analogous to rated current, 3.4.7).

[IEC 60050-421:1990, 421-05-10, modified]

3.5.10
full-power tapping
a tapping whose tapping power is equal to the rated power

[IEC 60050-421:1990, 421-05-14]

3.5.11
reduced-power tapping
a tapping whose tapping power is lower than the rated power

[IEC 60050-421:1990, 421-05-15]

3.5.12
on-load tap-changer
OLTC
a device for changing the tapping connections of a winding, suitable for operation while the transformer is energized or on load

[IEC 60050-421:1990, 421-11-01]

3.5.13
de-energized tap-changer
DETC
a device for changing the tapping connections of a winding, suitable for operation only while the transformer is de-energized (isolated from the system)

3.5.14
maximum allowable tapping service voltage
the voltage at rated frequency a transformer is designed to withstand continuously without damage at any particular tap position at the relevant tapping power

NOTE 1 This voltage is limited by U_m.

NOTE 2 This voltage will normally be limited to 105 % of the rated tapping voltage unless a higher voltage is required by the purchaser's specification of the tapping (see 6.4) either explicitly or as a result of a specification according to 6.4.2.

3.6 Losses and no-load current

NOTE The values are related to the principal tapping (see 3.5.2), unless another tapping is specifically stated.

3.6.1
no-load loss
the active power absorbed when a rated voltage (tapping voltage) at a rated frequency is applied to the terminals of one of the windings, the other winding or windings being open-circuited

[IEC 60050-421:1990, 421-06-01, modified]

3.6.2
no-load current
the r.m.s. value of the current flowing through a line terminal of a winding when rated voltage (tapping voltage) is applied at a rated frequency to that winding, the other winding or windings being open-circuited

NOTE 1 For a three-phase transformer, the value is the arithmetic mean of the values of current in the three lines.

NOTE 2 The no-load current of a winding is often expressed as a percentage of the rated current of that winding. For a multi-winding transformer, this percentage is referred to the winding with the highest rated power.

[IEC 60050-421:1990, 421-06-02, modified]

3.6.3
load loss
the absorbed active power at a rated frequency and reference temperature (see 11.1), associated with a pair of windings when rated current (tapping current) is flowing through the line terminals of one of the windings, and the terminals of the other winding are short-circuited. Further windings, if existing, are open-circuited

NOTE 1 For a two-winding transformer, there is only one winding combination and one value of load loss. For a multi-winding transformer, there are several values of load loss corresponding to the different two-winding combinations (see Clause 7 of IEC 60076-8:1997). A combined load loss figure for the complete transformer is referred to a specified winding load combination. In general, it is usually not accessible for direct measurement in testing.

NOTE 2 When the windings of the pair have different rated power values, the load loss is referred to rated current in the winding with the lower rated power and the reference power should be mentioned.

3.6.4
total losses
the sum of the no-load loss and the load loss

NOTE The power consumption of the auxiliary plant is not included in the total losses and is stated separately.

[IEC 60050-421:1990, 421-06-05, modified]

3.7 Short-circuit impedance and voltage drop

3.7.1
short-circuit impedance of a pair of windings
the equivalent series impedance $Z = R + jX$, in ohms, at rated frequency and reference temperature, across the terminals of one winding of a pair, when the terminals of the other winding are short-circuited and further windings, if existing, are open-circuited: for a three-phase transformer the impedance is expressed as phase impedance (equivalent star connection)

NOTE 1 In a transformer having a tapped winding, the short-circuit impedance is referred to a particular tapping. Unless otherwise specified, the principal tapping applies.

NOTE 2 This quantity can be expressed in relative, dimensionless form, as a fraction z of the reference impedance Z_{ref}, of the same winding of the pair. In percentage notation:

$$z = 100 \frac{Z}{Z_{ref}}$$

where

$Z_{ref} = \frac{U^2}{S_r}$ (formula valid for both three-phase and single-phase transformers);

U is the voltage (rated voltage or tapping voltage) of the winding to which Z and Z_{ref} belong;

S_r is the reference value of rated power.

The relative value is also equal to the ratio between the applied voltage during a short-circuit measurement which causes the relevant rated current (or tapping current) to flow, and rated voltage (or tapping voltage). This applied voltage is referred to as the short-circuit voltage (IEC 60050-421:1990, 421-07-01) of the pair of windings. It is normally expressed as a percentage.

[IEC 60050-421:1990, 421-07-02, modified]

3.7.2
voltage drop or rise for a specified load condition
the arithmetic difference between the no-load voltage of a winding and the voltage developed at the terminals of the same winding at a specified load and power factor, the voltage supplied to (one of) the other winding(s) being equal to:

– its rated value if the transformer is connected on the principal tapping (the no-load voltage of the winding is then equal to its rated value);
– the tapping voltage if the transformer is connected on another tapping.

This difference is generally expressed as a percentage of the no-load voltage of the winding

NOTE For multi-winding transformers, the voltage drop or rise depends not only on the load and power factor of the winding itself, but also on the load and power factor of the other windings (see IEC 60076-8).

[IEC 60050-421:1990, 421-07-03]

3.7.3
zero-sequence impedance (of a three-phase winding)
the impedance, expressed in ohms per phase at rated frequency, between the line terminals of a three-phase star-connected or zigzag-connected winding, connected together, and its neutral terminal

[IEC 60050-421:1990, 421-07-04, modified]

NOTE 1 The zero-sequence impedance may have several values because it depends on how the terminals of the other winding or windings are connected and loaded.

NOTE 2 The zero-sequence impedance may be dependent on the value of the current and the temperature, particularly in transformers without any delta-connected winding.

NOTE 3 The zero-sequence impedance may also be expressed as a relative value in the same way as the (positive sequence) short-circuit impedance (see 3.7.1).

3.8 Temperature rise

The difference between the temperature of the part under consideration and the temperature of the external cooling medium (see IEC 60076-2)

[IEC 60050-421:1990, 421-08-01, modified]

3.9 Insulation

For terms and definitions relating to insulation, see IEC 60076-3.

3.10 Connections

3.10.1
star connection
the winding connection so arranged that each of the phase windings of a three-phase transformer, or of each of the windings for the same rated voltage of single-phase transformers associated in a three-phase bank, is connected to a common point (the neutral point) and the other end to its appropriate line terminal

[IEC 60050-421:1990, 421-10-01, modified]

NOTE Star connection is sometimes referred to as Y-connection.

3.10.2
delta connection
the winding connection so arranged that the phase windings of a three-phase transformer, or the windings for the same rated voltage of single-phase transformers associated in a three-phase bank, are connected in series to form a closed circuit

[IEC 60050-421:1990, 421-10-02, modified]

NOTE Delta connection is sometimes referred to as D-connection.

3.10.3
open-delta connection
the winding connection in which the phase windings of a three-phase transformer, or the windings for the same rated voltage of single-phase transformers associated in a three-phase bank, are connected in series without closing one corner of the delta

[IEC 60050-421:1990, 421-10-03]

3.10.4
zigzag connection
Z-connection
a winding connection consisting of two winding sections, the first section connected in star, the second connected in series between the first section and the line terminals: the two sections are arranged so that each phase of the second section is wound on a different limb of the transformer to the part of the first section to which it is connected

NOTE See Annex D for cases where the winding sections have equal voltages.

3.10.5
open windings
the phase windings of a three-phase transformer which are not interconnected within the transformer

[IEC 60050-421:1990, 421-10-05, modified]

3.10.6
phase displacement (of a three-phase winding)
the angular difference between the phasors representing the voltages between the neutral point (real or imaginary) and the corresponding terminals of two windings, a positive-sequence voltage system being applied to the high-voltage terminals, following each other in alphabetical sequence if they are lettered, or in numerical sequence if they are numbered: the phasors are assumed to rotate in a counter-clockwise sense

[IEC 60050-421:1990, 421-10-08, modified]

NOTE 1 See Clause 7 and Annex D.

NOTE 2 The high-voltage winding phasor is taken as reference, and the displacement for any other winding is conventionally expressed by the 'clock notation', that is, the hour indicated by the winding phasor when the H.V. winding phasor is at 12 o'clock (rising numbers indicate increasing phase lag).

3.10.7
connection symbol
a conventional notation indicating the connections of the high-voltage, intermediate-voltage (if any), and low-voltage windings and their relative phase displacement(s) expressed as a combination of letters and clock-hour figure(s)

[IEC 60050-421:1990, 421-10-09, modified]

3.11 Test classification

3.11.1
routine test
a test to which each individual transformer is subjected

3.11.2
type test
a test made on a transformer which is representative of other transformers, to demonstrate that these transformers comply with the specified requirements not covered by the routine tests: a transformer is considered to be representative of others if it is built to the same drawings using the same techniques and materials in the same factory

NOTE 1 Design variations that are clearly irrelevant to a particular type test would not require that type test to be repeated.

NOITE 2 Design variations that cause a reduction in values and stresses relevant to a particular type test do not require a new type test if accepted by the purchaser and the manufacturer.

NOTE 3 For transformers below 20 MVA and $U_m \leq 72,5$ kV significant design variations may be acceptable if supported by demonstration of compliance with type test requirements.

3.11.3
special test
a test other than a type test or a routine test, agreed by the manufacturer and the purchaser

NOTE Special tests can be carried out on one transformer or all transformers of a particular design, as specified by the purchaser in the enquiry and order for every special test.

3.12 Meteorological data with respect to cooling

3.12.1
temperature of cooling medium at any time
the maximum temperature of the cooling medium measured over many years

3.12.2
monthly average temperature
half the sum of the average of the daily maxima and the average of the daily minima during a particular month over many years

3.12.3
yearly average temperature
one-twelfth of the sum of the monthly average temperatures

3.13 Other definitions

3.13.1
load current
the r.m.s. value of the current in any winding under service conditions

3.13.2
total harmonic content
the ratio of the effective value of all the harmonics to the effective value of the fundamental (E_1, I_1)

$$\text{total harmonic content} = \frac{\sqrt{\sum_{i=2}^{i=n} E_i^2}}{E_1} \text{ (for voltage)}$$

$$\text{total harmonic content} = \frac{\sqrt{\sum_{i=2}^{i=n} I_i^2}}{I_1} \text{ (for current)}$$

E_i represents the r.m.s. value of voltage of the i^{th} harmonic

I_i represents the r.m.s. value of current of the i^{th} harmonic

3.13.3
even harmonic content
the ratio of the effective value of all the even harmonics to the effective value of the fundamental (E_1, I_1)

$$\text{even harmonic content} = \frac{\sqrt{\sum_{i=1}^{i=n} E_{2i}^2}}{E_1} \text{ (for voltage)}$$

$$\text{even harmonic content} = \frac{\sqrt{\sum_{i=1}^{i=n} I_{2i}^2}}{I_1} \text{ (for current)}$$

E_i represents the r.m.s. value of voltage of the i^{th} harmonic

I_i represents the r.m.s. value of current of the i^{th} harmonic

4 Service conditions

4.1 General

The service conditions set out in 4.2 represent the normal scope of operation of a transformer specified to this standard. For any unusual service conditions which require special consideration in the design of a transformer see 5.5. Such conditions include high altitude, extreme high or low external cooling medium temperature, tropical humidity, seismic activity, severe contamination, unusual voltage or load current wave shapes, high solar radiation and intermittent loading. They may also concern conditions for shipment, storage and installation, such as weight or space limitations (see Annex A).

Supplementary rules for rating and testing are given in the following publications:

– temperature rise and cooling in high external cooling medium temperature or at high altitude: IEC 60076-2 for liquid-immersed transformers, and IEC 60076-11 for dry-type transformers;
– external insulation at high altitude: IEC 60076-3 for liquid-filled transformers, and IEC 60076-11 for dry-type transformers.

4.2 Normal service conditions

This part of IEC 60076 gives detailed requirements for transformers for use under the following conditions:

a) Altitude

   A height above sea-level not exceeding 1 000 m.

b) Temperature of cooling medium

   The temperature of cooling air at the inlet to the cooling equipment not exceeding:

   40 °C at any time;

   30 °C monthly average of the hottest month;

   20 °C yearly average.

   and not below:

   –25 °C in the case of outdoor transformers;

   –5 °C in the case of transformers where both the transformer and cooler are intended for installation indoors.

   At any time, monthly average and yearly average are defined in 3.12.

   The purchaser may specify a higher minimum temperature of cooling medium in which case the minimum temperature of cooling medium shall be stated on the rating plate.

   NOTE 1 This paragraph above is intended to allow the use of an alternative insulating liquid which does not meet minimum temperature requirements in circumstances where the minimum temperature of –25 °C is not appropriate.

   For water-cooled transformers, a temperature of cooling water at the inlet not exceeding:

   25 °C at any time;

   20 °C yearly average.

At any time and yearly average are defined in 3.12.

Further limitations, with regard to cooling are given for:

- liquid-immersed transformers in IEC 60076-2;
- dry-type transformers in IEC 60076-11.

NOTE 2 For transformers with both air/water and water/liquid heat exchangers, the temperature of cooling medium refers to the external air temperature rather than the water temperature in the intermediate circuit which may exceed the normal value

NOTE 3 The relevant temperature is at the inlet to the cooling equipment rather than the outside air temperature, this means that the user should take care that if the installation can create conditions where air recirculation from the output of the cooler can occur, that this is taken into account when assessing the cooling air temperature.

c) Wave shape of supply voltage

A sinusoidal supply voltage with a total harmonic content not exceeding 5 % and an even harmonic content not exceeding 1 %.

d) Load current harmonic content

Total harmonic content of the load current not exceeding 5 % of rated current.

NOTE 4 Transformers where total harmonic content of the load current exceeds 5 % of rated current, or transformers specifically intended to supply power electronic or rectifier loads should be specified according to IEC 61378 series.

NOTE 5 Transformers can operate at rated current without excessive loss of life with a current harmonic content of less than 5 %, however it should be noted that the temperature rise will increase for any harmonic loading and may exceed rated rise.

e) Symmetry of three-phase supply voltage

For three-phase transformers, a set of three-phase supply voltages which are approximately symmetrical. Approximately symmetrical shall be taken to mean that the highest phase to phase voltage is no more than 1 % higher than the lowest phase to phase voltage continuously or 2 % higher for short periods (approximately 30 min) under exceptional conditions.

f) Installation environment

An environment with a pollution rate (see IEC 60137 and IEC/TS 60815) that does not require special consideration regarding the external insulation of transformer bushings or of the transformer itself.

An environment not exposed to seismic disturbance which would require special consideration in the design. (This is assumed to be the case when the ground acceleration level a_g is below 2 ms^{-2} or approximately 0,2 g.) See IEC 60068-3-3.

Where the transformer is installed in an enclosure not supplied by the transformer manufacturer remotely from the cooling equipment, for example in an acoustic enclosure, the temperature of the air surrounding the transformer is not exceeding 40 °C at any time.

Environmental conditions within the following definitions according to IEC 60721-3-4:1995:

- climatic conditions 4K2 except that the minimum external cooling medium temperature is –25 °C;
- special climatic conditions 4Z2, 4Z4, 4Z7;
- biological conditions 4B1;
- chemically active substances 4C2;
- mechanically active substances 4S3;
- mechanical conditions 4M4.

For transformers intended to be installed indoors, some of these environmental conditions may not be applicable.

5 Rating and general requirements

5.1 Rated power

5.1.1 General

The rated power for each winding shall either be specified by the purchaser or the purchaser shall provide sufficient information to the manufacturer to determine the rated power at the enquiry stage.

The transformer shall have an assigned rated power for each winding which shall be marked on the rating plate. The rated power refers to continuous loading. This is a reference value for guarantees and tests concerning load losses and temperature rises.

If different values of apparent power are assigned under different circumstances, for example, with different methods of cooling, the highest of these values is the rated power.

A two-winding transformer has only one value of rated power, identical for both windings.

For multi-winding transformers, the purchaser shall specify the required power-loading combinations, stating, when necessary, the active and reactive outputs separately.

When the transformer has rated voltage applied to a primary winding, and rated current flows through the terminals of a secondary winding, the transformer receives the relevant rated power for that pair of windings.

The transformer shall be capable of carrying, in continuous service, the rated power (for a multi-winding transformer: the specified combination(s) of winding rated power(s)) under conditions listed in Clause 4 and without exceeding the temperature-rise limitations specified in IEC 60076-2 for liquid immersed transformers.

NOTE 1 The interpretation of rated power according to this subclause implies that it is a value of apparent power input to the transformer - including its own absorption of active and reactive power. The apparent power that the transformer delivers to the circuit connected to the terminals of the secondary winding under rated loading differs from the rated power. The voltage across the secondary terminals differs from rated voltage by the voltage drop (or rise) in the transformer. Allowance for voltage drop, with regard to load power factor, is made in the specification of the rated voltage and the tapping range (see Clause 7 of IEC 60076-8:1997).

National practices may be different.

NOTE 2 For a multi-winding transformer, half the arithmetic sum of the rated power values of all windings (separate windings, not auto-connected) gives a rough estimate of its physical size as compared with a two-winding transformer.

5.1.2 Preferred values of rated power

For transformers up to 20 MVA, values of rated power should preferably be taken from the R10 series given in ISO 3:1973, *Preferred numbers – series of preferred numbers*:

(...100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1 000, etc.) kVA.

NOTE National practices may be different.

5.1.3 Minimum power under alternative cooling modes

Where the user has a particular requirement for a minimum power under a particular cooling mode other than the cooling mode for rated power, this shall be stated in the enquiry.

The transformer shall be capable of carrying, in continuous service, the specified minimum power (for a multi-winding transformer: the specified combination(s) of winding rated power(s) under conditions listed in Clause 4, and under the specified cooling mode, without exceeding the temperature-rise limitations specified in IEC 60076-2 for liquid immersed transformers.

NOTE An example of this is where the transformer is required to operate at a particular minimum percentage of rated power with the forced cooling out of service (ONAN) to allow for the loss of auxiliary supply

5.1.4 Loading beyond rated power

A transformer and its component parts in accordance with this standard is able under some circumstances to carry loading beyond rated power. The method for calculating the permissible loading can be found in IEC 60076-7 for liquid immersed transformers and in IEC 60076-12 for dry-type transformers.

Any specific requirements for loading beyond rated power, operation at higher external cooling medium temperatures or reduced temperature rise limits shall be specified by the purchaser in the enquiry and the contract. Any additional tests or calculations required to verify compliance with these specific requirements shall also be specified.

NOTE 1 This option is intended to be used in particular to give a basis for design and guarantees concerning temporary emergency loading of power transformers.

The bushings, tap-changers, current transformers and other auxiliary equipment shall be selected so as not to restrict the loading capability of the transformer.

NOTE 2 The relevant component standards IEC 60137 for bushings and IEC 60214-1 for tap-changers should be consulted for the loading capability of those components.

NOTE 3 These requirements do not apply to transformers for special applications, which do not need a loading capability beyond rated power. For these transformers, if such a capability is required, it should be specified.

5.2 Cooling mode

The user shall specify the cooling medium (air or water).

If the user has particular requirements for the cooling method(s) or cooling equipment, this shall be stated in the enquiry.

For additional information see IEC 60076-2.

5.3 Load rejection on transformers directly connected to a generator

Transformers intended to be connected directly to generators in such a way that they may be subjected to load rejection conditions shall be able to withstand 1,4 times rated voltage for 5 s at the transformer terminals to which the generator is to be connected.

5.4 Rated voltage and rated frequency

5.4.1 Rated voltage

The rated voltage shall either be specified by the purchaser or for special applications the purchaser shall provide sufficient information to the manufacturer to determine the rated voltage at the enquiry stage.

The transformer shall have an assigned rated voltage for each winding which shall be marked on the rating plate.

5.4.2 Rated frequency

The rated frequency shall be specified by the purchaser to be the normal undisturbed frequency of the network.

The rated frequency is the basis for the guaranteed values such as losses, impedance, and sound level.

5.4.3 Operation at higher than rated voltage and/or at other than rated frequency

Methods for the specification of suitable rated voltage values and tapping range to cope with a set of loading cases (loading power and power factor, corresponding line-to-line service voltages) are described in IEC 60076-8.

Within the prescribed values of U_m, for the transformer windings, a transformer shall be capable of continuous operation at rated power without damage under conditions of 'overfluxing' where the value of voltage divided by frequency (V/Hz) exceeds the corresponding value at rated voltage and rated frequency by no more than 5 %, unless otherwise specified by the purchaser.

At no load, transformers shall be capable of continuous operation at a V/Hz of 110 % of the rated V/Hz.

At a current K times the transformer rated current ($0 \le K \le 1$), the overfluxing shall be limited in accordance with the following formula:

$$\frac{U}{U_r}\frac{f_r}{f}\times 100 \le 110 - 5\,K \quad (\%)$$

If the transformer is to be operated at V/Hz in excess of those stated above, this shall be identified by the purchaser in the enquiry.

5.5 Provision for unusual service conditions

The purchaser shall identify in his enquiry any service conditions not covered by the normal service conditions. Examples of such conditions are:

– external cooling medium temperature outside the limits prescribed in 4.2;
– restricted ventilation;
– altitude in excess of the limit prescribed in 4.2;
– damaging fumes and vapours;
– steam;
– humidity in excess of the limit prescribed in 4.2;
– dripping water;
– salt spray;
– excessive and abrasive dust;
– high harmonic content of the load current exceeding the requirements of 4.2;
– distortion of the supply voltage waveform exceeding the limits of 4.2;
– unusual high frequency switching transients, see Clause 13;
– superimposed DC current;
– seismic qualification which would otherwise require special considerations in the design, see 4.2;
– extreme mechanical shock and vibrations;
– solar radiation;
– regular frequent energisation in excess of 24 times per year;
– regular frequent short-circuits;
– V/Hz in excess of 5.4.3 above;

- if a generator step up transformer is intended to be used in back-feed mode when not connected to the generator without protection on the lower voltage side;
- corrosion protection, according to the kind of installation and the installation environment (see 4.2), the purchaser should choose classes of protection in ISO 12944 or by agreement between purchaser and manufacturer;
- load rejection conditions for generator transformers more severe than those given in 5.3 above.

Transformer specification for operation under such abnormal conditions shall be subject to agreement between the supplier and purchaser.

Supplementary requirements, within defined limits, for the rating and testing of transformers designed for other than normal service conditions listed in Clause 4, such as high temperature of cooling air or altitude above 1 000 m are given in IEC 60076-2.

5.6 Highest voltage for equipment U_m and dielectric tests levels

For line terminals, unless otherwise specified by the purchaser, U_m shall be taken to be the lowest value that exceeds the rated voltage of each winding given in IEC 60076-3.

For transformer windings with a highest voltage for equipment greater than (>) 72,5 kV the purchaser shall specify whether any neutral terminals for that winding are to be directly earthed in service or not, and if not, the U_m for the neutral terminals shall be specified by the purchaser.

Unless otherwise specified by the purchaser, dielectric test levels shall be taken to be the lowest applicable value corresponding to U_m, given in IEC 60076-3.

5.7 Additional information required for enquiry

5.7.1 Transformer classification

The kind of transformer, for example, separate winding transformer, auto-transformer or series transformer shall be specified by the user.

5.7.2 Winding connection and number of phases

The required winding connection shall be specified by the user in accordance with the terminology given in Clause 7 to suit the application.

If a delta connected stabilizing winding is required, it shall be specified by the purchaser. For star-star connected transformers or autotransformers, if the design has a closed magnetic circuit for zero sequence flux and no delta winding is specified, then the requirement shall be discussed between the manufacturer and the purchaser (see IEC 60076-8).

NOTE A closed magnetic circuit for zero sequence flux exists in a shell-form transformer, and in a core-form transformer with an unwound limb or limbs.

If there are requirements for high and low limits for the zero sequence impedance, this shall be stated by the purchaser and may influence the core configuration and the requirement for a delta winding. If the zero sequence requirements dictated the use of a delta connected winding that was not directly specified by the purchaser, then this shall be clearly stated by the manufacturer in the tender documents.

The transformer manufacturer shall not use a delta connected test winding if no delta winding has been specified, unless specifically agreed by the purchaser.

If there is a particular requirement for either a bank of single phase transformer or a three phase unit, then this shall be specified by the user; otherwise the manufacturer shall make it clear in the tender document what type of transformer is being offered.

5.7.3 Sound level

Where the purchaser has a specific requirement for a guaranteed maximum sound level, this shall be given in the enquiry and should preferably be expressed as a sound power level.

Unless otherwise specified, the sound level shall be taken as the no load sound level with all cooling equipment required to achieve rated power in operation. If an alternative cooling mode is specified (see 5.1.3) the sound level for each alternative mode may be specified by the purchaser and if specified shall be guaranteed by the manufacturer and measured on test.

The sound level in service is influenced by the load current (see IEC 60076-10). If the purchaser requires a load current sound level measurement test or a guarantee of the total noise level of the transformers, including load noise, this shall be stated in the enquiry.

The sound level measured in the test according to IEC 60076-10 shall not exceed the guaranteed maximum sound level. The guaranteed maximum sound level is a limit without tolerance.

5.7.4 Transport

5.7.4.1 Transport limitation

If transport size or weight limits apply, they shall be stated in the enquiry.

If any other special conditions apply during transportation, they shall be stated in the enquiry. This might include a restriction on the transportation with insulating liquid or different environmental conditions expected to be experienced during transportation than those expected in service.

5.7.4.2 Transport acceleration

The transformer shall be designed and manufactured to withstand a constant acceleration of at least 1 g in all directions (in addition to the acceleration due to gravity in the vertical direction) without any damage, demonstrated by static force calculations based on a constant value of acceleration.

If the transport is not the responsibility of the manufacturer and an acceleration in excess of 1 g is expected during transport, the accelerations and frequencies shall be defined in the enquiry. If higher accelerations are specified by the customer, the manufacturer shall demonstrate compliance by means of calculation.

If the transformer is intended to be used as a mobile transformer, this shall be stated in the enquiry.

NOTE The use of impact or shock recorders during transportation for large transformer is common practice.

5.8 Components and materials

All components and materials used in the construction of the transformer shall comply with the requirements of the relevant IEC standards where they exist unless otherwise agreed or specified. In particular bushings shall comply with IEC 60137, tap-changers shall comply with IEC 60214-1, and insulating liquid shall comply with IEC 60296 for mineral oil or as agreed for other liquids.

6 Requirements for transformers having a tapped winding

6.1 General – Notation of tapping range

The following subclauses apply to transformers in which only one of the windings is a tapped winding.

In a multi-winding transformer, the statements apply to the combination of the tapped winding with either of the untapped windings.

For transformers specified in accordance with 6.4.2, the notation shall be as specified by the purchaser in item 3 of that subclause.

In auto-connected transformers, tappings are sometimes arranged at the neutral which means that the effective number of turns is changed simultaneously in both windings. For such transformers, unless they are specified in accordance with 6.4.2, the tapping particulars are subject to agreement. The requirements of this subclause should be used as far as applicable.

Unless otherwise specified, the principal tapping is located in the middle of the tapping range. Other tappings are identified by their tapping factors. The number of tappings and the range of variation of the transformer ratio may be expressed in short notation by the deviations of the tapping factor percentages from the value 100 (for definitions of terms, see 3.5).

EXAMPLE A transformer with a tapped 160 kV winding with a tapping range of ±15 % having 21 tappings, symmetrically arranged around the rated voltage, is designated:

$$(160 \pm 10 \times 1{,}5\ \%)\ /\ 66\ \text{kV}$$

If the tapping range is specified asymmetrically around the rated voltage, this is designated as:

$$\left(160^{+12 \times 1{,}5\ \%}_{-8 \times 1{,}5\ \%}\right) \Big/ 66\ \text{kV}$$

Regarding the full presentation on the nameplate of data related to individual tappings, see Clause 8.

Some tappings may be 'reduced-power tappings' due to restrictions in either tapping voltage or tapping current. The boundary tappings where such limitations appear are called 'maximum voltage tapping' and 'maximum current tapping' (see Figures 1a, 1b and 1c).

6.2 Tapping voltage – tapping current. Standard categories of tapping voltage variation. Maximum voltage tapping

The short notation of tapping range and tapping steps indicates the variation range of the ratio of the transformer. But the assigned values of tapping quantities are not fully defined by this alone. Additional information is necessary. This can be given either in tabular form with tapping power, tapping voltage and tapping current for each tapping, or as text, indicating 'category of voltage variation' and possible limitations of the range within which the tappings are 'full-power tappings'.

The categories of tapping voltage variation are defined as follows:

a) Constant flux voltage variation (CFVV)

The tapping voltage in any untapped winding is constant from tapping to tapping. The tapping voltages in the tapped winding are proportional to the tapping factors. See Figure 1a.

b) Variable flux voltage variation (VFVV)

The tapping voltage in the tapped winding is constant from tapping to tapping. The tapping voltages in any untapped winding are inversely proportional to the tapping factor. See Figure 1b.

c) Combined voltage variation (CbVV)

In many applications and particularly with transformers having a large tapping range, a combination is specified using both principles applied to different parts of the range: combined voltage variation (CbVV). The change-over point is called 'maximum voltage tapping'. For this system the following applies:

CFVV applies for tappings with tapping factors below the maximum voltage tapping factor.

VFVV applies for tappings with tapping factors above the maximum voltage tapping factor.

See Figure 1c.

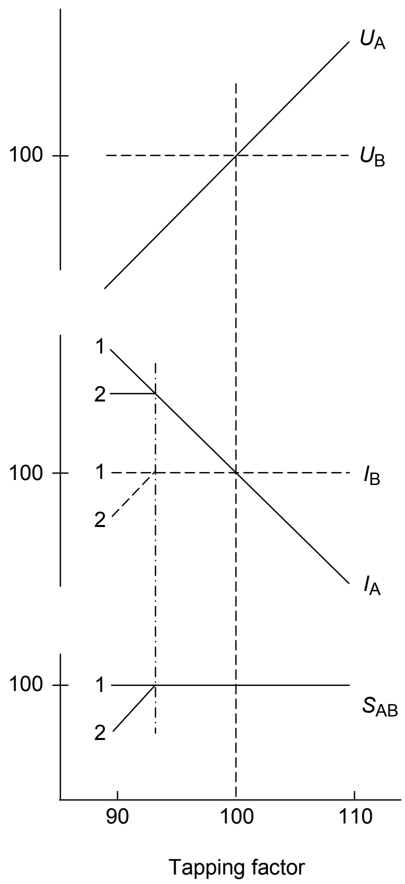


Figure 1a – Constant flux voltage variation (CFVV)

Optional maximum current tapping shown

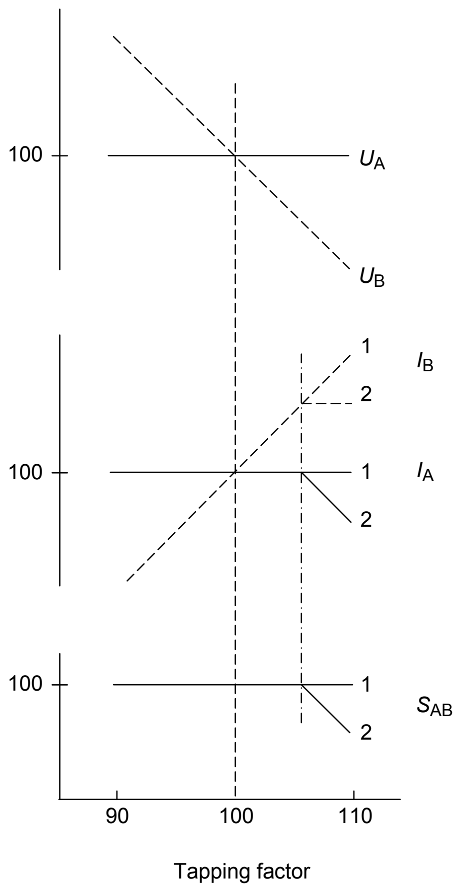


Figure 1b – Variable flux voltage variation (VFVV)

Optional maximum current tapping shown

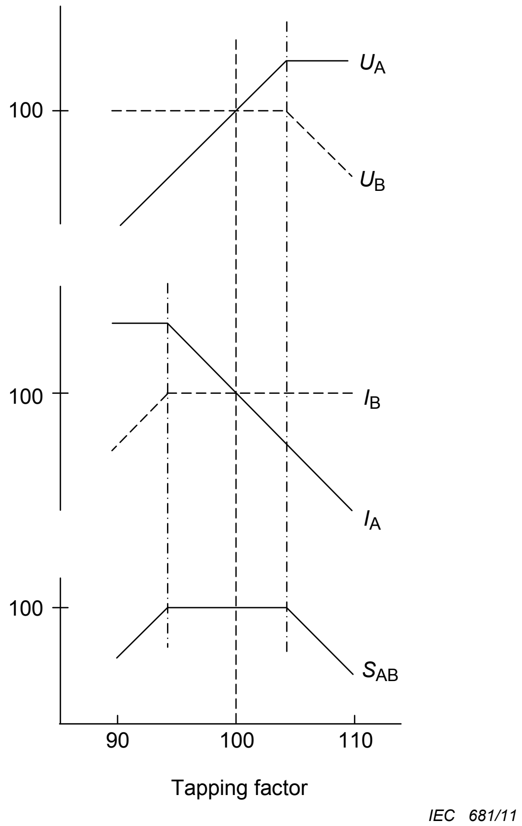


Figure 1c – Combined voltage variation (CbVV)

The change-over point is shown in the plus tapping range. It constitutes both a maximum voltage tapping (U_A) and a maximum current tapping (I_B constant, not rising above the change-over point). An additional, optional maximum current tapping (in the CFVV range) is also shown.

Key for Figure 1a, 1b and 1c:

U_A , I_A	tapping voltage and tapping current in the tapped winding
U_B , I_B	tapping voltage and tapping current in the untapped winding
S_{AB}	tapping power
Abscissa	tapping factor, percentage (indicating relative number of effective turns in tapped winding)
1	indicates full-power tappings throughout the tapping range
2	indicates 'maximum-voltage tapping', 'maximum current tapping' and range of reduced power tappings

Figure 1 – Different types of voltage variation

6.3 Tapping power. Full-power tappings – reduced-power tappings

The following shall apply unless the voltage and current at each tapping is otherwise specified.

All tappings shall be full-power tappings, that is, the rated tapping current at each tapping shall be the rated power divided by the rated tapping voltage at each tap except as specified below.

In separate-winding transformers up to and including 2 500 kVA with a tapping range not exceeding ±5 %, the rated tapping current at all minus tappings shall be equal to the rated tapping current at the principal tapping. This means that the principal tapping is a 'maximum current tapping'.

In transformers with a tapping range wider than ±5 %, restrictions may be specified on values of tapping voltage or tapping current which would otherwise rise considerably above the rated values. When such restrictions are specified, the tappings concerned will be 'reduced-power tappings'. This subclause describes such arrangements.

When the tapping factor deviates from unity, the tapping current for full-power tappings may rise above rated current on one of the windings. As Figure 1a illustrates, this applies for minus tappings, on the tapped winding, under CFVV, and for plus tappings on the untapped winding under VFVV (Figure 1b). In order to limit the corresponding reinforcement of the winding in question, it is possible to specify a maximum current tapping. From this tapping onwards the tapping current values for the winding are then specified to be constant. This means that the remaining tappings towards the extreme tapping are reduced-power tappings (see Figures 1a, 1b and 1c).

Under CbVV, the 'maximum voltage tapping', the change-over point between CFVV and VFVV shall at the same time be a 'maximum current tapping' unless otherwise specified. This means that the untapped winding current stays constant up to the extreme plus tapping (Figure 1c).

6.4 Specification of tappings in enquiry and order

6.4.1 General

The purchaser shall specify the requirements for tapping either according to 6.4.2 or 6.4.3.

The purchaser shall specify if the tap changer or tap changers are intended to be operated on load or de-energized.

Where variable flux voltage variation VFVV is used, it is normally only possible for the design ratio to match the specified ratio at two positions over the regulation range. The purchaser shall specify where the design ratio shall match the specified ratio, e.g. extreme taps, principal and maximum tap or principal and mininimum tap. If not otherwise specified, the two extreme taps shall be the ratios to match.

NOTE Subclause 6.4.2 requires the user to specify which winding is to be tapped and particular tapping powers. Subclause 6.4.3 defines overall voltage and current requirements and requires the manufacturer to select which winding or windings will be tapped. Such a specification may result in a variety of possible transformer designs. IEC 60076-8 gives details of tapping arrangements and voltage drop calculations.

6.4.2 Constructional specification

The following data are necessary to define the design of the transformer:

a) which winding shall be tapped;
b) the number of steps and the tapping step (or the tapping range and number of steps). Unless otherwise specified, it shall be assumed that the range is symmetrical around the principal tapping and that the tapping steps in the tapped winding are equal. If for some reason, the design has unequal steps, this shall be indicated in the tender;
c) the category of voltage variation and, if combined variation is applied, the change-over point ('maximum voltage tapping', see 6.2);
d) whether maximum current limitation (reduced power tappings) shall apply, and if so, for which tappings.

Instead of items c) and d), tabulation of the same type as used on the rating plate may be used to advantage (see example in Annex B).

6.4.3 Functional specification

This type of specification is intended to allow the purchaser to specify operational requirements and not the category of voltage variation or which winding is to be tapped.

This method of specification is not applicable to separate-winding transformers up to and including 2 500 kVA with a tapping range not exceeding ±5 %.

The following information shall be given by the purchaser in the enquiry in addition to the rated voltage and rated power defined in Clause 5:

a) Direction of power flow (can be both directions).
b) The number of tapping steps and the size of the tapping step expressed as a percentage of the rated voltage at the principal tapping. If the tapping range is not symmetrical about the principal tapping then this shall be indicated. If the tapping steps are not equal across the range then this shall be indicated.

NOTE 1 It may be that the range of variation and the number of steps is more important than achieving the exact voltage at the principal tap. In this case the range of variation and the number of steps may be specified. For example +5 % to –10 % in 11 steps.

c) Which voltage shall vary for the purpose of defining rated tapping voltage.

NOTE 2 The rated tapping voltage is needed to determine the impedance base for each tap. Where the functional method of specification is adopted, the rated tapping voltage cannot be used to determine the rated tapping power.

d) Any requirements for fixing the ratio of turns between two particular windings on a more than two winding transformer.
e) Minimum full load power factor (this affects the voltage drop of the transformer).
f) Whether any tapping or range of tappings can be reduced power tappings.

The manufacturer will choose the arrangement of windings, the winding or windings that are tapped. The transformer shall be able to supply the rated current on the secondary winding on all tapping positions consistent with the above operating conditions, without exceeding the temperature rise requirements defined by IEC 60076-2.

The transformer shall be designed to withstand without damage the voltages and fluxes arising from the above specified loading conditions (including any specified overload conditions). A calculation showing that this condition is satisfied shall be supplied to the purchaser on request.

An example is given in Annex B (example 4).

Alternatively, the user may submit a set of loading cases with values of active and reactive power (clearly indicating the direction of power flow), and corresponding on-load voltages. These cases should indicate the extreme values of voltage ratio under full and reduced power (see “the six-parameter method” of IEC 60076-8). Based on this information, the manufacturer will then select the tapped winding and specify rated quantities and tapping quantities in his tender proposal. An agreement shall be reached between the manufacturer and the purchaser on the design tapping quantities.

6.5 Specification of short-circuit impedance

For transformers with no tappings exceeding a voltage variation of ±5 % from the principal tapping, the short-circuit impedance of a pair of windings shall be specified at the principal tapping only, either in terms of ohms per phase Z or in percentage terms z referred to the rated power and rated voltage of the transformer (see 3.7.1). Alternatively, the impedance may be specified in accordance with one of the methods below.

For transformers with tappings exceeding a voltage variation of ±5 % from the principal tapping, impedance values expressed in terms of Z or z shall be specified for the principal tapping and the extreme tapping(s) exceeding 5 %. On such transformers, these values of impedance shall also be measured during the short-circuit impedance and load losses test (see 11.4) and shall be subject to the tolerances given in Clause 10. If the impedance is expressed in percentage terms *z*, this shall be referred to the rated tapping voltage (at that tapping) and the rated power of the transformer (at the principal tapping).

NOTE 1 The selection of an impedance value by the user is subject to conflicting demands: limitation of voltage drop versus limitation of overcurrent under system fault conditions. Economic optimization of the design, bearing in mind loss, leads towards a certain range of impedance values. Parallel operation with an existing transformer requires matching impedance (see Clause 6 of IEC 60076-8:1997).

NOTE 2 If an enquiry contains a specification of not only the impedance at the principal tapping but also its variation across the tapping range, this can impose an important restriction on the design of the transformer (the arrangement of the windings in relation to each other and their geometry). The transformer specification and design also need to take into account that large changes in impedance between taps can reduce or exaggerate the effect of the tappings.

Alternatively maximum and minimum impedances in terms of *z* or *Z* may be specified for each tapping across the whole tapping range. This may be done with the aid of a graph or a table. (See Annex C). The boundaries should where possible be at least as far apart as to permit the double-sided tolerances of Clause 10 to be applied on a median value between them. Measured values shall not fall outside the boundaries, which are limits without tolerance.

NOTE 3 The specified maximum and minimum impedances should allow an impedance tolerance at least as great as the tolerances given in Clause 10 but where necessary a tighter tolerance may be used by agreement between manufacturer and purchaser.

NOTE 4 Basing the impedance on the rated tapping voltage and the rated power of the transformer at the principal tapping means that the relationship between ohms per phase *Z* and percentage impedance *z* will be different for each tap and will also depend on which winding the voltage variation is specified. Great care is therefore needed to ensure that the specified impedance is correct. This is particularly important for transformers specified with tapping powers different to rated power at principal tapping.

6.6 Load loss and temperature rise

a) If the tapping range is within ±5 %, and the rated power not above 2 500 kVA, load loss guarantees and temperature rise refer to the principal tapping only, and the temperature rise test is run on that tapping.

b) If the tapping range exceeds ±5 % or the rated power is above 2 500 kVA, the guaranteed losses shall be stated on the principal tapping position, unless otherwise specified by the purchaser at the enquiry stage. If such a requirement exists, it shall be stated for which tappings, in addition to the principal tapping, the load losses are to be guaranteed by the manufacturer. These load losses are referred to the relevant tapping current values. The temperature-rise limits are valid for all tappings, at the appropriate tapping power, tapping voltage and tapping current.

   The temperature-rise type test shall be carried out on one tapping only, unless otherwise specified. It will, unless otherwise agreed, be the 'maximum current tapping' (which is usually the tapping with the highest load loss). The maximum total loss on any tapping is the test power for determination of liquid temperature rise during the temperature rise test, and the tapping current for the selected tapping is the reference current for determination of winding temperature rise above liquid. For information about rules and tests regarding the temperature rise of liquid-immersed transformers, see IEC 60076-2.

   In principle, the temperature-rise type test shall demonstrate that the cooling equipment is sufficient for dissipation of maximum total loss on any tapping, and that the temperature rise over external cooling medium temperature of any winding, at any tapping, does not exceed the specified maximum value.

   NOTE 1 For an autotransformer, the maximum current in the series and common windings are usually at two different tap positions. Therefore an intermediate tap position may be selected for test to allow the requirements of IEC 60076-2 to be met on both windings during the same test.

   NOTE 2 For some tapping arrangements, the tapping winding is not carrying current in the maximum current tapping position. Therefore, if the temperature rise of the tapping winding needs to be determined, another tapping may be selected or an extra test may be agreed.

7 Connection phase displacement symbols

7.1 Connection and phase displacement symbols for three-phase transformers and for single phase transformers connected in a three phase bank

7.1.1 Connection symbol

The star, delta, or zigzag connection of a set of phase windings of a three-phase transformer or of windings of the same voltage of single-phase transformers associated in a three-phase bank shall be indicated by the capital letters Y, D or Z for the high-voltage (HV) winding and small letters y, d or z for the intermediate and low-voltage (LV) windings.

If the neutral point of a star-connected or zigzag-connected winding is brought out, the indication shall be YN (yn) or ZN (zn) respectively. This also applies to transformers where the neutral end connections for each phase winding is brought out separately but are connected together to form a neutral point for service.

For an auto-connected pair of windings, the symbol of the lower voltage winding is replaced by the letter a.

Open windings in a three-phase transformer (that are not connected together in the transformer but have both ends of each phase winding brought out to terminals, for example the line windings of series and phase-shifting transformers) are indicated as III (HV), or iii (intermediate or low-voltage windings).

Letter symbols for the different windings of a transformer are noted in descending order of rated voltage independently of the intended power flow. The winding connection letter for any intermediate and low-voltage winding is immediately followed by its phase displacement 'clock number' (see 3.10.6).

Examples of connections in general use, with connection diagrams, are shown in Annex D.

7.1.2 Phase displacement in clock number notation

The following conventions of notation apply.

The connection diagrams show the high-voltage winding above, and the low-voltage winding below. (The directions of induced voltages are on the upper part of the windings as indicated in Figure 2.)

The high-voltage winding phasor diagram is oriented with phase I pointing at 12 o'clock. The phase I phasor of the low-voltage winding is oriented according to the induced voltage relation which results for the connection shown. The clock number symbol is the hour on which the low voltage points.

The sense of rotation of the phasor diagrams is counter-clockwise, giving the sequence I – II – III.

NOTE This numbering is arbitrary. Terminal marking on the transformer follows national practice. Guidance may be found in IEC/TR 60616.

Open windings do not have a clock number notation because the phase relationship of these windings with other windings depends on the external connection.

7.1.3 Windings not intended to be loaded

The existence of a stabilizing or a test winding (a delta or star-connected winding which is not terminated for external three-phase loading) is indicated, after the symbols of loadable windings, with the symbol '+d' or '+y ' according to its connection as in the examples below:

Symbol: YNa0+d. or YNa0+y.

7.1.4 Reconnectable windings

If a transformer is specified with a reconfigurable winding connection, the alternative coupling voltage and connection is noted in brackets after the delivered configuration as indicated by the following examples:

If HV can be 220 kV or 110 kV (dual voltage) but star-connection is required for both voltages and the transformer is delivered in 220 kV configuration and LV is 10,5 kV delta connected:

Symbol: YNd11 220 (110) / 10,5 kV

If LV can be 11 kV in star and 6,35 kV in delta and the transformer is delivered in 11 kV star configuration and HV is 110 kV star connected:

Symbol: YNy0 (d11) 110 / 11 (6,35) kV

If the LV vector group is reconfigurable without changing the rated voltages (11 kV in this example) and the transformer is delivered in d11 and the HV is 110 kV star connected:

Symbol: YNd11 (d1) 110 / 11 kV

7.1.5 Examples

Examples are shown below and their graphical representations are shown in Figures 2 and 3.

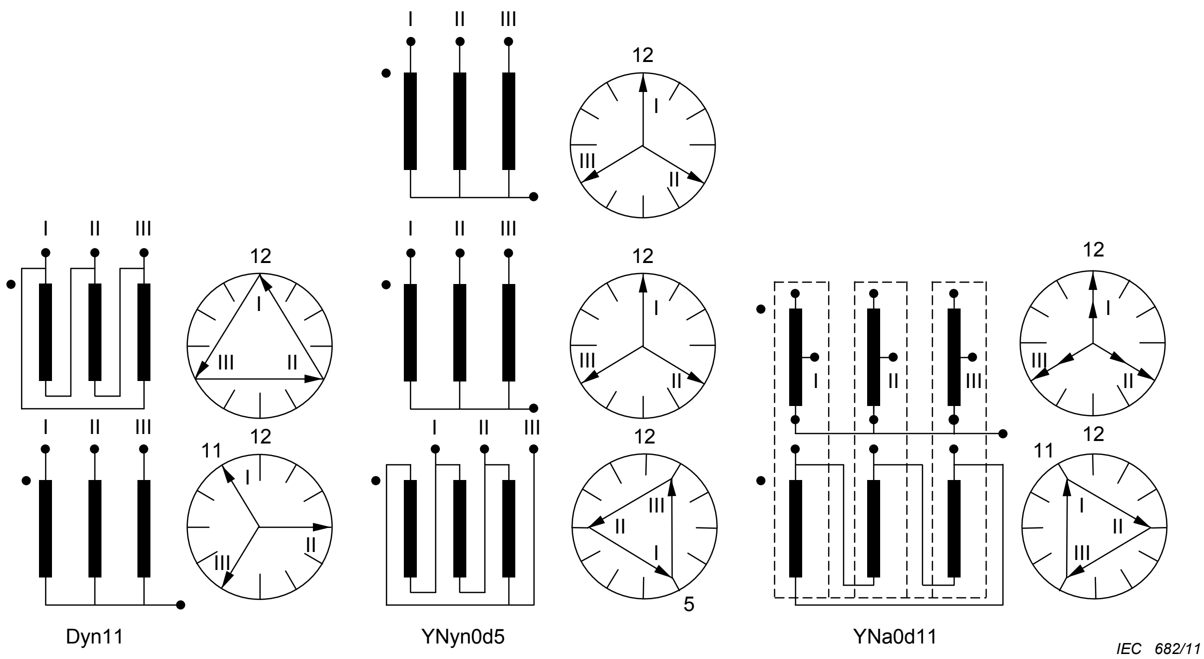


Figure 2 – Illustration of 'clock number' notation

– A transformer with the high-voltage winding rated 20 kV, delta-connected, the low-voltage winding rated 400 V star-connected with neutral brought out. The LV winding lags the HV by 330°.

Symbol: Dyn11 20 000 / 400 V

– A three-winding transformer with the high-voltage winding rated 123 kV, star connected with neutral brought out. An intermediate-voltage winding of 36 kV, star connected with neutral brought out, in phase with the high-voltage winding but not auto-connected, and a 7,2 kV delta-connected third winding, lagging by 150°.

Symbol: YNyn0d5 123 / 36 / 7,2 kV

– A group of three single-phase auto-transformers designed for a 400 kV HV and a 130 kV intermediate voltage with 22 kV tertiary windings. The auto-connected windings are connected in star, while the tertiary windings are connected in delta. The delta winding lags the high-voltage winding by 330°.

Symbol: YNa0d11 $\frac{400}{\sqrt{3}} \Big/ \frac{130}{\sqrt{3}} \; /22\,\text{kV}$

If the delta winding is not brought out to three line terminals but only provided as a stabilizing winding, the symbol would indicate this by a plus sign. No phase displacement notation would then apply for the stabilizing winding.

Symbol: YNa0+d $\frac{400}{\sqrt{3}} \Big/ \frac{130}{\sqrt{3}} \; /22\,\text{kV}$

The symbol would be the same for a three-phase auto-transformer with the same connection, internally with the exception of the voltage notation. See example below.

– A three-phase autotransformer designed for a 400 kV HV and a 130 kV intermediate voltage with 22 kV tertiary windings. The auto-connected windings are connected in star, while the tertiary windings are connected in delta. The delta winding lags the high-voltage winding by 330°.

Symbol: YNa0d11 400 / 130 / 22 kV

– If the delta winding is not brought out to three line terminals but only provided as a stabilizing winding, the symbol would indicate this by a plus sign. No phase displacement notation would then apply for the stabilizing winding.

Symbol: YNa0+d 400 / 130 / 22 kV

– A three-phase generator step up transformer designed for a 20 kV network and an 8,4 kV generator side. The windings connected to the generator are connected in delta, while the network side windings are connected in star. The delta winding lags the high-voltage winding by 330°.

Symbol: YNd11 20 / 8,4 kV

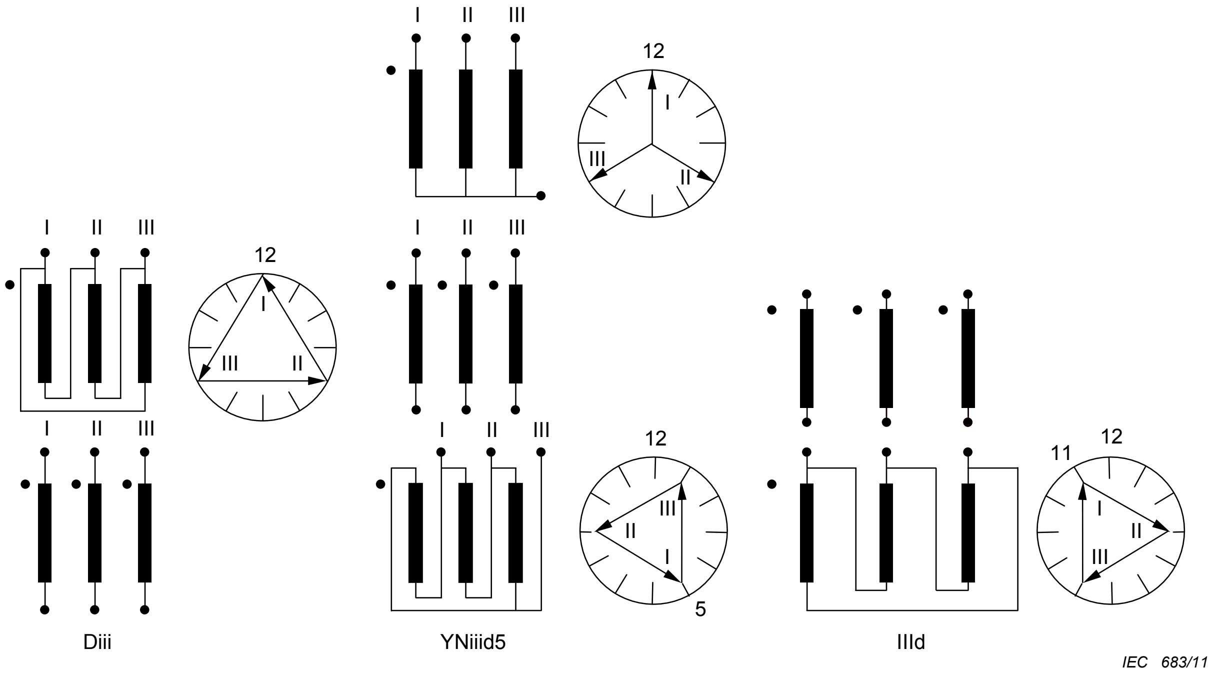


Figure 3 – Illustration of 'clock number' notation for transformers with open windings

– A three-phase transformer designed for a 20 kV delta connected HV and with a 10 kV open winding.

Symbol: Diii 20 / 10 kV

– A three-phase three winding transformer designed for a 220 kV star connected HV with a 40 kV open winding and a 10 kV third winding delta connected.

Symbol: YNiiid5 220 / 40 / 10 kV

– A three-phase series transformer designed for a 400 kV network and with a 40 kV excitation winding delta connected.

Symbol: IIId 400 / 40 kV

7.2 Connection and phase displacement symbols for single phase transformers not in three phase bank

7.2.1 Connection symbol

The connection of a set of phase windings of single-phase transformers is indicated by the capital letter I for the high-voltage (HV) winding and small letter i for the intermediate and low-voltage (LV) windings.

Letter symbols for the different windings of a transformer are noted in descending order of rated voltage independently of the intended power flow. The winding connection letter for any intermediate and low-voltage winding is immediately followed by its phase displacement 'clock number' (see definition 3.10.6).

For an auto-connected pair of windings, the symbol of the lower voltage winding is replaced by the letter a.

7.2.2 Phase displacement in clock number notation

The clock number of single-phase transformers is determined as for three phase transformers but can only be 0 if both windings are in phase or 6 if they are in opposition.

7.2.3 Windings not intended to be loaded

The existence of a test or additional winding, which is not terminated for external loading, is indicated, after the symbols of loadable windings, with the symbol '+i' as in the example below

Symbol: Ii0+i.

7.2.4 Reconnectable windings

If a transformer is specified with a reconfigurable winding connection, the alternative coupling voltage and connection is noted in brackets after the delivered configuration as indicated by the following examples

– If HV can be 220 kV or 110 kV (dual voltage) but with the same connection required for both voltages

  Symbol: Ii0 220 (110) / 27,5 kV

– If LV can be 11 kV in 0 and 5,5 kV in 6 and the transformer is delivered in 11 kV 0 configuration and HV is 110 kV:

  Symbol: Ii0 (i6) 110 / 11 (5,5) kV

– If the LV vector group is reconfigurable without changing the rated voltages (11 kV in this example) and the transformer is delivered in i0 and the HV is 110 kV:

  Symbol: Ii0 (i6) 110 / 11 kV

Examples

Examples are shown below and some of their graphical representations are on Figure 4.

The same convention as in Figure 2 applies.

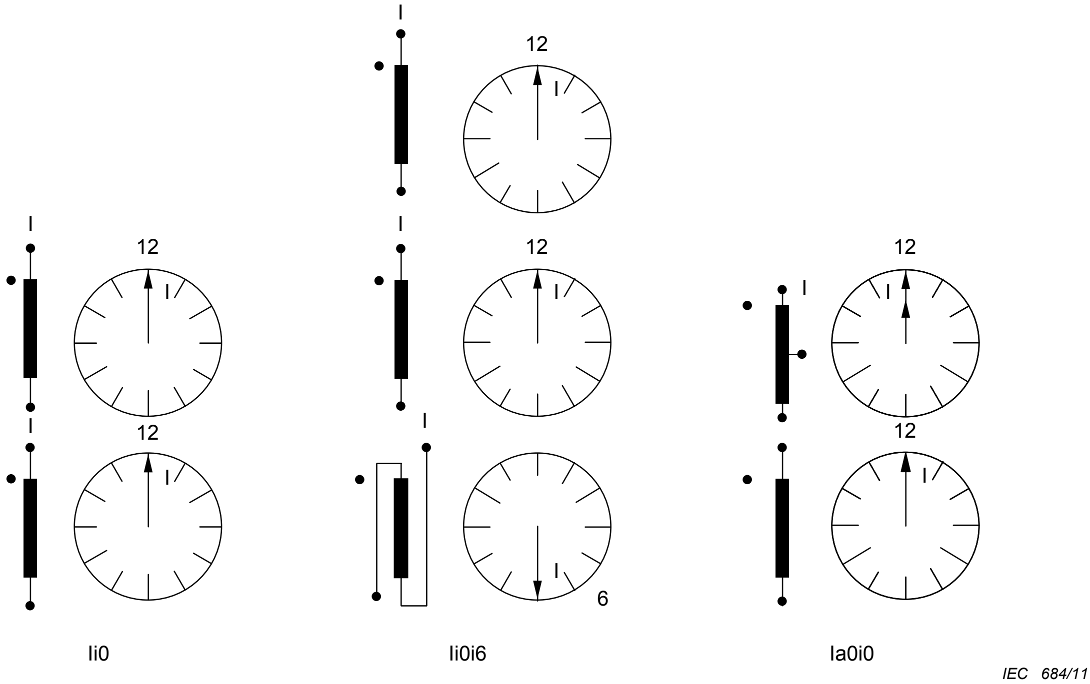


Figure 4 – Illustration of 'clock number' notation

– A transformer with the high-voltage winding rated 20 kV, the low-voltage winding rated 400 V, the LV winding being in phase with the high voltage.

Symbol: Ii0 20 000 / 400 V

– A three-winding transformer: with a 123 kV HV, an intermediate voltage winding of 36 kV, in phase with the HV winding but not auto-connected, and a 7,2 kV third winding, lagging by 180°.

Symbol: Ii0i6 123 / 36 / 7,2 kV

– A single-phase autotransformer designed for a 400 kV HV and a 130 kV intermediate voltage with 22 kV tertiary windings all in phase

Symbol: Ia0i0 400 / 130 / 22 kV

If the third winding is not intended to be loaded, the symbol would indicate this by a plus sign. No phase displacement notation would then apply for the third winding.

Symbol: Ii0+i 400 / 130 / 22 kV

8 Rating plates

8.1 General

The transformer shall be provided with a rating plate of weatherproof material, fitted in a visible position, showing the appropriate items indicated below. The entries on the plate shall be indelibly marked.

8.2 Information to be given in all cases

a) Kind of transformer (for example transformer, auto-transformer, series transformer, etc.).

b) Number of this standard.
c) Manufacturer's name, country and town where the transformer was assembled.
d) Manufacturer's serial number.
e) Year of manufacture.
f) Number of phases.
g) Rated power (in kVA or MVA). (For multi-winding transformers, the rated power of each winding shall be given. The loading combinations shall also be indicated unless the rated power of one of the windings is the sum of the rated powers of the other windings.)
h) Rated frequency (in Hz).
i) Rated voltages (in V or kV) and tapping range.
j) Rated currents (in A or kA).
k) Connection and phase displacement symbol.
l) Short-circuit impedance, measured value in percentage. For multi-winding transformers, several impedances for different two-winding combinations are to be given with the respective reference power values. For transformers having a tapped winding, see also 6.5 and item b) of 8.3.
m) Type of cooling. (If the transformer has several assigned cooling methods, the respective power values may be expressed as percentages of rated power, for example ONAN/ONAF 70/100 %.)
n) Total mass.
o) Mass and type of insulating liquid with reference to the relevant IEC standard.
p) Maximum system short-circuit power or current used to determine the transformer withstand capability if not infinite.

If the transformer has more than one set of ratings, depending upon different connections of windings which have been specifically allowed for in the design, the additional ratings shall all be given on the rating plate, or separate rating plates shall be fitted for each set.

8.3 Additional information to be given when applicable

The information listed below shall be included on the rating plate when it is applicable to a particular transformer.

a) For transformers having one or more windings with 'highest voltage for equipment' U_m equal to or above 3,6 kV:
   – short notation of insulation levels (withstand voltages) as described in IEC 60076-3.
b) Tapping designations
   – For transformers with highest rated voltage less than or equal to 72,5 kV and with rated power less than or equal to 20 MVA (three phase) or 6,7 MVA (single phase) having a tapping range not exceeding ±5 %, tapping voltages on the tapped winding for all tappings.
   – For all other transformers
      • a table stating tapping voltage and maximum allowable tapping service voltage, tapping current, tapping power, and internal connection for all tappings,
      • a table showing the short-circuit impedance values for the principal tapping and at least the extreme tappings in % with the reference power.
c) Guaranteed maximum temperature rises of top liquid and windings (if not normal values).

   When a transformer is intended for installation at high altitude, the altitude, power rating and temperature rise at that altitude shall be indicated on the nameplate together with one of the following:

– If the transformer is designed for installation at high altitude, the (reduced) temperature rise for rated power under normal external cooling medium temperature conditions.

– If the transformer is designed for normal external cooling medium temperature conditions, the rated power for guaranteed temperature rise under normal external cooling medium temperature conditions.

d) Connection diagram (in cases where the connection symbol will not give complete information regarding the internal connections). If the connections can be changed inside the transformer, this shall be indicated either on the same plate, a separate plate or with duplicate or reversible rating plates. The connection fitted at delivery shall be indicated. Where non-linear resistors or fuses are employed within the transformer, the location and connection of such equipment shall be shown on the connection diagram plate with terminal markings. An indication of any built-in current transformers when used shall be presented on the diagram.

e) Transportation mass (if different from total mass).

f) Untanking mass (for transformers exceeding 5 t total mass).

g) Vacuum withstand capability of the tank, conservator, tap-changers and cooling equipment.

h) For multi-winding transformers, any restriction on power-loading combinations.

i) For transformers equipped with winding temperature indicators (WTI), the settings for each WTI. This is normally the difference between the winding hot-spot temperature at rated power and the top liquid temperature calculated from temperature rise test results. If more than one cooling method is specified, different settings may be required for each cooling method.

j) For all current transformers installed inside the transformer, the location, ratio(s), accuracy class and rated output (VA rating) of the current transformer.

k) Minimum temperature of cooling medium if not –5 °C for indoor transformers or –25 °C for outdoor transformers

Plates with identification and characteristics of auxiliary equipment according to standards for such components (bushings, tap-changers, current transformers, special cooling equipment) shall be provided either on the components themselves or on the transformer.

9 Safety, environmental and other requirements

9.1 Safety and environmental requirements

9.1.1 Liquid leaks

Transformer manufacturers shall consider the effective containment of the liquid of the transformer and take effective measures to prevent leakage. Consideration shall be given to the long term performance of items such as:

– joint design;
– gasket materials;
– welds;
– corrosion prevention.

Transformers shall be designed to be leak free and any leakage found on site at the end of commissioning shall be corrected by the responsible supplier.

9.1.2 Safety considerations

The manufacturer shall consider the safety of operators and maintenance staff in the design of the transformer in particular the following aspects:

- accessibility to parts with high temperatures;
- accessibility of live parts;
- accessibility of moving parts;
- lifting and handling provisions;
- access for maintenance, where maintenance is required;
- working at height.

Where installation may affect any of the above, suitable installation instructions shall be provided with the transformer.

NOTE ISO 14122 series, *Safety of machinery – Permanent means of access to machinery*, should be consulted where ladders, platforms and similar means of access are provided with the transformer.

9.2 Dimensioning of neutral connection

The neutral conductor and terminal of transformers intended to carry a load between phase and neutral (for example, distribution transformers) shall be rated for the appropriate load current and earth-fault current (see IEC 60076-8).

The neutral conductor and terminal of transformers not intended to carry load between phase and neutral shall be designed to carry earth-fault current as if the transformer was directly earthed.

9.3 Liquid preservation system

For liquid-immersed transformers, the type of liquid preservation system may be specified in the enquiry and order. If not specified, the manufacturer shall indicate the liquid preservation system in the tender. The following types are distinguished:

- Freely breathing system or conservator system where there is free communication between the ambient air and an air-filled expansion space above the surface of the liquid, in the tank or in a separate expansion vessel (conservator). A moisture-removing breather is fitted in the connection to the atmosphere.
- Diaphragm or bladder-type liquid preservation system where an expansion volume of air at atmospheric pressure is provided above the liquid but prevented from direct contact with the liquid by a flexible diaphragm or bladder. A moisture-removing breather is fitted in the connection to the atmosphere.
- Inert gas pressure system where an expansion space above the liquid is filled with dry inert gas at slight over-pressure, being connected to either a pressure controlled source or an elastic bladder.
- Sealed-tank system with gas cushion, in which a volume of gas above the liquid surface in a stiff tank accommodates the liquid expansion under variable pressure.
- Sealed, completely filled system in which the expansion of the liquid is taken up by elastic movement of the permanently sealed, usually corrugated tank or radiators.

The size of the conservator or expansion system shall be sufficient to accommodate the change in liquid volume from the coldest ambient when the transformer is de-energized to the highest mean liquid temperature experienced when the transformer is loaded to the highest level allowed by the provisions of the loading guide in IEC 60076-7 for mineral oil or as specified for an alternative cooling liquid.

NOTE Allowance should be made for the variation of the coefficient of thermal expansion that may be experienced for different liquids of the same type.

9.4 DC currents in neutral circuits

A transformer with a grounded neutral can be influenced by DC currents flowing through the neutral. For example, the DC current can be generated by:

– DC traction systems;
– cathodic protection systems;
– rectifier systems;
– geomagnetically induced currents (GIC).

When a transformer is subjected to DC currents in the neutral, a DC magnetization bias of the magnetic circuit will result. The magnetizing current becomes strongly asymmetrical and will have a high harmonic content. The possible consequences are:

– an increase of sound level;
– relay malfunction and false tripping;
– stray flux overheating;
– significant increase in magnetizing current;
– increase in no-load losses.

The phenomenon depends on the ability of the DC current to magnetize the core and on the core design. The resulting effects are a function of the magnitude and duration of the DC current, core type and general transformer design features.

If a transformer may be subject to DC currents, then the levels of these currents shall be stated by the purchaser in the enquiry together with any required limits on the consequences of these current levels. See also 4.11 of IEC 60076-8:1997.

9.5 Centre of gravity marking

The centre of gravity of the transformer in the transport configuration shall be permanently marked on at least two adjacent sides of the transformer for transformers with a transport mass in excess of 5 tonnes.

10 Tolerances

It is not always possible, particularly in large, multi-winding transformers with relatively low rated voltages, to accommodate turns ratios which correspond to specified rated voltage ratios with high accuracy. There are also other quantities which may not be accurately explored at the time of tender, or are subject to manufacturing and measuring uncertainty.

Therefore tolerances are necessary on certain specified and design values.

A transformer is considered as complying with this part when the quantities subject to tolerances are not outside the tolerances given in Table 1. Where a tolerance in one direction is omitted, there is no restriction on the value in that direction.

This clause is for the purposes of acceptance or rejection only and does not replace the purchasers' prescribed guarantees for economic evaluation purposes (for example penalties on losses). It does not take precedence over any limits specified in the enquiry.

Table 1 – Tolerances

Item	Tolerance
1. a) Total losses See Note 1 b) Measured component losses See Note 1	+10 % of the total losses +15 % of each component loss, provided that the tolerance for total losses is not exceeded
2. Measured voltage ratio at no load on principal tapping for a specified first pair of windings or the extreme tappings, if specified	The lower of the following values: a) ±0,5 % of the specified ratio b) ±1/10 of the actual percentage impedance on the principal tapping
Measured voltage ratio on other tappings, same pair	±0,5 % of the design value of turns ratio
Measured voltage ratio for further pairs	±0,5 % of the design value of turns ratio
3. Measured short-circuit impedance for: – a separate-winding transformer with two windings, or – a specified first pair of separate windings in a multi-winding transformer	
a) principal tapping	When the impedance value is ≥10 % ±7,5 % of the specified value When the impedance value is <10 % ±10 % of the specified value
b) any other tapping of the pair	When the impedance value is ≥10 % ±10 % of the specified value When the impedance value is <10 % ±15 % of the specified value
4. Measured short-circuit impedance for: – an auto-connected pair of winding, or – a specified second pair of separate windings in a multi-winding transformer	
a) principal tapping	±10 % of the specified value
b) any other tapping of the pair	±10 % of the design value for that tapping
– further pairs of windings	To be agreed, but ≥±15 %
5. Measured no-load current	+30 % of the design value

NOTE 1 The loss tolerances of multi-winding transformers apply to every pair of windings unless the guarantee states that they apply to a given load condition.

NOTE 2 For certain auto-transformers and series transformers the low value of their impedance may justify a more liberal tolerance. Transformers having large tapping ranges, particularly if the range is asymmetrical, may also require special consideration. On the other hand, for example, when a transformer is to be combined with previously existing units, it may be justified to specify and agree on narrower impedance tolerances. Any special tolerances should be indicated in the enquiry, and any revised tolerances agreed upon between manufacturer and purchaser.

11 Tests

11.1 General requirements for routine, type and special tests

11.1.1 General

Transformers shall be subjected to tests as specified below.

Tests other than temperature rise tests shall be made at an external cooling medium temperature between 10 °C and 40 °C. See IEC 60076-2 for temperature rise tests.

Tests shall be made at the manufacturer's works, unless otherwise agreed between the manufacturer and the purchaser.

All external components and fittings that are likely to affect the performance of the transformer during the test shall be in place.

If the transformer cannot be mounted in its intended operating condition for testing (for example if the transformer is fitted with test-turrets and test-bushings or the arrangement of cooling equipment cannot be mounted in the in-service position, during the relevant factory test), an agreement shall be found between manufacturer and purchaser before the commencement of tests. If there are any limitations known at the tender stage, these shall be made clear by the manufacturer.

If a transformer is intended for delivery with liquid/SF_6 bushings, by agreement between manufacturer and purchaser the test can be conducted with equivalent liquid/air bushings instead provided that the liquid-immersed end of the test bushing is identical to the service bushing and the service bushing is tested to at least the same level as the transformer.

Tapped windings shall be connected on their principal tapping, unless the relevant test clause requires otherwise or unless the manufacturer and the purchaser agree otherwise.

The test basis for all characteristics other than insulation is the rated condition, unless the test clause states otherwise.

All measuring systems used for the tests shall have certified, traceable accuracy and be subjected to periodic calibration, according to the rules given in ISO 9001.

Specific requirements on the accuracy and verification of the measuring systems are described in IEC 60060 series and IEC 60076-8.

Where it is required that test results are to be corrected to a reference temperature, this shall be:

a) for dry-type transformers, the reference temperature shall be according to the general requirements for tests in IEC 60076-11;
b) for liquid-immersed transformers with rated average winding temperature rise less than or equal to 65 K for OF or ON, or 70 K for OD;
    1) reference temperature is 75 °C;
    2) on request by the customer, reference temperature is rated average winding temperature rise + 20 °C, or rated average winding temperature rise + yearly external cooling medium average temperature, whichever is higher;
c) for liquid-immersed transformers with other rated average winding temperature rise, the reference temperature is equal to rated average winding temperature rise + 20 °C, or rated average winding temperature rise + yearly external cooling medium average temperature, whichever is higher.

If a purchaser needs to make a comparison between the losses of transformers in category b) with transformers in categories a) and c) (with different insulation systems and with different average winding temperature rises) it is necessary for the reference temperature to be determined according to b)2 above. If the purchaser wishes to make such a comparison, he shall state this in the tender inquiry.

NOTE 1 For existing designs, the conversion between losses at alternative reference temperatures is performed by calculation. It is not intended that any type tests, including the temperature rise test, would need to be repeated solely as a result of changing the reference temperature.

NOTE 2 For yearly average external cooling medium temperatures significantly different than 20 °C, the actual losses experienced in service may be different than the losses derived at the reference temperature. The actual losses experienced in service will depend on both the load and temperature profile.

Liquid-immersed transformers shall be tested with the same type and specification of liquid that they will contain in service.

NOTE 3 The intention is that the transformer is tested with a liquid such that the test results are fully representative of the performance of the transformer in service.

All measurements and tests requiring power frequency supply shall be performed with the supply frequency within 1 % of the rated frequency of the transformer. The waveshape of the supply voltage shall be such that the total harmonic content does not exceed 5 %. If this condition is not satisfied then the effect of the waveshape on the measured parameter shall be evaluated by the manufacturer and subject to approval by the purchaser. Loss measurements should not be corrected downwards to account for harmonics in the supply voltage except as allowed in 11.5. Where a three-phase supply is used, the supply voltage shall be symmetrical. The maximum voltage across each phase winding under test shall not differ from the minimum voltage by more than 3 %.

Any inability of the manufacturer to perform the test or measurement at the rated frequency shall be stated by the manufacturer at the tender stage and appropriate conversion factors agreed.

The following list of tests is not in any specific order. If the purchaser requires the tests performed in a particular order, this shall be included in the enquiry.

11.1.2 Routine tests

11.1.2.1 Routine test for all transformers

a) Measurement of winding resistance (11.2).

b) Measurement of voltage ratio and check of phase displacement (11.3).

c) Measurement of short-circuit impedance and load loss (11.4).

d) Measurement of no-load loss and current (11.5).

e) Dielectric routine tests (IEC 60076-3).

f) Tests on on-load tap-changers, where appropriate (11.7).

g) Leak testing with pressure for liquid-immersed transformers (tightness test) (11.8).

h) Tightness tests and pressure tests for tanks for gas-filled transformers (refer to 60076-15).

i) Check of the ratio and polarity of built-in current transformers.

j) Check of core and frame insulation for liquid immersed transformers with core or frame insulation (11.12).

11.1.2.2 Additional routine tests for transformers with U_m > 72,5 kV

a) Determination of capacitances windings-to-earth and between windings.

b) Measurement of d.c. insulation resistance between each winding to earth and between windings.

c) Measurement of dissipation factor (tan δ) of the insulation system capacitances.

d) Measurement of dissolved gasses in dielectric liquid from each separate oil compartment except diverter switch compartment.

e) Measurement of no-load loss and current at 90 % and 110 % of rated voltage (11.5).

11.1.3 Type tests

a) Temperature-rise type test (IEC 60076-2).

b) Dielectric type tests (IEC 60076-3).

c) Determination of sound level (IEC 60076-10) for each method of cooling for which a guaranteed sound level is specified.

d) Measurement of the power taken by the fan and liquid pump motors.

e) Measurement of no-load loss and current at 90 % and 110 % of rated voltage.

11.1.4 Special tests

a) Dielectric special tests (IEC 60076-3).
b) Winding hot-spot temperature-rise measurements.
c) Determination of capacitances windings-to-earth, and between windings.
d) Measurement of dissipation factor (tan δ) of the insulation system capacitances.
e) Determination of transient voltage transfer characteristics (Annex B of IEC 60076-3:2000).
f) Measurement of zero-sequence impedance(s) on three-phase transformers (11.6).
g) Short-circuit withstand test (IEC 60076-5).
h) Measurement of d.c. insulation resistance each winding to earth and between windings.
i) Vacuum deflection test on liquid immersed transformers (11.9).
j) Pressure deflection test on liquid immersed transformers (11.10).
k) Vacuum tightness test on site on liquid immersed transformers (11.11).
l) Measurement of frequency response (Frequency Response Analysis or FRA). The test procedure shall be agreed between manufacturer and purchaser.
m) Check of external coating (ISO 2178 and ISO 2409 or as specified).
n) Measurement of dissolved gasses in dielectric liquid.
o) Mechanical test or assessment of tank for suitability for transport (to customer specification).
p) Determination of weight with transformer arranged for transport. For transformers up to 1,6 MVA by measurement. For larger transformers by measurement or calculation as agreed between manufacturer and purchaser.

Other tests for transformers may be defined in the specific documents for specialized transformers such as dry-type, self-protected and other groups.

If test methods are not prescribed in this standard, or if tests other than those listed above are specified in the contract, such test methods are subject to agreement.

11.2 Measurement of winding resistance

11.2.1 General

The resistance of each winding, the terminals between which it is measured and the temperature of the windings shall be recorded. Direct current shall be used for the measurement.

In all resistance measurements, care shall be taken that the effects of self-induction are minimized.

11.2.2 Dry-type transformers

Before measurement the external cooling medium temperature shall not have changed by more than 3 °C for at least 3 h and all winding temperatures of the transformer measured by the internal temperature sensors shall not differ from the external cooling medium temperature by more than 2 °C.

Winding resistance and winding temperature shall be measured at the same time. The winding temperature shall be measured by sensors placed at representative positions, preferably inside the set of windings, for example, in a duct between the high-voltage and low-voltage windings.

11.2.3 Liquid-immersed type transformers

After the transformer has been under liquid without excitation for at least 3 h, the average liquid temperature shall be determined and the temperature of the winding shall be deemed to be the same as the average liquid temperature. The average liquid temperature is taken as the mean of the top and bottom liquid temperatures.

In measuring the cold resistance for the purpose of temperature-rise determination, special efforts shall be made to determine the average winding temperature accurately. Thus, the difference in temperature between the top and bottom liquid shall not exceed 5 K. To obtain this result more rapidly, the liquid may be circulated by a pump.

11.3 Measurement of voltage ratio and check of phase displacement

The voltage ratio shall be measured on each tapping. The polarity of single-phase transformers and the connection symbol of three-phase transformers shall be checked. If a voltage measurement is used, the voltages of both windings shall be measured simultaneously.

11.4 Measurement of short-circuit impedance and load loss

The short-circuit impedance and load loss for a pair of windings shall be measured at rated frequency with voltage applied to the terminals of one winding, with the terminals of the other winding short-circuited, and with possible other windings open-circuited. (For selection of tapping for the test, see 6.5 and 6.6). The supplied current should be equal to the relevant rated current (tapping current) but shall not be less than 50 % thereof. The measurements shall be performed quickly so that temperature rises do not cause significant errors. The difference in temperature between the top liquid and the bottom liquid shall be small enough to enable the mean temperature to be determined accurately. The difference in temperature between the top and bottom liquid shall not exceed 5 K. To obtain this result more rapidly, the liquid may be circulated by a pump.

The measured value of load loss shall be multiplied with the square of the ratio of rated current (tapping current) to test current. The resulting figure shall then be corrected to reference temperature (11.1). The I^2R loss (R being d.c. resistance) is taken as varying directly with the temperature and all other losses inversely with the temperature. The measurement of winding resistance shall be made according to 11.2. The temperature correction procedure is detailed in Annex E.

The short-circuit impedance is represented as reactance and a.c. resistance in series. The impedance is corrected to reference temperature assuming that the reactance is constant and that the a.c. resistance derived from the load loss varies as described above.

On transformers having a tapped winding with tapping range not exceeding ±5 %, the short-circuit impedance shall be measured on the principal tapping.

For transformers with tappings exceeding a voltage variation of 5 % from the principal tapping, impedance values shall be measured for the principal tapping and the extreme tapping(s) exceeding 5 %. Measurements at other tap positions may be specified in the enquiry.

If the tapping range is asymmetrical, if specified by the purchaser, measurements shall also be made on the middle tapping.

On a three-winding transformer, measurements are performed on the three different two-winding combinations. The results are re-calculated, allocating impedances and losses to individual windings (see IEC 60076-8). Total losses for specified loading cases involving all these windings are determined accordingly.

NOTE 1 For transformers with two secondary windings having the same rated power and rated voltage and equal impedance to the primary (sometimes referred to as 'dual-secondary transformers'), it may be agreed that the symmetrical loading case is investigated by an extra test with both secondary windings short-circuited simultaneously.

NOTE 2 The measurement of load loss on a large transformer requires considerable care and good measuring equipment because of the low power factor and the often large test currents. Any errors and external circuit losses should be minimized. Correction for measuring transformer errors and for resistance of the test connections should be applied unless they are obviously negligible (see IEC 60076-8).

11.5 Measurement of no-load loss and current

The no-load loss and the no-load current shall be measured on one of the windings at rated frequency and at a voltage corresponding to rated voltage if the test is performed on the principal tapping, or to the appropriate tapping voltage if the test is performed on another tapping. The remaining winding or windings shall be left open-circuited and any windings which can be connected in open delta shall have the delta closed. Where indicated in 11.1.2 and 11.1.3, the measurement shall also be made at 90 % and 110 % of rated voltage (or appropriate tapping voltage).

The transformer shall be approximately at factory ambient temperature.

For a three-phase transformer, the selection of the winding and the connection to the test power source shall be made to provide, as far as possible, symmetrical and sinusoidal voltages across the three phases.

The test voltage shall be adjusted according to a voltmeter responsive to the mean value of voltage but scaled to read the r.m.s. voltage of a sinusoidal wave having the same mean value. The reading of this voltmeter is U'.

At the same time, a voltmeter responsive to the r.m.s. value of voltage shall be connected in parallel with the mean-value voltmeter and its indicated voltage U shall be recorded.

When a three-phase transformer is tested, the voltages shall be measured between line terminals, if a delta-connected winding is energized, and between phase and neutral terminals if a YN or ZN connected winding is energized.

Phase to phase voltages may be derived from phase to ground measurements, but phase to neutral voltages shall not be derived from phase to phase measurements.

The test voltage wave shape is satisfactory if the readings U' and U are equal within 3 %. If the difference between voltmeter readings is larger than 3 %, the validity of the test is subject to agreement. A larger difference may be acceptable at higher than rated voltage unless this measurement is subject to guarantee.

NOTE 1 It is recognized that the most severe loading conditions for test voltage source accuracy are usually imposed by large single-phase transformers.

The measured no-load loss is P_m, and the corrected no load loss is taken as:

$$P_o = P_m (1 + d)$$

$$d = \frac{U' - U}{U'} \text{ (usually negative)}$$

The r.m.s. value of no-load current is measured at the same time as the loss. For a three-phase transformer, the mean value of readings in the three phases is taken.

The no load losses shall not be corrected for any effect of temperature.

NOTE 2 In deciding the place of the no-load test in the complete test sequence, it should be borne in mind that no-load loss measurements performed before impulse tests and/or resistance measurements are, in general, representative of the average loss level over long time in service, assuming, that the core is not pre-magnetized. That means, if no-load tests are carried out after resistance measurements and/or lightning impulse tests, the core of the transformer should be demagnetized by overexcitation before the no-load test is carried out.

11.6 Measurement of zero-sequence impedance(s) on three-phase transformers

The zero-sequence impedance is measured at rated frequency between the line terminals of a star-connected or zigzag-connected winding connected together, and its neutral terminal. It is expressed in ohms per phase and is given by $\frac{3U}{I}$, where U is the test voltage and I is the test current.

The test current per phase $\frac{I}{3}$ shall be stated in the test report.

It shall be ensured that the current in the neutral connection is compatible with its current-carrying capability.

In the case of a transformer with an additional delta-connected winding, the value of the test current shall be such that the current in the delta-connected winding is not excessive, taking into account the duration of application.

If winding balancing ampere-turns are missing in the zero-sequence system, for example, in a star-star-connected transformer without delta winding, the applied voltage shall not exceed the phase-to-neutral voltage at normal operation. The current in the neutral and the duration of application should be limited to avoid excessive temperatures of metallic constructional parts.

In the case of transformers having more than one star-connected winding with neutral terminal, the zero-sequence impedance is dependent upon the connection (see 3.7.3) and the tests to be made shall be subject to agreement between the manufacturer and the purchaser.

For autotransformers and YY transformers, there are several combinations of tests to perform:

– HV with LV open circuit;
– HV with LV short circuit;
– LV with HV open circuit;
– LV with HV short circuit.

For YD transformers, the zero sequence impedance is measured from the Y side only.

Auto-transformers with a neutral terminal intended to be permanently connected to earth shall be treated as normal transformers with two star-connected windings. Thereby, the series winding and the common winding together form one measuring circuit, and the common winding alone forms the other. The measurements are carried out with a current not exceeding the difference between the rated currents on the low-voltage side and the high-voltage side.

NOTE 1 In conditions where winding balancing ampere-turns are missing, the relation between voltage and current is generally not linear. In that case, several measurements at different values of current may give useful information.

NOTE 2 The zero-sequence impedance is dependent upon the physical disposition of the windings and the magnetic parts, measurements on different windings may therefore not agree. In particular, for a transformer with a zigzag winding the zero sequence impedance measured between line terminals connected together and the neutral may result in a different value to that obtained when a three phase symmetrical voltage is applied and one line terminal is connected to the neutral.

NOTE 3 An additional zero-sequence impedance test may be required for transformers with delta windings with two connections to one corner brought out so that it can be either open or closed.

NOTE 4 Further guidance is given in IEC 60076-8.

11.7 Tests on on-load tap-changers – Operation test

With the tap-changer fully assembled on the transformer, the following sequence of operations shall be performed without failure:

a) with the transformer de-energized, eight complete cycles of operation (a cycle of operation goes from one end of the tapping range to the other, and back again).
b) with the transformer de-energized, and with the auxiliary voltage reduced to 85 % of its rated value, one complete cycle of operation.
c) with the transformer energized at rated voltage and frequency at no load, one complete cycle of operation.
d) with one winding short-circuited and, as far as practicable, rated current in the tapped winding, 10 cycles of tap-change operations across the range of two steps on each side from where a coarse or reversing changeover selector operates, or otherwise from the middle tapping (the tapchanger will pass 20 times through the changeover position).

11.8 Leak testing with pressure for liquid immersed transformers (tightness test)

The transformer manufacturer shall perform an agreed test to prove the transformer tank will not leak in service. If there is no agreement, a pressure of at least 30 kPa over the normal liquid pressure shall be applied and maintained for 24 h for transformers greater than 20 MVA or 72,5 kV, and 8 h for transformers of lower rating and voltage. Typically, this is applied either using a liquid column or gas pressure in the conservator. Thereafter, the entire transformer shall be visually inspected for leaks. For tanks that are specifically designed to be flexible for liquid expansion (corrugated), leak and lifetime tests need to be agreed.

11.9 Vacuum deflection test for liquid immersed transformers

This test is applicable to transformers designed to be vacuum filled in their own tanks on site.

Generally, these transformers are transported without liquid.

Where specified the deflection of the tank when vacuum is applied and the permanent deflection of the tank when the vacuum is released shall be measured.

The test shall be carried out on the transformer when it is complete in all relevant respects and on all compartments that require vacuum to be applied on-site.

Before vacuum is applied, a suitable measuring reference point, attached rigidly to the test room structure or floor, independent of the transformer shall be established as close as possible to the point on the tank where the maximum deflection under vacuum is expected. The distance from the reference point to the tank wall in a direction approximately normal to the tank wall shall be measured and noted.

Following the application of the vacuum to the level required for the site operation, the distance from the reference point to the tank wall in a direction approximately normal to the tank wall shall be measured again. The deflection under vacuum is the difference between this measurement and the first measurement.

The vacuum shall then be released and a third measurement of the distance from the reference point to the tank wall in a direction approximately normal to the tank wall shall be taken. The permanent deflection is the difference between this measurement and the first measurement.

Alternative equivalent methods of measurement may be used and additional measurements on the opposite side of the transformer may be required to compensate for tank movement during the test.

Normally the expected deflection under vacuum and the permanent deflection shall be calculated and declared by the manufacturer before the test. Alternatively the following typical values shall be used:

a) medium range transformers between 20 MVA and 100 MVA:
   - permanent deflection after vacuum is released: 1 mm;
b) large power transformers (with plain tank walls), above 100 MVA:
   - permanent deflection after vacuum is released: 5 mm.

If the expected values are exceeded, the test shall be repeated to see if the tank dimensions have stabilized. If not, remedial actions, for example adding additional stiffening to the tank, shall be carried out.

11.10 Pressure deflection test for liquid immersed transformers

Where specified, the deflection of the tank when pressure is applied and the permanent deflection of the tank when the pressure is released shall be measured. For tanks that are specifically designed to be flexible for liquid expansion (corrugated), this test is not applicable.

The test shall be carried out on the transformer when it is complete in all relevant respects and filled with liquid. It shall be carried out on all separate compartments that contain liquid.

Unless otherwise specified, the test pressure in the tank shall be 35 kPa over the normal operating pressure. If the transformer is fitted with pressure relief devices, the pressure, applied during this test shall exceed the pressure required to operate the pressure relief device by at least 10 kPa. Pressure relief devices will therefore need to be blanked off during this test.

NOTE The specified overpressure may conveniently be applied by adjusting the height of a liquid column (for example by lifting a separate conservator attached to a crane).

Before pressure is applied, whilst the tank is at its normal working liquid level, a suitable measuring reference point, attached rigidly to the test room structure or floor, independent of the transformer shall be established as close as possible to the point on the tank where the maximum deflection under pressure is expected, taking into account the expected deflection. The distance from the reference point to the tank wall in a direction approximately normal to the tank wall shall be measured and noted.

Following the application of the additional pressure, the distance from the reference point to the tank wall in a direction approximately normal to the tank wall shall be measured again. The deflection under pressure is the difference between this measurement and the first measurement.

Alternative equivalent methods of measurement may be used and additional measurements on the opposite side of the transformer may be required to compensate for tank movement during the test.

The pressure shall then be reduced back to the originally established level and a third measurement of the distance from the reference point to the tank wall in a direction approximately normal to the tank wall shall be taken. The permanent deflection is the difference between this measurement and the first measurement.

Normally the expected deflection under pressure and the permanent deflection shall be calculated and declared by the manufacturer before the test. Alternatively the following typical values shall be used:

a) medium range transformers between 20 MVA and 100 MVA:
   - permanent deflection after overpressure: 1 mm;
b) large power transformers (with plain tank walls), above 100 MVA:
   - permanent deflection after overpressure: 5 mm.

If the expected values are exceeded, the test shall be repeated to see if the tank dimensions have stabilized. If not, remedial actions, for example adding additional stiffening to the tank, shall be carried out.

11.11 Vacuum tightness test on site for liquid immersed transformers

This test is applicable to transformers designed to be vacuum filled in their own tanks on site and transported without liquid. Following erection on-site but before liquid filling, the ability of a transformer that requires the application of vacuum for filling or other site operations to hold a vacuum without admitting air shall be demonstrated as follows:

A vacuum to the highest level required by the site operation shall be applied for a period of two hours or until a stable vacuum level is obtained. The vacuum pump shall then be stopped and the transformer sealed.

The vacuum inside the transformer shall then be monitored, using a suitable vacuum gauge until a steady rate of change of vacuum is observed. The increase in pressure shall be less than 0,2 kPa per hour measured over a period of at least 30 min.

11.12 Check of core and frame insulation

This test shall be carried out on all liquid immersed transformers which incorporate insulation separating core and frame and/or frame and tank.

For transformers where the core and frame earth connections are not accessible when the transformer is liquid filled, the insulation shall be tested at 500 V d.c. for 1 min without breakdown before the active part is installed in the tank.

For transformers where the core and frame earth connections are accessible when the transformer is liquid filled, the insulation shall be tested at 2 500 V d.c. for 1 min without breakdown after the transformer is filled with liquid.

12 Electromagnetic compatibility (EMC)

Power transformers shall be considered as passive elements in respect to emission of, and immunity to, electromagnetic disturbances.

NOTE 1 Certain accessories may be susceptible to electromagnetic interference.

NOTE 2 Passive elements are not liable to cause electromagnetic disturbances and their performance is not liable to be affected by such disturbances.

13 High frequency switching transients

Switching lightly loaded and/or low power factor (inductively loaded) transformers with vacuum and SF_6 interrupters may subject the transformer to potentially damaging voltage transients with frequencies up to the MHz range and voltages exceeding the transformer impulse withstand. Mitigation measures, while not part of the transformer, might include means to increase damping through resistor-capacitor snubbers, pre-insertion resistors within the switches, or switching under load. If specified by the purchaser, the manufacturer shall provide details of natural resonant frequencies and/or high frequency model parameters of the transformer.

NOTE More information is available in IEEE C57.142 Guide to describe the occurrence and mitigation of switching transients induced by transformer, switching device, and system interaction

Annex A
(informative)

Check list of information to be provided with enquiry and order

A.1 Rating and general data

A.1.1 Normal information

The following information shall be given in all cases:

a) Particulars of the specifications to which the transformer shall comply.
b) Kind of transformer, for example, separate winding transformer, auto-transformer or series transformer.
c) Single or three-phase unit.
d) Number of phases in system.
e) Frequency.
f) Dry-type or liquid-immersed type. If liquid-immersed type, whether mineral oil, natural insulating liquid or synthetic insulating liquid. If dry-type, degree of protection (see IEC 60529).
g) Indoor or outdoor type.
h) Type of cooling.
i) Rated power for each winding and, for tapping range exceeding ±5 %, the specified maximum current tapping, if applicable.

   If the transformer is specified with alternative methods of cooling, the respective lower power values are to be stated together with the rated power (which refers to the most efficient cooling).
j) Rated voltage for each winding.
k) For a transformer with tappings (see 6.4):
   - whether ‘de-energized' or 'on-load' tap-changing is required;
   - any requirements for fixing the ratio of turns between two particular windings on a more than two winding transformer;
   - whether any tapping or range of tappings can be reduced power tappings;
   - the number of tapping steps and the size of the tapping step or the tapping range;

   and either:
      - which winding is tapped;
      - if the tapping range is more than ±5 %, the type of voltage variation, and the location of the maximum current tapping, if applicable;

   or:
      - direction of power flow (can be both directions);
      - which voltage shall vary for the purpose of defining rated tapping voltage;
      - minimum full load power factor.
l) Highest voltage for equipment (U_m) for each winding line and neutral terminals (with respect to insulation, see IEC 60076-3).
m) Method of system earthing (for each winding).
n) Insulation level and dielectric test levels (see IEC 60076-3), for each winding line and neutral terminals.

o) Connection symbol and neutral terminal requirements for each winding.

p) Any peculiarities of installation, assembly, transport and handling. Restrictions on dimensions and mass.

q) Details of auxiliary supply voltage (for fans and pumps, tap-changer, alarms, etc.).

r) Fittings required and an indication of the side from which meters, rating plates, liquid-level indicators, etc., shall be legible.

s) Type of liquid preservation system.

t) For multi-winding transformers, required power-loading combinations, stating, when necessary, the active and reactive outputs separately, especially in the case of multi-winding auto-transformers.

u) Guaranteed maximum temperature rise information.

v) Unusual service conditions (see Clause 4 and 5.5).

w) Details of type and arrangement of terminals, for example air bushings or cable box or gas insulated bus bar.

x) Whether the core and frame connections should be brought out for external earthing.

A.1.2 Special information

The following additional information shall be given if the particular item is required by the purchaser:

a) If a lightning impulse voltage test is required, and whether or not the test is to include chopped waves (see IEC 60076-3).

b) Whether a stabilizing winding is required and, if so, the method of earthing.

c) Short-circuit impedance, or impedance range (see Annex C). For multi-winding transformers, any impedances that are specified for particular pairs of windings (together with relevant reference ratings if percentage values are given).

d) Tolerances on voltage ratios and short-circuit impedances as left to agreement in Table 1, or deviating from values given in the table.

e) If a transformer has alternative winding connections, how they should be changed, and which connection is required ex works.

f) Short-circuit characteristics of the connected systems (expressed as short-circuit power or current, or system impedance data) and possible limitations affecting the transformer design (see IEC 60076-5).

g) Details of sound-level requirements, guarantees, and special measurements (see IEC 60076-10).

h) Vacuum withstand of the transformer tank, conservator, and cooling equipment if a specific value is required.

i) Any special tests not referred to above which are required by the purchaser.

j) Loss evaluation information or maximum losses.

k) Any physical size limitations, for example for installation on an existing foundation or in a building. Special installation space restrictions which may influence the insulation clearances and terminal locations on the transformer.

l) Shipping size and weight limitations. Minimum acceleration withstand values if higher than specified in 5.7.4.2.

m) Transport and storage conditions not covered by normal conditions described in 5.7.4 and 4.2.

n) Any particular maintenance requirements or limitations.

o) Whether a disconnection chamber is required for direct cable connections.

p) Whether facilities for condition monitoring are required (see Annex F).

q) Any particular environmental considerations regarding the impact of the transformer on the environment that shall be taken into account in the transformer design, see Annex G.

r) Any particular health and safety considerations that shall be taken into account in the transformer design regarding manufacture, installation, operation, maintenance and disposal, see Annex G.

s) Unusual electrical operating conditions as follows:

   1) whether a transformer is to be connected to a generator directly or through switchgear, and whether it will be subjected to load rejection conditions and any special load rejection conditions.

   2) whether load current wave shape will be heavily distorted. Whether unbalanced three-phase loading is anticipated. In both cases, details to be given.

   3) whether a transformer is to be connected directly or by a short length of overhead line to gas-insulated switchgear (GIS).

   4) whether transformers will be subjected to frequent overcurrents, for example, furnace transformers and traction feeding transformers.

   5) details of intended regular cyclic overloading other than covered by 5.1.4 (to enable the rating of the transformer auxiliary equipment to be established).

   6) unbalanced a.c. voltages, or departure of a.c. system voltages from a substantially sinusoidal wave form.

   7) loads involving abnormal harmonic currents such as those that may result where appreciable load currents are controlled by solid-state or similar devices. Such harmonic currents can cause excessive losses and abnormal heating.

   8) specified loading conditions (kVA outputs, winding load power factors, and winding voltages) associated with multi-winding transformers and autotransformers.

   9) excitation exceeding either 110 % rated voltage or 110 % rated V / Hz.

   10) planned short circuits as a part of regular operating or relaying practice.

   11) unusual short-circuit application conditions differing from those in IEC 60076-5.

   12) unusual voltage conditions including transient overvoltages, resonance, switching surges, etc. which may require special consideration in insulation design.

   13) unusually strong magnetic fields. It should be noted that solar-magnetic disturbances can result in telluric currents in transformer neutrals.

   14) large transformers with high-current bus bar arrangements. It should be noted that high-current isolated phase bus ducts with accompanying strong magnetic fields may cause unanticipated circulating currents in transformer tanks, covers, and in the bus ducts. The losses resulting from these unanticipated currents may result in excessive temperatures when corrective measures are not included in the design.

   15) parallel operation. It should be noted that while parallel operation is not unusual, it is advisable that users advise the manufacturer when paralleling with other transformers is planned and identify the transformers involved.

   16) regular frequent energisation in excess of 24 times per year.

   17) frequent short circuits.

t) Unusual physical environmental conditions

   1) altitude above sea-level, if in excess of 1 000 m (3 300 ft).

   2) special external cooling medium temperature conditions, outside the normal range (see 4.2 b)), or restrictions to circulation of cooling air.

   3) expected seismic activity at the installation site which requires special consideration.

   4) damaging fumes of vapours, excessive or abrasive dust, explosive mixtures of dust or gasses, steam, salt spray, excessive moisture, or dripping water, etc.

   5) abnormal vibration, tilting, or shock.

A.2 Parallel operation

If parallel operation with existing transformers is required, this shall be stated and the following information on the existing transformers given:

a) Rated power.
b) Rated voltage ratio.
c) Voltage ratios corresponding to tappings other than the principal tapping.
d) Load loss at rated current on the principal tapping, corrected to the appropriate reference temperature, see 11.1.
e) Short-circuit impedance on the principal tapping and on the extreme tappings, if the voltage on the extreme tappings is more than 5 % different to the principal tapping. Impedance on other tappings if available.
f) Diagram of connections, or connection symbol, or both.

NOTE On multi-winding transformers, supplementary information will generally be required.

Annex B
(informative)

Examples of specifications for transformers with tappings

B.1 Example 1 – Constant flux voltage variation

Transformer having a 66 kV/20 kV three-phase 40 MVA rating and a ±10 % tapping range on the 66 kV winding, with 11 tapping positions. Short notation: (66 ± 5 × 2 %) / 20 kV.

category of voltage variation:	CFVV
rated power:	40 MVA
rated voltages:	66 kV/20 kV
tapped winding:	66 kV (tapping range ±10 %)
number of tapping positions:	11

If this transformer shall have reduced power tappings, say, from tapping –6 %, add:

maximum current tapping:	tapping –6 %

The tapping current of the HV winding is then limited to 372 A from the tapping –6 % to the extreme tapping –10 % where tapping power is reduced to 38,3 MVA.

B.2 Example 2 – Variable flux voltage variation

Transformer having a 66 kV/6 kV, three-phase 20 MVA rating and a +15 %, –5 % tapping range on the HV winding, but having a constant tapping voltage for the HV winding and a variable tapping voltage for the LV winding, between:

$$\frac{6}{0{,}95} = 6{,}32 \text{ kV} \quad \text{to} \quad \frac{6}{1{,}15} = 5{,}22 \text{ kV}$$

category of voltage variation:	VFVV
rated power:	20 MVA
rated voltages:	66 kV/6 kV
tapped winding:	66 kV (tapping range +15 %, –5 %)
number of tapping positions:	13
tapping voltages of 6 kV winding:	6,32 kV, 6 kV, 5,22 kV

If this transformer shall have reduced power tappings, add for example:

maximum current tapping:	tapping +5 %

The 'tapping current' of the untapped winding (LV) is then limited to 2 020 A from the tapping +5 % to the extreme tapping +15 % where the tapping power is reduced to 18,3 MVA.

B.3 Example 3 – Combined voltage variation

Transformer having a 160 kV/20 kV three-phase 40 MVA rating and a ±15 % tapping range on the 160 kV winding. The changeover point (maximum voltage tapping), is at +6 %, and there is also a maximum current tapping in the CFVV range at –9 %:

tapped winding: 160 kV, range ± 10 × 1,5 %.

Table B.1 – Example of combined voltage variation

Tappings	**Voltage ratio**	**Tapping voltage**		**Tapping current**		**Tapping power**
		U_{HV} kV	U_{LV} kV	I_{HV} A	I_{LV} A	S MVA
1 (+15 %)	9,20	169,6	18,43	125,6	1 155	36,86
7 (+6 %)	8,48	169,6	20	136,2	1 155	40
11 (0 %)	8	160	20	144,4	1 155	40
17 (–9 %)	7,28	145,6	20	158,7	1 155	40
21 (–15 %)	6,80	136	20	158,7	1 080	37,4

NOTE 1 On completing with data for intermediate tappings, the preceding table can be used on a rating plate.

NOTE 2 Compare this specification and a CFVV specification which would be:

(160 ± 15 %) / 20 kV – 40 MVA

The difference is that the HV tapping voltage, according to the example, does not exceed the 'system highest voltage' of the HV system, which is 170 kV (IEC standardized value). The quantity 'highest voltage for equipment' which characterizes the insulation of the winding, is also 170 kV (see IEC 60076-3).

B.4 Example 4 – Functional specification of tapping

The principle of the functional specification of a transformer with tappings according to 6.4.3 is to provide a framework for the specification of the operational requirements whilst leaving the detailed design of winding and tapping arrangements to the manufacturer.

The three specific requirements that shall be properly defined are:

– the operating voltage;
– the load current capability;
– the impedance.

Unless otherwise specified, the maximum operating voltage is to be taken as being on any tapping and is an upper limit on the voltage on all windings simultaneously, for example a step down transformer with a +15 % LV tapping and a specified maximum operating voltage of +10 % of rated voltage will not be used at no load on that tapping at HV voltages exceeding –5 % of rated voltage, but on load, the tapping may be used at higher HV voltages to compensate for voltage drop in the transformer. Short periods of operation at higher LV voltage may be required under load rejection situations.

The current on the load side is given by the rated power divided by the rated voltage (at the principal tapping). A transformer specified according to 6.4.3 will be capable of supplying this load current at all tapping positions. Alternatively, the load current capability may be specified for each tapping.

Particular care needs to be given to the specification of impedance in percentage terms and the basis in terms of voltage and power shall either be explicit or follow the convention that the impedance for a particular tapping is based on the rated power at principal tapping and the voltage of that particular tapping. For this reason only, the voltage variation shall be given as either on the HV or the LV.

The following are examples of such a specification and the resulting transformer

B.4.1 Example 4.1 – Transformer specified with HV voltage variation

Transformer to be suitable for step down operation

rated power S_r:	70 MVA at principal tapping
rated voltages:	220 kV / 90 kV
maximum operating voltage:	+10 %
number of tapping steps:	26
size of tapping step:	1 %
variation on HV voltage:	+10 % –15 %
impedance:	10 % on all tappings on 70 MVA base
minimum full load power factor:	0,8

Table B.2 – Example of functional specification with HV voltage variation

Tappings	No load voltage ratio	Rated tapping voltage		Max continuous voltage (on load)		Rated tapping current		Tapping power	Short-circuit impedance		SC current available on LV at 220 kV
		U_{HV} kV	U_{LV} kV	HV kV	LV kV	I_{HV} A	I_{LV} A	S_{tap} MVA	Z % [a]	Z_{HV} Ω/ Phase	kA
1 (+10 %)	2,69	242	90	242	99	167	449	70	10	84	4,08
7 (+5 %)	2,57	231	90	242	99	175	449	70	10	76	4,28
11 (0 %)	2,44	220	90	242	99	184	449	70	10	69	4,49
17 (–5 %)	2,32	209	90	242	99	193	449	70	10	62	4,73
21 (–10 %)	2,20	198	90	242	99	204	449	70	10	56	4,99
27 (–15 %)	2,08	187	90	242	99	216	449	70	10	50	5,28

[a] referred to 70 MVA.

NOTE 1 The short circuit current available at the LV terminals with 220 kV applied to the HV terminals is calculated as follows assuming no system network impedance.

$$I_{SC} = \frac{220}{U_{HV}} \times I_{LV} \times \frac{100}{z} \times \frac{S_r}{S_{tap}}$$

NOTE 2 The impedance *z* in the example is constant with tap position for simplicity. This is not necessarily a realistic situation.

NOTE 3 The impedance of the transformer in terms of ohms per phase is calculated as follows

$$Z_{HV} = \frac{z}{100} \times \frac{U_{HV}^{\ 2}}{S_r}$$

B.4.2 Example 4.2 – Transformer specified with LV voltage variation

Transformer to be suitable for step down operation

rated power:	70 MVA at principal tapping
rated voltages:	220 kV / 90 kV
maximum operating voltage:	+10 %
number of tapping steps:	26
size of tapping step:	1 %
variation on LV voltage:	+10 % –15 %
impedance:	10 % on all tappings on 70 MVA base
minimum full load power factor:	0,8

NOTE The specification is the same as example 4.1 except for the change from HV voltage variation to LV voltage variation. Except on principal tap, when compared with the transformer in example 1, this transformer will have different ohmic impedances and therefore different short circuit currents are available at the LV even when the HV voltage and tap-position are the same.

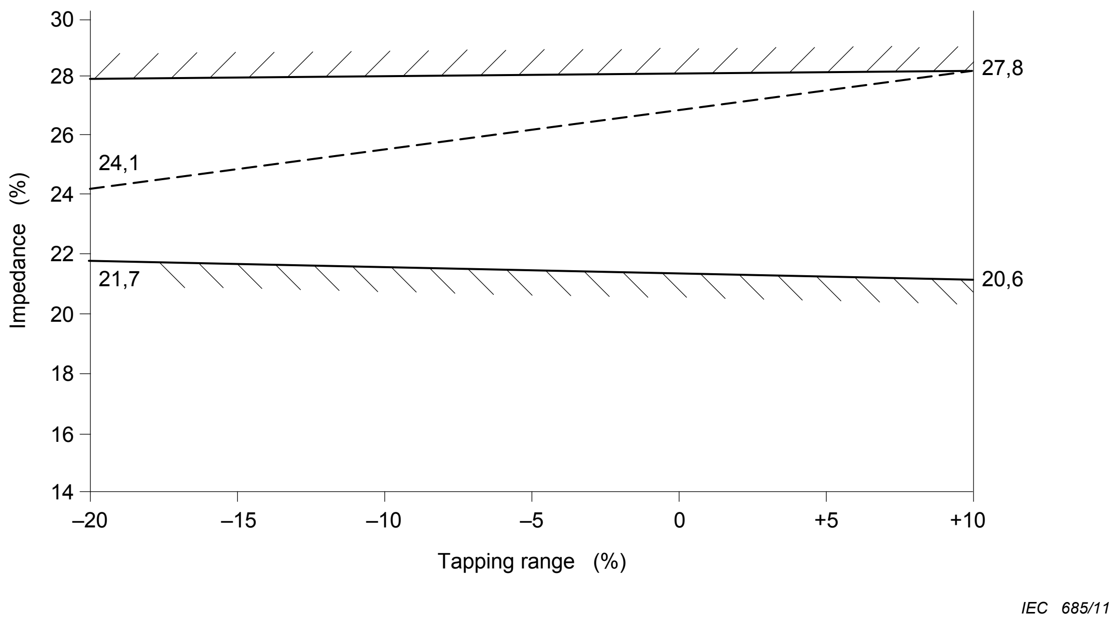
Table B.3 – Example of functional specification with LV voltage variation

Tappings	No load voltage ratio	Rated tapping voltage		Max continuous voltage (on load)		Rated tapping current		Tapping power	Short-circuit impedance		SC current available on LV at 220 kV
		U_{HV} kV	U_{LV} kV	HV kV	LV kV	I_{HV} A	I_{LV} A	S_{tap} MVA	z % [a]	Z_{HV} Ω/ Phase	kA
1 (+10 %)	2,72	220	81	242	99	165	449	63	10	69	4,99
7 (+5 %)	2,57	220	85,5	242	99	175	449	66,5	10	69	4,73
11 (0 %)	2,44	220	90	242	99	184	449	70	10	69	4,49
17 (–5 %)	2,33	220	94,5	242	99	193	449	73,5	10	69	4,28
21 (–10 %)	2,22	220	99	242	99	202	449	77	10	69	4,08
27 (–15 %)	2,13	220	103,5	242	99	211	449	80,5	10	69	3,90

[a] referred to 70 MVA.

Annex C
(informative)

Specification of short-circuit impedance by boundaries



The upper boundary is a constant value of short-circuit impedance as a percentage, which is determined by the permissible voltage drop at a specified loading and at a specified power factor.

The lower boundary is determined by permissible overcurrent on the secondary side during a through-fault.

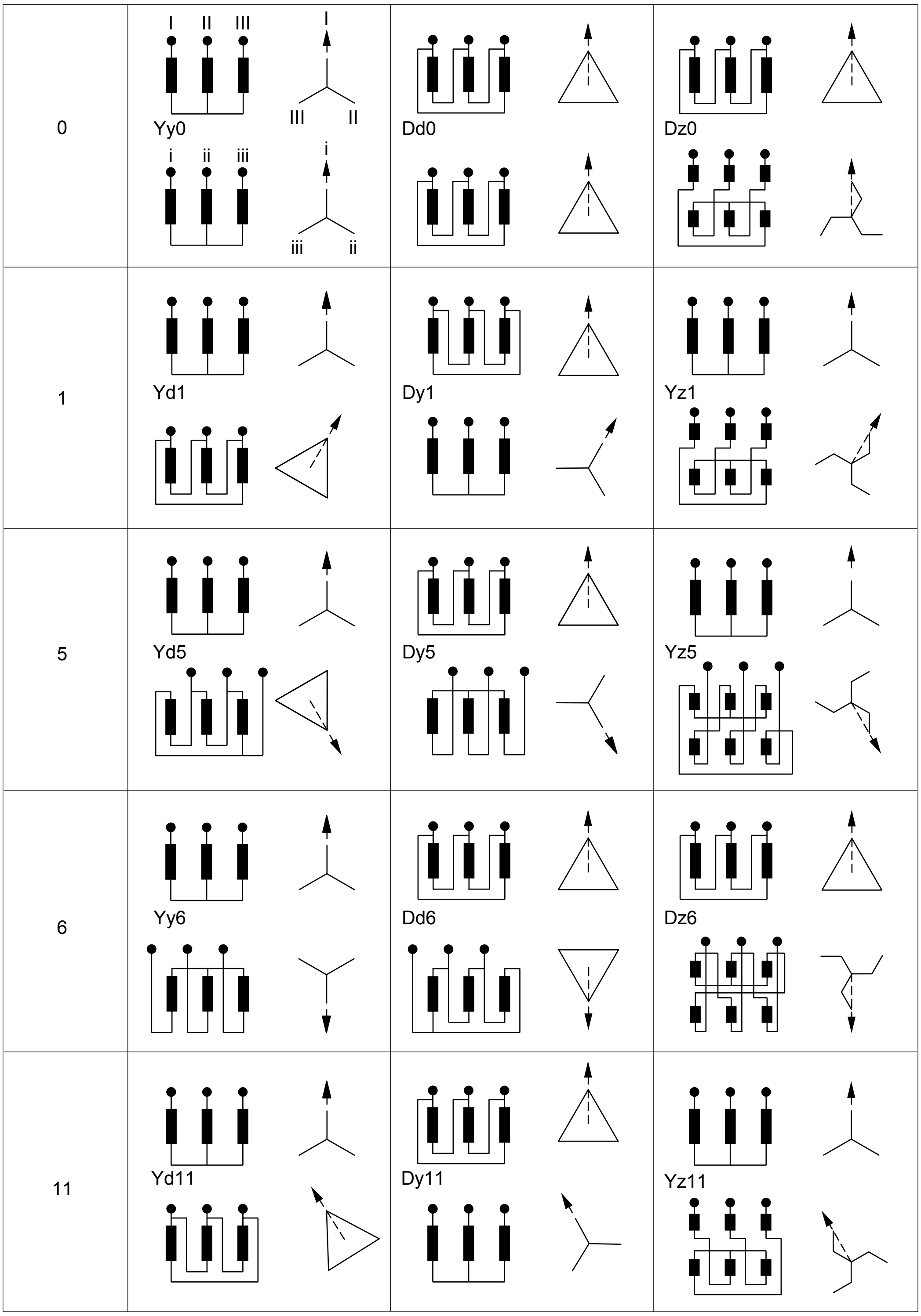
The dashed line is an example of a transformer short-circuit impedance curve which would satisfy this specification.

Figure C.1 – Example of specification of short-circuit impedance by boundaries

Annex D
(informative)

Examples of three-phase transformer connections

Common connections are shown in Figure D.1 below.

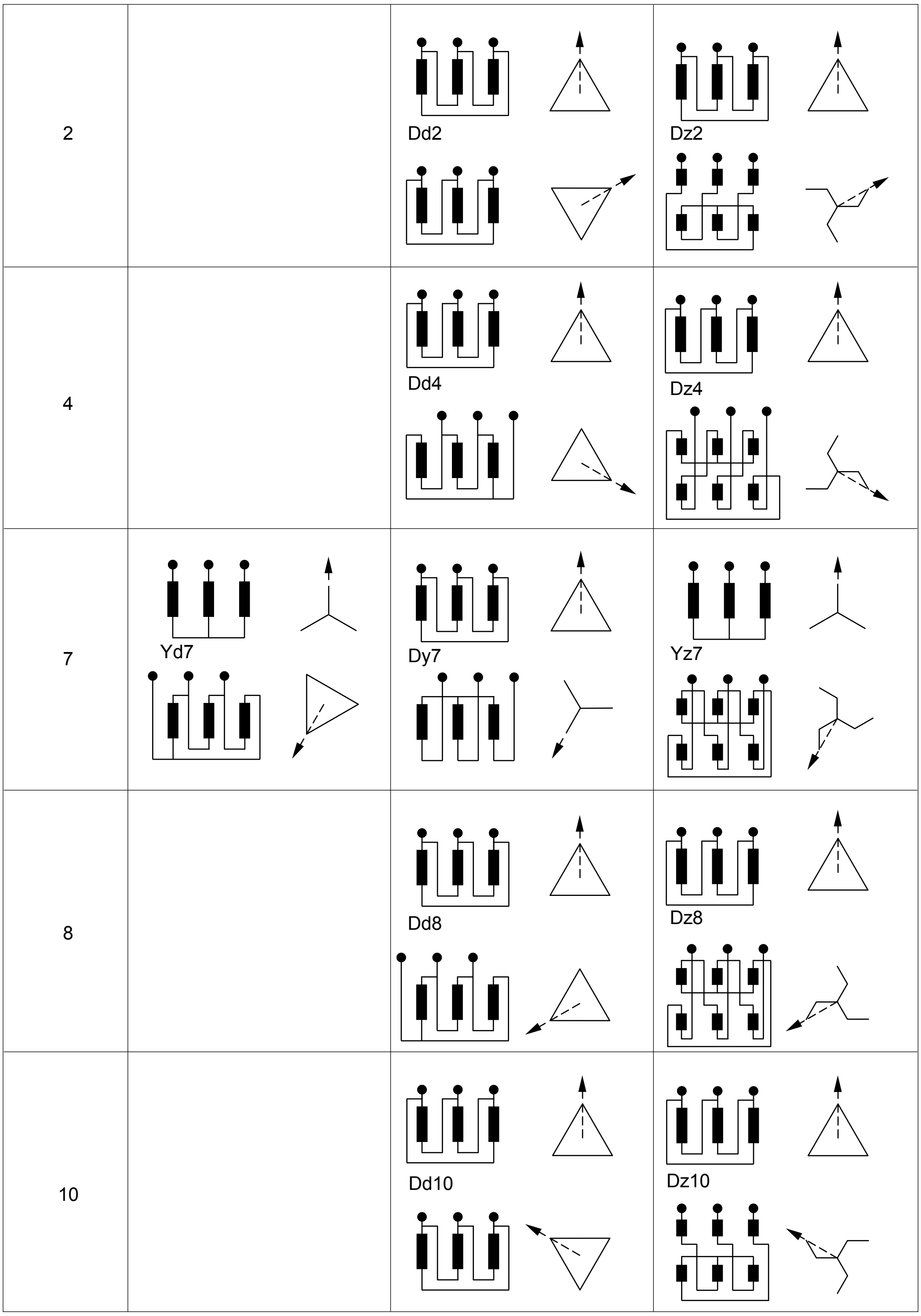


IEC 686/11

Conventions of drawing are the same as in Figure 2 (Clause 7) of the main document.

Figure D.1 – Common connections

Additional connections are shown in Figure D.2 below.



IEC 687/11

Conventions of drawing are the same as in Figure 2 (clause 7) of the main document.

Figure D.2 – Additional connections

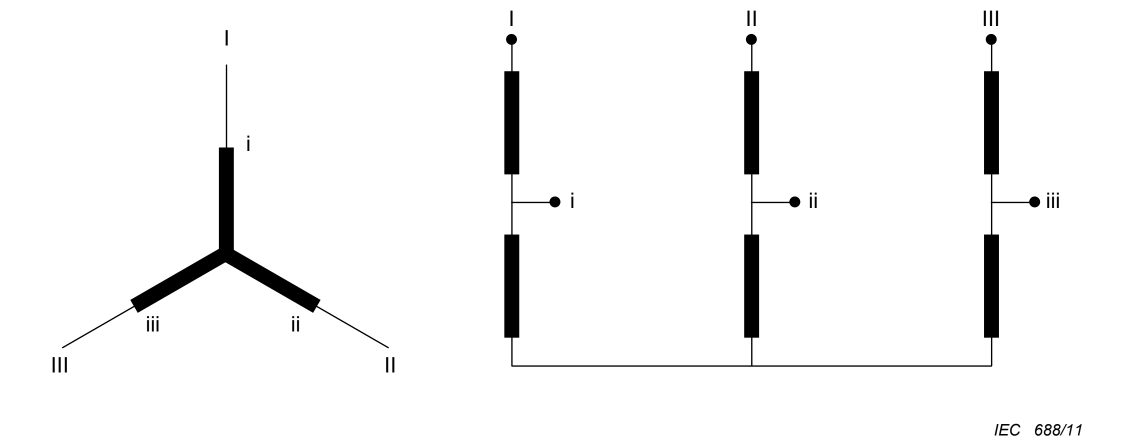


Figure D.3 – Designation of connections of three-phase auto-transformers by connection symbols (auto-transformer Ya0)

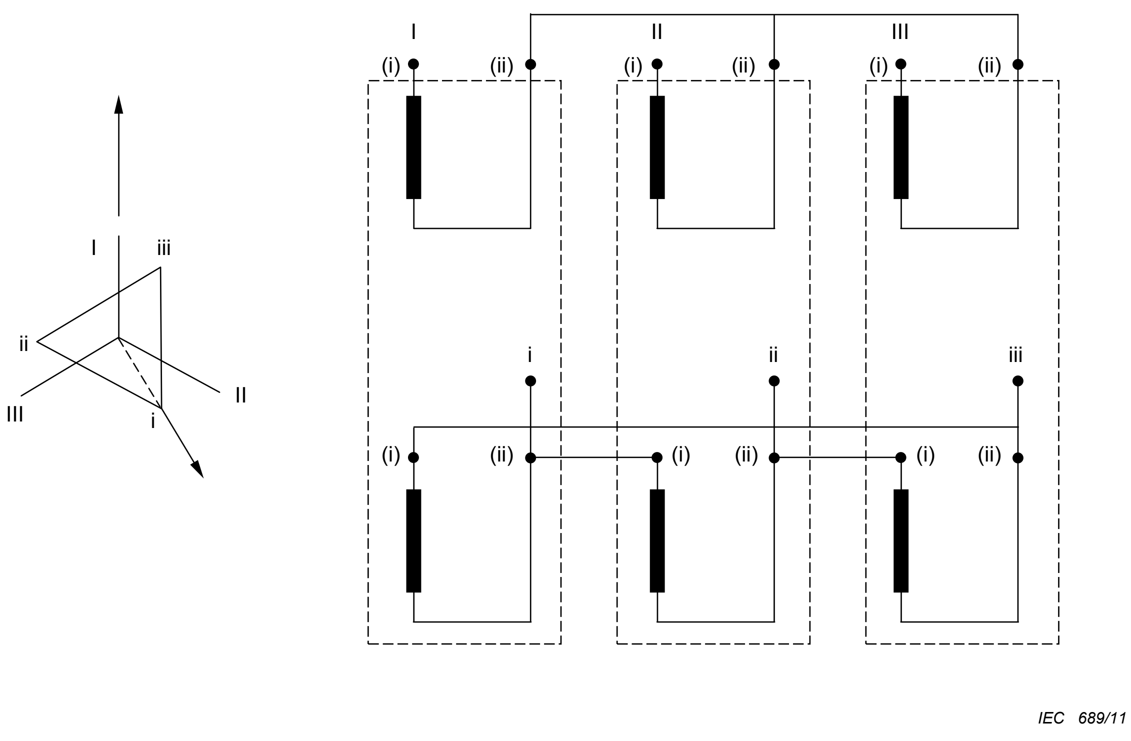


Figure D.4 – Example of three single-phase transformers connected to form a three-phase bank (connection symbol Yd5)

Annex E
(normative)

Temperature correction of load loss

List of symbols

Index 1	refers to measurement of 'cold winding resistance' (11.2);
Index 2	indicates conditions during measurement of load loss (11.4);
r	indicates conditions at 'reference temperature' (11.1);
R	resistance;
θ	winding temperature in °C;
P	load loss;
I	specified load current for loss determination (rated current, tapping current, other specified value related to a particular loading case);
P_a	'additional loss'.

The winding resistance measurement is made at a temperature θ_1. The measured value is R_1.

The load loss is measured with the winding at an average temperature θ_2. The measured loss referred to specified current I, is P_2. This loss is composed of 'ohmic loss': I^2R_2 and 'additional loss': P_{a2}

$$R_2 = R_1 \frac{235 + \theta_2}{235 + \theta_1} \text{ (copper)} \qquad R_2 = R_1 \frac{225 + \theta_2}{225 + \theta_1} \text{ (aluminium)}$$

$$P_{a2} = P_2 - \sum I^2 R_2$$

$\sum I^2 R_2$ is sum of the d.c. resistive losses in all windings.

At reference temperature θ_r, the winding resistance is R_r, the additional loss P_{ar}, the whole load loss P_r.

$$R_r = R_1 \frac{235 + \theta_r}{235 + \theta_1} \text{ (copper)} \qquad R_r = R_1 \frac{225 + \theta_r}{225 + \theta_1} \text{ (aluminium)}$$

$$P_{ar} = P_{a2} \frac{235 + \theta_2}{235 + \theta_r} \qquad P_{ar} = P_{a2} \frac{225 + \theta_2}{225 + \theta_r}$$

For liquid-immersed transformers with reference temperature 75 °C, the formulae become as follows:

$$R_r = R_1 \frac{310}{235 + \theta_1} \text{ (copper)} \qquad R_r = R_1 \frac{300}{225 + \theta_1} \text{ (aluminium)}$$

$$P_{ar} = P_{a2} \frac{235 + \theta_2}{310} \qquad P_{ar} = P_{a2} \frac{225 + \theta_2}{300}$$

Finally: $P_r = \sum I^2 R_r + P_{ar}$

Annex F
(informative)

Facilities for future fitting of condition monitoring systems to transformers

Where it is desired to provide the necessary facilities for the future fitting of a monitoring system to a transformer, the following sensors and facilities should be considered. The actual sensors and facilities provided shall be agreed between manufacturer and purchaser and will depend on the size and criticality of the transformer.

Further guidance is contained in CIGRE brochure 343.

Table F.1 – Facilities for condition monitoring

Monitoring parameter	**Suggested preparation for monitoring**
Top oil temperature	Sensor
Bottom oil temperature	Sensor
Gas-in-oil content (single output)	Facility to fit sensor
Moisture in oil	Facility to fit sensor
Oil level in conservator alarm	Alarm contact
Oil level in conservator indication	Sensor
Multiple gas monitor	Facility to fit sensor
Partial discharge sensor	Facility to fit sensor
DC neutral current	Facility to fit sensor
Magnetic circuit	Earth connection brought out
Cooling medium temperature	Sensor
Cooler operation	Flow sensor or auxiliary contact
Cooler inlet oil temperature	Sensor
Cooler outlet oil temperature	Sensor
Voltage at bushing tap	Facility to fit transducer
Load current	Additional ct
Bushing oil pressure	Facility to fit sensor
Tap-position	Sensor
Active power consumption of motor drive	Facility to fit transducer
Diverter switch compartment oil temperature	Facility to fit sensor
Selector compartment oil temperature	Facility to fit sensor
Main tank temperature near tap-changer	Facility to fit sensor
Diverter oil level indication	Facility to fit sensor
Diverter oil level alarm	Alarm contact
Diverter oil condition	Facility to fit sensor
Diverter switching supervision	Auxiliary contacts in diverter
Winding hot-spot temperature	Sensor

Annex G
(informative)

Environmental and safety considerations

The environmental impact of the transformer should be considered by both the manufacturer and the user over the lifetime of the unit from design to disposal. The following factors should be taken into account during this consideration and efforts made to minimise the overall impact of production, use and disposal.

1) The raw materials for the transformer should be evaluated against the following criterion:
   a) energy consumption during extraction, refining and production;
   b) waste products and pollution during extraction, refining and production;
   c) toxicity or other health effects of the materials or processes on workers during extraction refining and production;
   d) environmental impact of the material.
2) The specification and design of the transformer should consider:
   a) safety of persons during manufacture, installation, operation, maintenance and disposal;
   b) energy consumption during the lifetime of the transformer;
   c) sustainable use of raw materials in the transformer;
   d) elimination or minimisation of the use of hazardous or environmentally damaging materials;
   e) containment of any hazardous or environmentally damaging materials;
   f) the disposal of the transformer, eliminating or minimising the use of materials or mixtures of materials that will be difficult or impossible to re-use or recycle.
3) With regard to the manufacturing phase, the client should consider in the specification and the manufacturer should consider during the manufacturing of the transformer:
   a) the use of an environmental management system (ISO 14001);
   b) the efficient use of energy and resources;
   c) elimination or reduction of environmentally harmful emissions and waste;
   d) re-use or recycling of any waste;
   e) health and safety of the workforce.
4) Other considerations
   a) energy use and environmental impact of transport to site;
   b) disposal or re-use of any packaging material;
   c) the health or environmental impact of any substances which may be generated by potential fault conditions;
   d) the potential for release of environmentally damaging materials during abnormal operation or fault.

The life cycle of the transformer may be considered in terms of material and energy inputs and waste outputs.

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