

Australian/New Zealand Standard™

Power transformers

Part 1: General (IEC 60076-1, Ed. 3.0 (2011) MOD)



AS/NZS 60076.1:2014

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This Standard was issued in draft form for comment as DR AS/NZS 60076.1.

Australian/New Zealand Standard™

Power transformers

Part 1: General (IEC 60076-1, Ed. 3.0 (2011) MOD)

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EL-008, Power Transformers, to supersede AS 60076.1—2005, *Power transformers*, Part 1: *General* (IEC 60076-1, Ed. 2.1 (2000) MOD).

The objective of this Standard is to provide manufacturers, suppliers, test laboratories, purchasers and users of power transformers with general requirements for three-phase and single-phase transformers. The exceptions are some small and special purpose transformers.

This Standard is an adoption with national modifications. It has been reproduced from IEC 60076-1, Ed. 3.0 (2011), *Power transformers*, Part 1: *General*, and has been varied as indicated to take account of Australian/New Zealand conditions.

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

- (a) Addition of a definition of harmonic content.
- (b) Addition of a subclause on transport.
- (c) Addition of functional method of specification.
- (d) Addition of connection symbols for single-phase transformers.
- (e) Addition of safety and environmental requirements.
- (f) Addition of requirements for liquid preservation systems.
- (g) Addition of a clause on DC currents.
- (h) Addition of vacuum, pressure and leak tests on tanks.
- (i) The requirements formerly in Annex A are now incorporated in the text and Annex A is now an informative checklist.
- (j) Informative annexes have been added on facilities for condition monitoring and environmental and safety considerations.

This Standard is structured as follows:

- (i) Preface.
- (ii) IEC 60076-1, Ed. 3.0 (2011) (unedited from the contents page to the final clause of the source document).
- (iii) Appendix ZZ—(Australian/New Zealand) variations to the source document.
- (iv) Appendices ZA and ZB—for Australia/New Zealand.

This Standard is Part 1 of the AS/NZS 60076 series which is progressively replacing the AS 2374 series. This series will consist of adoptions, with national modifications when necessary, of the IEC 60076 series on power transformers.

The variations listed in Appendix ZZ address issues, including the following:

- (A) Definition and details of T-T connected transformers.
- (B) Clarification to the type testing scope for Australian/New Zealand conditions.
- (C) Clarification of the scope and limitations for sound level to ensure consistency with AS/NZS 60076.10, which includes the required maximum sound levels.
- (D) Additional items to appear on the rating plate to suit Australian/New Zealand conditions and practices.
- (E) Additional safety considerations to suit Australian/New Zealand conditions and practices.
- (F) Additional special information items for order/enquiry to suit Australian/New Zealand conditions and practices.

The variations described in Appendix ZZ form the Australian/New Zealand variations for the purposes of the IECEE CB Scheme for recognition of testing to standards for safety of electrical equipment.

Table 6.1 of AS 2067 (minimum values for separating outdoor transformers) was consulted during the preparation of this Standard, with respect to liquid volumes contained in outdoor transformers.

As this Standard is reproduced from an International Standard, the following applies:

- (1) In the source text ‘this part of IEC 60076’ should read ‘this Australian/New Zealand Standard’.
- (2) A full point substitutes for a comma when referring to a decimal marker.

References to International Standards should be replaced by references to Australian or Australian/New Zealand Standards, as follows:

<i>Reference to International Standard</i>		<i>Australian/New Zealand Standard</i>	
IEC		AS/NZS	
60076	Power transformers	60076	Power transformers
60076-2	Part 2: Temperature rise for liquid-immersed transformers	60076.2	Part 2: Temperature rise for liquid-immersed transformers
60076-3	Part 3: Insulation levels, dielectric tests and external clearances in air	60076.3	Part 3: Insulation levels, dielectric tests and external clearances in air (IEC 60076-3, Ed. 2 (2000) MOD)
60076-5	Part 5: Ability to withstand short circuit	60076.5	Part 5: Ability to withstand short circuit (IEC 60076-5, Ed. 3.0 (2006) MOD)
60076-6	Part 6: Reactors	60076.6	Part 6: Reactors
60076-7	Part 7: Loading guide for oil-immersed power transformers	60076.7	Part 7: Loading guide for oil-immersed power transformers
		AS	
60076-8	Part 8: Application guide	2374.8	Part 8: Application guide
		AS/NZS	
60076-10	Part 10: Determination of sound levels	60076.10	Part 10: Determination of sound levels
		AS	
60076-11	Part 11: Dry-type transformers	60076.11	Part 11: Dry-type transformers
		AS/NZS	
60137	Insulated bushings for alternating voltages above 1 000 V	60137	Insulated bushings for alternating voltages above 1000 V (IEC 60137, Ed. 5.0 (2003) MOD)
		AS	
60214	Tap-changers	60214	Tap-changers
60214-1	Part 1: Performance requirements and test methods	60214.1	Part 1: Performance requirements and test methods
		1767	
60296	Fluids for electrotechnical applications—Unused mineral insulating oils for transformers and switchgear	1767.1	Part 1: Specification for unused mineral insulating oils for transformers and switchgear

Only normative references that have been adopted as Australian or Australian/New Zealand Standards have been listed.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the annex or appendix to which they apply. A ‘normative’ annex or appendix is an integral part of a Standard, whereas an ‘informative’ annex or appendix is only for information and guidance.

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AUSTRALIAN/NEW ZEALAND STANDARD

Power transformers**Part 1:****General (IEC 60076-1, Ed. 3.0 (2011) MOD)****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]

* 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 tapplings, rated quantities are related to the principal tapping (see 3.5.2), unless otherwise specified. Corresponding quantities with analogous meaning, related to other specific tapplings, 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 $\sqrt{3}$,

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

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:

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

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 $\pm a\%$, 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:

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

where

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

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.

NOTE 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)

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

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

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)

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

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

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 ($0 \leq K \leq 1$), the overfluxing shall be limited in accordance with the following formula:

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

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, tapplings 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 tapplings are identified by their tapping factors. The number of tapplings 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 $\pm 15\%$ having 21 tapplings, 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:

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

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

Some tapplings may be 'reduced-power tapplings' due to restrictions in either tapping voltage or tapping current. The boundary tapplings 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 tapplings are 'full-power tapplings'.

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.

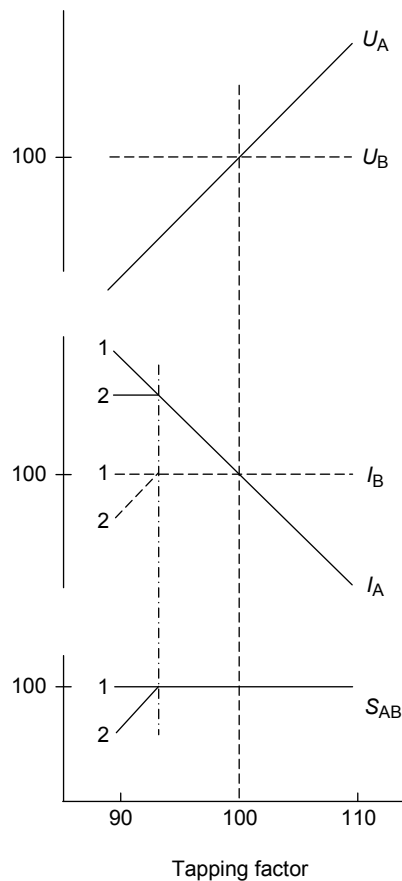


Figure 1a – Constant flux voltage variation (CFVV)

Optional maximum current tapping shown