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Interested committees:

Title: BS EN IEC 60076-1 Power transformers

Part 1: General

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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IEC 60076-1 ED4

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14/1112/RR

IEC TC 14 : POWER TRANSFORMERS

SECRETARIAT:

United Kingdom

SECRETARY:

Ms Stephanie Lavy

OF INTEREST TO THE FOLLOWING COMMITTEES:

PROPOSED HORIZONTAL STANDARD:



Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.

FUNCTIONS CONCERNED:

☐ EMC☐ ENVIRONMENT☐ QUALITY ASSURANCE☐ SAFETY

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TITLE:

Power transformers - Part 1: General

NOTE FROM TC/SC OFFICERS:

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

- Incorporation of thermal requirements from IEC 60076-2, IEC 60076-7 and IEC 60076-14;
- Change from specification of temperature rise to specification of ambient temperature;
- update of references to other standards for example climatic conditions;
- addition of requirement for short circuit capability;
- addition of reference to energy performance;
- changes to rating plate requirements;
- addition of lifetime test for corrugated tanks;
- Change to normal basis of reference temperature;
- addition of annex on high temperature insulation;

- addition of annex on offshore applications;
- addition of definition of distribution transformer;
- addition of definition of electromagnetic power transformer and change of power transformer definition to allow for alternative technologies.

.

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

FDIS	Report on voting

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

Scope

This part of IEC 60076 applies to power transformers with the exception of certain categories of small and special transformers such as:

- transformers with rated power less than 1 kVA per phase
- transformers which have no windings with a highest voltage for equipment with a U_m 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
- transformers covered by the scope of TC96.

When IEC standards do not exist for such categories of transformers (in particular transformers which have no windings with a highest voltage for equipment with a U_m higher than 1 000 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 to the extent to which it is specifically called up by cross-reference in the other standard. Such standards exist for:

- reactors (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/IEEE 60076-16);
- traction transformers and traction reactors (IEC 60310);
- converter transformers for industrial applications (IEC 61378-1);
- converter transformers for HVDC applications (IEC/IEEE 60076-57-129);
- phase shifting transformers (IEC/IEEE 60076-57-1202);
- voltage regulated distribution transformers (IEC 60076-24)

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 customer. The matters should preferably be raised at an early stage and the agreements included in the contract specification.

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*

– Add 76-14 if referred to in a normative context otherwise move to bibliography

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

IEC 60152:2021 *Designation of phase difference by hour numbers*

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*

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

transformer (IEV 151-13-42) with the purpose of transmitting electric power, by changing a system of alternating voltage (IEV 131-11-25) and alternating current (IEV 131-11-24) into another system of alternating voltage and alternating current

Note 1 to entry: transformer (IEV 151-13-42): electric energy converter (IEV 151-13-36) without moving parts that changes voltages and currents associated with electric energy without change of frequency

385 Note 2 to entry: electric energy converter (IEV 151-13-36): device for changing one or more characteristics
386 associated with electric energy

387 Note 3 to entry: characteristics associated with energy are for example voltage, number of phases and frequency
388 including zero frequency. [SOURCE: 811-19-01 MOD]

389 Note 4 to entry: alternating voltage (IEV 131-11-25): voltage that is a periodic function of time with a zero direct
390 component or, by extension, a negligible direct component

391 Note 5 to entry: alternating current (IEV 131-11-24): electric current that is a periodic function of time with a zero
392 direct component or, by extension, a negligible direct component

393 Note 6 to entry: For the qualifier AC, see IEC 60050-151, 151-15-01.

394 Note 7 to entry: for the purpose of this definition, transformers with auxiliary equipment such as fans, pumps and
395 tap-changers, although moving parts and part of the transformer are still considered power transformers.

396 3.1.2

397 **electromagnetic power transformer**

398 power transformer with two or more electromagnetically coupled windings

399 3.1.3

400 **small power transformer**

401 power transformer with a highest rated power of the highest rated winding ≤ 3150 kVA three
402 phase, or ≤ 1050 kVA single phase

403 3.1.4

404 **medium power transformer**

405 power transformer with a highest rated power of the highest rated winding > 3150 kVA but $\leq$
406 31.5 MVA three phase or > 1050 kVA but less than 10.5 MVA single phase

407 3.1.5

408 **large power transformer**

409 power transformer with a highest rated power of the highest rated winding > 31.5 MVA three
410 phase or > 10.5 MVA single phase

411 3.1.6

412 **distribution transformer**

413 small power transformer with a U_m for the highest voltage winding ≤ 36 kV transformer and
414 which is to be used for transferring electrical energy between a distribution circuit and a
415 consumer circuit with a $U_m \leq 1.1$ kV and which is not subject to any assembly or liquid filling
416 at the installation site and has no on-load tap-changer and no forced cooling

417 Note 1 to entry: consumer is defined according to IEC 691-01-04.

418 Note 2 to entry: this definition is for the purpose of defining a class of transformers that are not subject to some
419 tests as defined in clause 10 and it is not intended to include all transformers that may be referred to as 'distribution
420 transformers' in other contexts.

421

422 3.1.7

423 **auto-transformer**

424 electromagnetic power transformer in which at least two windings have a common part

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

426 Note 1 to entry: Where there is a need to express that a transformer is not auto-connected, use is made of terms
427 such as separate winding transformer, or double-wound transformer (see IEC 60050-421:1990, 421-01-13).

3.1.8

series transformer

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 1 to entry: In some countries Series transformers are called booster transformers.

3.1.9

liquid-immersed type transformer

transformer in which the magnetic circuit and windings are immersed in liquid

Note 1 to entry: Liquid-immersed transformer and liquid-filled transformer are synonymous for the purposes of the IEC 60076 series of standards.

3.1.10

dry-type transformer

transformer in which the magnetic circuit and windings are not immersed in an insulating fluid other than air

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

3.1.11

liquid preservation system

system in a liquid-immersed transformer by which the thermal expansion of the liquid is accommodated

Note 1 to entry: Contact between the liquid and external air may sometimes be diminished or prevented.

3.1.12

specified value

the value specified by the customer in the contract specification

3.1.13

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

3.1.14

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

3.1.15

insulation system

system composed of solid, liquid and/or gaseous insulating materials and their combinations

3.1.16

thermal class

designation of an insulating material or system by a number that is equal to the numerical value of the maximum temperature expressed in degrees Celsius for which the material or system is appropriate in normal use

Note 1 to entry: It may be necessary to assign different thermal classes to the same material or system for different service conditions of the insulating material or system.

Note 2 to entry: the thermal class refers to the insulation system used to insulate the transformer part (winding, winding portion, core, etc.) in question.

[IEV 212-12-31 modified]

3.1.17

transformer thermal class

The thermal class of the winding or winding part with the lowest thermal class

Note 1 to entry: The description of an electrotechnical product as being of a particular thermal class does not mean, and must not be taken to imply that each insulating material used in its construction is of the same thermal capability.

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 in an electromagnetic power transformer forming an electrical circuit associated with one of the voltages assigned to the transformer

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

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

511 **3.3.2**

512 **tapped winding**

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

514 **3.3.3**

515 **phase winding**

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

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

518 Note 1 to entry: The term 'phase winding' should not be used for identifying the assembly of all coils on a specific
519 leg.

520 **3.3.4**

521 **high-voltage winding, HV winding***

522 the winding having the highest rated voltage

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

524 **3.3.5**

525 **low-voltage winding, LV winding***

526 the winding having the lowest rated voltage

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

528 Note 1 to entry: For a series transformer, the winding having the lower rated voltage may be that having the higher
529 insulation level.

530 **3.3.6**

531 **intermediate-voltage winding***

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

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

535 **3.3.7**

536 **auxiliary winding**

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

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

539 **3.3.8**

540 **stabilizing winding**

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

* 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.

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

544 Note 1 to entry: A winding is referred to as a stabilizing winding only if it is not intended for three-phase connection
545 to an external circuit.

546 **3.3.9**

547 **common winding**

548 the common part of the windings of an auto-transformer

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

550 **3.3.10**

551 **series winding**

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

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

555 **3.3.11**

556 **energizing winding (of a series transformer)**

557 the winding of a series transformer which is intended to supply power to the series winding

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

559 **3.3.12**

560 **auto-connected windings**

561 the series and common windings of an auto-transformer

562 **3.4 Rating**

563 **3.4.1**

564 **rating**

565 those numerical values assigned to the quantities which define the operation of the trans-
566 former in the conditions specified in this part of IEC 60076 and on which the manufacturer's
567 guarantees and the tests are based

568 **3.4.2**

569 **rated quantities**

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

571 Note 1 to entry: For transformers having tapplings, rated quantities are related to the principal tapping (see 3.5.2),
572 unless otherwise specified. Corresponding quantities with analogous meaning, related to other specific tapplings, are
573 called tapping quantities (see 3.5.9).

574 Note 2 to entry: Voltages and currents are always expressed by their r.m.s. values, unless otherwise specified.

575 **3.4.3**

576 **rated voltage of a winding U_r**

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

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

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

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

586 Note 3 to entry: For single phase transformers intended to be connected between phases of a network, the rated
587 voltage is indicated as the phase-to-phase voltage.

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

590 **3.4.4**

591 **rated voltage ratio**

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

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

595 **3.4.5**

596 **rated frequency f_r**

597 the frequency at which the transformer is designed to operate

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

599 **3.4.6**

600 **rated power S_r**

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

603 Note 1 to entry: Both windings of a two-winding transformer have the same rated power which by definition is the
604 rated power of the whole transformer.

605 **3.4.7**

606 **rated current I_r**

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

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

610 Note 1 to entry: For a three-phase winding the rated current I_r is given by:

$$611 \quad I_r = \frac{S_r}{\sqrt{3} \times U_r}$$

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

$$614 \quad I_r = \frac{I_{line}}{\sqrt{3}}$$

615 Note 3 to entry: For a single phase transformer not intended to be connected to form a three phase bank, the rated
616 current is

$$617 \quad I_r = \frac{S_r}{U_r}$$

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

$$620 \quad I_r = \frac{S_r}{\text{No. of phases} \times U_r}$$

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 1 to entry: 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 1 to entry: 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'

661 Note 1 to entry: If this factor ranges from $100 + a$ to $100 - b$, the tapping range is said to be: $+a\%$, $-b\%$ or $\pm a\%$,
662 if $a = b$. [IEC 60050-421:1990, 421-05-07]

663 3.5.8

664 **tapping voltage ratio (of a pair of windings)**

665 the ratio which is equal to the rated voltage ratio:

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

667 – divided by the tapping factor of the tapped winding if this is the low-voltage winding

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

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

671 3.5.9

672 **tapping quantities**

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

675 Note 1 to entry: Tapping quantities exist for any winding in the transformer, not only for the tapped winding (see 6.2
676 and 6.3).

677 The tapping quantities are:

678 –tapping voltage (analogous to rated voltage, 3.4.3);

679 –tapping power (analogous to rated power, 3.4.6);

680 –tapping current (analogous to rated current, 3.4.7).

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

682 3.5.10

683 **full-power tapping**

684 a tapping whose tapping power is equal to the rated power

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

686 3.5.11

687 **reduced-power tapping**

688 a tapping whose tapping power is lower than the rated power

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

690 3.5.12

691 **on-load tap-changer OLTC**

692 a device for changing the tapping connections of a winding, suitable for operation while the
693 transformer is energized or on load

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

695 3.5.13

696 **de-energized tap-changer DETC**

697 a device for changing the tapping connections of a winding, suitable for operation only while
698 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 to entry: This voltage is limited by U_m .

Note 2 to entry: This voltage will normally be limited to 105 % of the rated tapping voltage unless a higher voltage is required by the customer'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 1 to entry: 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 to entry: For a three-phase transformer, the value is the arithmetic mean of the values of current in the three lines.

Note 2 to entry: 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 to entry: 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 to entry: 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 1 to entry: 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 to entry: 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 to entry: 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

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

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 1 to entry: 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]

785 Note 1 to entry: The zero-sequence impedance may have several values because it depends on how the terminals
786 of the other winding or windings are connected and loaded.

787 Note 2 to entry: The zero-sequence impedance may be dependent on the value of the current and the temperature,
788 particularly in transformers without any delta-connected winding.

789 Note 3 to entry: The zero-sequence impedance may also be expressed as a relative value in the same way as the
790 (positive sequence) short-circuit impedance (see 3.7.1).

791 **3.8 Thermal parameters and rating**

792 **3.8.1**

793 **temperature rise**

794 The difference between the temperature of the part under consideration and the temperature
795 of the external cooling medium

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

797 Note 1 to entry: An example of 'the temperature of the part under consideration' would be the average winding
798 temperature.

799 **3.8.2**

800 **internal cooling medium**

801 the fluid in contact with the windings and other transformer parts by means of which the heat
802 produced by the losses is transferred to the external cooling medium

803 **3.8.3**

804 **external cooling medium**

805 the medium external to the transformer cooling system (air or water) into which the heat
806 produced by the transformer losses is transferred

807 **3.8.4**

808 **temperature of external cooling medium**

809 the temperature of the external cooling medium outside the influence of local radiation or
810 recirculation or other similar thermal influences from the transformer

811 Note 1 to entry: In service this is the ambient temperature in the case of air and the inlet temperature in the case of
812 water. The measurement of the temperature of the external cooling medium during thermal tests is covered by IEC
813 60076-2.

814 Note 2 to entry: For the purposes of considering the minimum external cooling medium temperature then this is the
815 lowest temperature of any cooling medium if more than one cooling system is used, for example in the case of a heat
816 recovery system incorporating a heat pump.

817 **3.8.5**

818 **rated temperature of external cooling medium**

819 temperature of external cooling medium used in the determination of the transformer thermal
820 requirements in °C

821 **3.8.6**

822 **maximum temperature of external cooling medium at any time**

823 the maximum temperature of the external cooling medium expected during the lifetime of the
824 transformer in °C

825 Note 1 to entry: the maximum temperature of external cooling medium at any time is intended to reflect the reasonable
826 absolute maximum temperature of the external cooling medium in a practical way that affects the rating and lifetime
827 of the transformer. Short time extreme events lasting for less than the thermal time constant of the whole transformer
828 or which are not expected to repeat regularly are excluded.

829 Note 2 to entry: where the meaning is unambiguous, term 3.9.6 is also called 'maximum temperature at any time'

3.8.7

yearly average temperature

one-twelfth of the sum of the monthly average temperatures

3.8.8

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

3.8.9

top-liquid temperature

$$\theta_o$$

the effective highest temperature of the internal cooling medium measured according to IEC 60076-2.

Note 1 to entry: the effective highest temperature is normally the temperature of the top layer of the insulating liquid in the tank of a conventional transformer

3.8.10

top-liquid temperature rise

$$\Delta\theta_o$$

the temperature difference between the top-liquid temperature and the external cooling medium temperature

3.8.11

average winding temperature

$$\theta_w$$

the winding temperature determined at the end of temperature rise test from the measurement of winding d.c. resistance

3.8.12

average winding temperature rise

$$\Delta\theta_w$$

the difference between the average winding temperature and the external cooling medium temperature

3.8.13

hot-spot winding temperature

$$\theta_h$$

the hottest temperature of winding conductors in contact with solid insulation or insulating liquid

3.8.14

hot-spot winding temperature rise

$$\Delta\theta_h$$

the difference between hot-spot winding temperature and the external cooling medium temperature

3.8.15 Internal core hot-spot temperature

the hottest core internal temperature calculated from the no load temperature rise at highest core excitation and the fluid temperatures relevant to the operating condition

Note 1 to entry: The method of determining the internal core hot-spot temperature rise by is given in IEC 60076-2.

3.8.16**kraft paper**

paper made entirely from soft-wood pulp manufactured by the sulphate process according to IEC 60554-1 or IEC 60641-1 which is not thermally upgraded

3.8.17**thermally upgraded paper**

Cellulose based paper that has been chemically modified to reduce the rate at which the paper decomposes. Ageing effects are reduced either by partial elimination of water forming agents (as in cyanoethylation) or by inhibiting the formation of water through the use of stabilizing agents (as in amine addition with dicyandiamide).

A paper is considered to be thermally upgraded if all of the following are true:

1. When tested in accordance with IEEE C57.100, Annex H, "Standard Test Procedure for Qualification of Thermally Upgraded Kraft Paper," it retains a minimum of 50% of initial tensile strength for a time/temperature combination given by the equation:

$$\text{Time (h)} = 65\,000 e^{\left(\frac{15\,000}{\theta_h + 273} - \frac{15\,000}{110 + 273}\right)} = e^{(15,000/(T+273)-28.082)}$$

Where: T = test temperature in °C,

2. The unused paper has a minimum nitrogen content of 1.3 %,
3. The tested paper retains a minimum of 50% of initial nitrogen content after performing the IEEE C57.100, Annex H test.

alternatively the definition and standard for this material given in an IEC document may be used

Note 1 to entry: A typical test time/temperature combination is 476 hours at 165 °C,

Note 2 to entry: The criterion to retain 50% tensile strength should be considered only as a qualification criterion to determine if a kraft paper can be considered thermally upgraded. The actual expected life of the paper in equipment is longer than given by the formula. Decades of operating equipment manufactured using the Industry Proven System (IPS) including thermally upgraded kraft paper, cellulose pressboard, Polyvinyl Formal (PVF) coated magnet wire, and mineral oil, has shown that a minimum life expectancy of at least 180 000 hours may be assumed, if the hottest-spot temperature of 110 °C, at rated load as defined in IEEE Std C57.12.00 or IEC 60076-1, is maintained.

Note 3 to entry: Because the thermal upgrading chemicals used today contain nitrogen, which is not present in kraft pulp, the degree of chemical modification is determined by testing for the amount of nitrogen present in the treated paper in accordance with ASTM D-982.

Note 4 to entry: it is anticipated that a revision to the IEC 60554 series of standards will include a definition of thermally upgraded paper

3.9 Insulation

For terms and definitions relating to insulation system dielectric performance 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 1 to entry: 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 1 to entry: 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 1 to entry: 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 to entry: 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 or measurement to which each individual transformer is subjected

3.11.2

type test

a test or measurement 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 to entry: Design variations that are clearly irrelevant to a particular type test would not require that type test to be repeated.

Note 2 to entry: 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 customer and the manufacturer.

Note 3 to entry: 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 or measurement other than a type test or a routine test, agreed by the manufacturer and the customer

Note 1 to entry: Special tests can be carried out on one transformer or all transformers of a particular design, as specified by the customer in the enquiry and order for every special test.

3.12 Other definitions

3.12.1

load current

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

3.12.2

total harmonic content

the ratio of the effective value of all harmonics up to the nth harmonic to the effective value of the fundamental (E_1 , I_1). The choice of n shall be such that increasing n does not increase the total harmonic content by more than 0.001

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

994

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

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

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

998 Note 1 to entry IEC 61378-1 uses 25th harmonic as the highest relevant n in the examples.

999 3.12.3

1000 even harmonic content

1001 the ratio of the effective value of all the even harmonics to the effective value of the
1002 fundamental (E_1 , I_1)

$$1003 \text{ Voltage even harmonic content} = \frac{\sqrt{\sum_{j=1}^{\frac{n}{2}} E_{2j}^2}}{E_1}$$

$$1004 \text{ Current even harmonic content} = \frac{\sqrt{\sum_{j=1}^{\frac{n}{2}} I_{2j}^2}}{I_1}$$

1005 E_{2j} represents the r.m.s. value of voltage of the $2j^{\text{th}}$ (even) harmonic

1006 I_{2j} represents the r.m.s. value of current of the $2j^{\text{th}}$ (even) harmonic

1007 Service conditions

1008 4.1 General

1009 The service conditions set out in clause 4.2 represent the normal scope of operation within
1010 which a transformer specified to this standard shall be capable of reliable service. For any
1011 unusual service conditions which require special consideration in the design of a transformer
1012 see clause 5.10. Such conditions include offshore application (see Annex J), high altitude,
1013 extreme high or low external cooling medium temperature, tropical humidity, seismic activity,
1014 severe contamination, unusual voltage or load current wave shapes, high solar radiation and
1015 intermittent loading. They may also concern conditions for shipment, storage and installation,
1016 such as mass or space limitations (see Annex A).

1017 Supplementary rules for rating and testing are given in the following publications:

- 1018 – temperature rise and cooling at high altitude in IEC 60076-11 for dry-type transformers;
- 1019 – external insulation at high altitude: IEC 60076-3 for liquid-filled transformers, and
- 1020 IEC 60076-11 for dry-type transformers.

1021 4.2 Normal service conditions

1022 This part of IEC 60076 gives detailed requirements for transformers for use under the following
1023 conditions:

1024 a) Altitude

1025 A height above sea-level not exceeding 1 000 m.

1026 b) Temperature of external cooling medium at transformer installation site

1027 For air-cooled transformers, the temperature of cooling air at the inlet to the cooling equipment
1028 not exceeding the maximum temperature at any time which shall be the rated temperature of
1029 external cooling medium plus 20 °C See clause 5.3.

1030 The temperature of cooling air at the inlet to the cooling equipment at any time not below
1031 at any time:

1032 –25 °C in the case of outdoor transformers;

1033 –5 °C in the case of transformers where both the transformer and cooler are intended
1034 for installation indoors.

1035 The customer may specify a higher minimum temperature of cooling medium, in which case the
1036 specified minimum temperature shall be respected at all times. If the transformer has any
1037 operational limitations at temperatures above the standard minimum temperature of cooling
1038 medium (-25°C) this shall be stated on the rating plate.

1039 NOTE 1 This paragraph above is intended to allow for example the use of an alternative insulating liquid or other
1040 components which do not meet minimum temperature requirements in circumstances where the minimum
1041 temperature of –25 °C is not appropriate. Lower minimum temperatures would not be covered by normal service
1042 conditions and will need to be specified by the customer see clause 5.10.

1043 For water-cooled transformers, the temperature of cooling water at the inlet to the cooling equipment
1044 not exceeding the maximum temperature at any time which shall be the rated temperature of external
1045 cooling medium plus 5 °C;

1046 Further limitations with regard to cooling are given for dry-type transformers in IEC 60076-11.

1047 NOTE 2 For transformers with both air/water and water/liquid heat exchangers, the temperature of cooling medium
1048 refers to the external air temperature rather than the water temperature in the intermediate circuit which may exceed
1049 the normal value.

1050 NOTE 3 The relevant temperature is at the inlet to the cooling equipment rather than the outside air temperature,
1051 this means that the user should take care that if the installation can create conditions where air recirculation from
1052 the output of the cooler can occur, that this is taken into account when assessing the cooling air temperature.

1053 c) Wave shape of supply voltage

1054 A sinusoidal supply voltage with a total harmonic content not exceeding 5 % and an even harmonic
1055 content not exceeding 1 %.

1056 d) Load current harmonic content

1057 Total harmonic content of the load current not exceeding 5 % of rated current.

1058 NOTE 4 Transformers where total harmonic content of the load current exceeds 5 % of rated current, or transformers
1059 specifically intended to supply power electronic or rectifier loads should be specified according to IEC 61378 series.

1060 NOTE 5 Transformers can operate at rated current without excessive loss of life with a current harmonic content of
1061 less than 5 %, however it should be noted that the temperature rise will increase for any harmonic loading and may
1062 exceed rated rise.

1063 e) Symmetry of three-phase supply voltage

1064 For three-phase transformers, a set of three-phase supply voltages which are approximately
1065 symmetrical. Approximately symmetrical shall be taken to mean that the highest phase to phase
1066 voltage is no more than 1 % higher than the lowest phase to phase voltage continuously or 2 % higher
1067 for short periods (approximately 30 min) under exceptional conditions.

1068 f) Installation environment

1069 An environment with a pollution rate (see IEC 60137 and IEC/TS 60815) that does not require special
1070 consideration regarding the external insulation of transformer bushings or of the transformer itself.

1071 An environment not exposed to seismic disturbance which would require special consideration in the
1072 design of the transformer. This may be assumed to be the case when the ground acceleration level a_g
1073 is below 2 ms^{-2} or approximately 0,2 g.

1074 NOTE 6 This requirement is for the transformer itself, the seismic withstand capability of the transformer installation
1075 as a whole is not covered by this clause and might be lower according to local circumstances. See IEC TS 62271-
1076 210.

1077 Where the transformer is separate from the cooling equipment and the transformer and any tank
1078 attached equipment but not the coolers are installed in an enclosure not supplied by the transformer
1079 manufacturer, for example in an acoustic enclosure, the temperature of the air surrounding the
1080 transformer is not exceeding 50°C .

1081 NOTE 7 This clause is intended to cover installations where personnel access to the transformer in service is allowed
1082 or possible, where this is not the case and auxiliary equipment is situated outside the enclosure then this would be
1083 considered to be a special requirement and would need to be specified.

1084 Environmental conditions within the following definitions according to IEC 60721-3-4:2019:

- 1085 – climatic conditions 4K26 except that the maximum and minimum external cooling
1086 medium temperatures are as given in b) above;
- 1087 – Splashing water 4Z14

1088 NOTE 8 4Z14 might not be sufficient if a fire protection system is installed

- 1089 – Snow load 4Z17
- 1090 – Wind 4Z4 (108kmph) for the transformer and its components except for components
1091 which are covered by their own standard (for example bushings and surge arresters)
1092 although mountings for such components must comply.
- 1093 – biological conditions 4B2

1094

1095 Corrosivity of the atmospheric environment according to ISO 9223:2012 class C4

1096 For coastal and offshore application C4 is not adequate and the special conditions associated with
1097 these applications must be specified by the customer.

1098 For transformers intended to be installed indoors, some of these environmental conditions may not be
1099 applicable.

1100 NOTE 9 For transformers for installation in substations further information can be found in IEC Guide 111.

1101

1102 Rating and general requirements

1103 5.1 Rated power

1104 5.1.1 General

1105 The rated power for each winding shall either be specified by the customer or the customer
1106 shall provide sufficient information to the manufacturer to determine the rated power at the
1107 enquiry stage.

1108 The transformer shall have an assigned rated power for each winding which shall be marked
1109 on the rating plate. The rated power refers to continuous loading. This is a reference value for
1110 guarantees and tests concerning load losses and temperature rises.

1111 If different values of apparent power are assigned under different circumstances, for example,
1112 with different methods of cooling, the highest of these values is the rated power.

1113 A two-winding transformer has only one value of rated power, identical for both windings.

1114 For multi-winding transformers, the customer shall specify the required power-loading
1115 combinations, stating, when necessary, the active and reactive outputs separately.

1116 When the transformer has rated voltage applied to a primary winding, and rated current flows
1117 through the terminals of a secondary winding, the transformer receives the relevant rated power
1118 for that pair of windings.

1119 The transformer shall be capable of carrying, in continuous service, the rated power (for a multi-
1120 winding transformer: the specified combination(s) of winding rated power(s)) under conditions
1121 listed in Clause 4 and without exceeding the temperature limitations specified in clause 5.4 for
1122 liquid-immersed transformers.

1123 NOTE 1 The interpretation of rated power according to this subclause implies that it is a value of apparent power
1124 input to the transformer - including its own absorption of active and reactive power. The apparent power that the
1125 transformer delivers to the circuit connected to the terminals of the secondary winding under rated loading differs
1126 from the rated power. The voltage across the secondary terminals differs from rated voltage by the voltage drop (or
1127 rise) in the transformer. Allowance for voltage drop, with regard to load power factor, is made in the specification of
1128 the rated voltage and the tapping range (see Clause 7 of IEC 60076-8:1997).

1129 National practices may be different.

1130 NOTE 2 For a multi-winding transformer, half the arithmetic sum of the rated power values of all windings (separate
1131 windings, not auto-connected) gives a rough estimate of its physical size as compared with a two-winding
1132 transformer.

1133 A transformer may be categorised according to the highest rated power of the highest rated
1134 winding as a small power transformer, medium power transformer or large power transformer
1135 as defined in clauses 3.1.3, 3.1.4 and 3.1.5.

1136 **5.1.2 Preferred values of rated power**

1137 For transformers up to 20 MVA, values of rated power should preferably be taken from the R10
1138 series given in ISO 3:1973, *Preferred numbers – series of preferred numbers*:

1139 (...100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1 000, etc.) kVA.

1140 NOTE National practices may be different.

1141 **5.1.3 Minimum power under alternative cooling modes**

1142 Where the user has a particular requirement for a minimum power under a particular cooling
1143 mode other than the cooling mode for rated power, this shall be stated in the enquiry.

1144 The transformer shall be capable of carrying, in continuous service, the specified minimum
1145 power (for a multi-winding transformer: the specified combination(s) of winding rated power(s))
1146 under conditions listed in Clause 4, and under the specified cooling mode, without exceeding
1147 the temperature limitations as specified in clause 5.4 for liquid immersed transformers.

1148 NOTE An example of this is where the transformer is required to operate at a particular minimum percentage of
1149 rated power with the forced cooling out of service (ONAN) to allow for the loss of auxiliary supply

5.2 Cooling modes

5.2.1 Specification

Unless otherwise specified the cooling medium is air or water.

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

5.2.2 Identification symbols

Transformers shall be identified according to the cooling method employed. For liquid-immersed transformers, this identification is expressed by a four-letter code as described below.

First letter: Internal cooling medium:

O: mineral oil or other insulating liquid with fire point ≤ 300 °C;

K: insulating liquid with fire point > 300 °C;

L: insulating liquid with no measurable fire point.

Where K or L class liquid is used as the internal cooling medium and identified as such on the nameplate, but a lower fire point liquid is present in another part of the transformer for example in a tap-changer this shall be clearly indicated on the nameplate.

Second letter: Circulation mechanism for internal cooling medium:

N: natural thermosiphon flow through cooling equipment and in windings;

F: forced circulation through cooling equipment, thermosiphon flow in windings;

D: forced circulation through cooling equipment, directed from the cooling equipment into at least the main windings.

Third letter: External cooling medium:

A: air;

W: water.

Fourth letter: Circulation mechanism for external cooling medium:

N: natural convection;

F: forced circulation (fans, pumps).

If an intermediate cooling circuit is included in the transformer design then this shall be indicated using brackets.

For example

1179 OF(WF)AF in the case where the transformer has an intermediate water cooling circuit with
1180 water pumps, oil pumps and fans, together with water to air and oil to water coolers.

1181 NOTE 1 It is important to note that the transformer performance is affected by the selected type of insulating liquid
1182 (internal cooling medium) and an exchange with another type of insulating liquid is therefore normally not advisable
1183 unless the design was specifically made (and preferably tested) also for that other type of insulating liquid without a
1184 careful review.

1185 If the type of insulating liquid in an in-service transformer is intended to be exchanged and the design was not made
1186 for the new type of insulating liquid (retrofit solution), a design study is required that includes as a minimum the
1187 following:

- 1188 - adjustment of power rating(s),
- 1189 - validation of dielectric withstand capability and
- 1190 - requirements for the type of preservation system including sealed systems
- 1191 - Compatibility of materials used in the construction of the transformer
- 1192 - Compatibility of accessories

1193 It is recommended and this is done in a consultation between manufacturer and user.

1194 NOTE 2 In a transformer designated as having forced directed insulating liquid circulation (second code letter D),
1195 the rate of liquid flow through the main windings is determined by the pumps and is not, in principle, determined by
1196 the loading. A minor fraction of the flow of liquid through the cooling equipment may be directed as a controlled
1197 bypass to provide cooling for core and other parts outside the main windings. Regulating windings and/or other
1198 windings having relatively low power may also have non-directed circulation of bypass liquid.

1199 In a transformer with forced, non-directed cooling (second code letter F), the rates of flow of liquid through all the
1200 windings are variable with the loading, and not directly related to the pumped flow through the cooling equipment.

1201

1202 5.2.3 Transformers with alternative cooling modes

1203 A transformer may be specified with alternative cooling modes. In this case, the specification
1204 and the rating plate shall then carry information about the power values at which the transformer
1205 fulfils the temperature rise limits specified in clause 5.4 when these alternatives apply.

1206 The power value for the alternative cooling modes with the highest cooling capacity is the rated
1207 power of the transformer (or of an individual winding of a multi-winding transformer, see clause
1208 5.1. The alternative cooling modes are conventionally listed in rising order of cooling capacity.

1209 Examples:

1210 ONAN/ONAF. The transformer has a set of fans which may be put into service as desired at
1211 high loading. The insulating liquid circulation is by thermosiphon effect only, in both cases.
1212 Rated power of this transformer is the rating at ONAF cooling mode but a reduced rated power
1213 at ONAN is also specified.

1214 ONAN/OFAF. The transformer has cooling equipment with pumps and fans but is also specified
1215 with a reduced rated power under natural cooling. The rated power of this transformer is the
1216 rating for the OFAF cooling mode.

1217 5.3 Rated Temperature of cooling medium

1218 The rated temperature of the cooling medium as specified by the customer shall at minimum
1219 be representative of the ambient conditions relevant to the operation of the transformer at the
1220 installation site. It is normally half the sum of the yearly average temperature and the monthly

1221 average temperature of the hottest month rounded up to next 5 or 10 (whatever is closer) in
1222 °C at the intended installation site.

1223 The temperature pairs consisting of the rated temperature and the maximum temperature at
1224 any time for the appropriate cooling medium shown in the individual columns of Table 1
1225 characterize the ambient temperature conditions at different installation sites. (for definitions
1226 see 3.8.5 and 3.8.6). If the temperature pair for the application matches one of the pairs in a
1227 column of Table 1, the installation site falls under normal service conditions for those thermal
1228 parameters.

1229 The customer may in specific cases choose a higher rated temperature of cooling medium
1230 than that which is strictly required to match the meteorological conditions at the installation
1231 site in order to take account of particular situations, for example to reduce the temperature
1232 rise to increase lifetime or to allow for external cooling medium recirculation at the site.

1233 NOTE 1 The temperature pairs listed in Table 1 cover ambient temperature conditions in all regions worldwide with
1234 exemption of a very few extreme cold regions. For more information see Annex H.

1235 **Table 1- Standard combinations of temperatures of the external cooling medium**

Rated temperature in °C	10	15	20	25	30	35
Maximum temperature of air at any time in °C for air-cooled transformers	30	35	40	45	50	55
Maximum temperature of water at any time in °C for water-cooled transformers	15	20	25	30	35	40

1236 If the rated temperature is not specified by the customer then the manufacturer shall make the
1237 calculation above for the intended installation site or range of sites and apply the appropriate
1238 rated temperature, making the scope of application clear to the customer.

1239 The maximum temperature at any time excludes short time extreme events lasting for less than
1240 the thermal time constant of the whole transformer or which are not expected to repeat regularly.

1241 NOTE In previous versions of this standard 20°C was assumed as an effective rated temperature and this might
1242 be used for example in repeat designs for temperate regions, but a proper consideration of the installation
1243 environment is considered essential.

1244 **5.4 Temperature and temperature rise limits**

1245 **5.4.1 General**

1246 Ageing and lifetime of the insulation system is directly dependent on the temperatures
1247 experienced by the transformer component parts in service, leading to following requirements:

- 1248 - The temperature of any part under any standard or specified loading condition shall
1249 not cause the failure of the transformer in a short timescale.
- 1250 - The temperature of any component part of the transformer under continuous and any
1251 specified short-term loading shall not exceed the proven capability of the material or
1252 materials used in the construction of that component part.

1253 It is therefore essential to respect the temperature limits given in clause 5.4.2 for continuous
1254 service at rated load and for the specified overloading cycles. Details of how to calculate an
1255 equivalent use of life for an overloading cycle are given in IEC 60076-7.

1256 Acceptable insulation system thermal aging performance may be assumed if the insulation
1257 system, when tested in accordance with IEEE Std C57.100 (or equivalent testing or service
1258 experience) demonstrates a minimum life expectancy of at least 20.5 years (180 000 h) at the
1259 hot-spot temperature experienced when the transformer is operated at rated load, and rated
1260 temperature.

1261 In the case of a kraft paper/mineral oil insulation system with a thermal class of 105, service
1262 experience allows the use of this type of insulation at the temperatures given in this standard.

1263 NOTE The set of requirements for standard and specified overloading is applicable mainly to large system
1264 transformers for which emergency loading conditions deserve attention and should not be regularly used for small
1265 and medium-size standardized transformers.

1266 It is assumed throughout this part that the service temperatures of different parts of a
1267 transformer can each be described as the sum of the external cooling medium temperature
1268 (cooling air or cooling water) and the temperature rise of the transformer part.

1269 Temperature and temperature rise limits provided in clauses 5.4.2 and 5.4.3 apply for normal
1270 service conditions as described in clause 4.2.

1271 Throughout clause 5.4, the temperature and temperature rise requirements for transformers
1272 with a transformer thermal class 105 and transformer thermal class 120 are provided.
1273 Temperature and temperature rise requirements for other (higher temperature) transformer
1274 thermal class or insulation system thermal classes are provided in Annex I.

1275 No plus tolerance is permitted on temperature rise limits.

1276

1277 **5.4.2 Temperature limits for each insulation system**

1278 The thermal capability of each part of the transformer's insulation system is indicated by the
1279 assigned thermal class of that part.

1280 In the case of a winding, the thermal class refers to the solid insulation material used to insulate the
1281 hottest parts of that winding (normally the insulation of the winding conductors in the region of the hot-
1282 spot and any other insulation in the winding structure that will achieve a similar temperature). In the
1283 case of other insulation for example associated with the core or other parts not carrying load current,
1284 the thermal class refers to the insulation in contact with that part.

1285 The temperature of parts outside the winding must not limit the rating of the transformer.

1286 A conventional transformer utilising kraft paper and cellulose based pressboard insulation immersed in
1287 class O, K or L liquid (see IEC 61039) shall be assumed to be thermal class 105. It is necessary to
1288 use insulation of a higher thermal class for any non-winding parts of the transformer that experience
1289 higher temperatures in service than the winding itself.

1290 If higher thermal class materials for example thermally upgraded kraft paper are used at all the parts
1291 of the winding where the temperatures for thermal class 105 in table 3 are exceeded and the
1292 transformer sealing is such that moisture and oxygen in the insulating liquid are expected to be
1293 retained at a low level over the lifetime of the transformer then the winding may be assigned thermal
1294 class 120. The manufacturer must make clear to the user any maintenance requirements needed to
1295 maintain the conditions required to allow a thermal class of 120.

1296 Thermal classes higher than 120 may be assigned for higher temperature insulation systems (solid,
1297 liquid and in combination) based on testing and validation of the system for that thermal class (see
1298 annex).

1299 In the situation where there is no solid insulation covering a metallic part then the temperature limit
1300 depends on the liquid thermal capability. For mineral oil the limit is 110°C where the oil in contact with
1301 the hot spot is not moving and 120°C where forced or natural convection at the surface can occur. For
1302 other liquids the temperature must be chosen so that the liquid does not decompose or produce
1303 diagnostic gas. See table 4a.

1304 A transformer may be assigned a lower thermal class than would be indicated by the insulation system
1305 actually used if the temperature rise and corresponding rated power for the lower thermal class are
1306 also assigned to that transformer.

1307 NOTE This is intended to prevent the required use of a higher reference temperature solely because more thermally
1308 capable insulation is used in the design if the rated power and temperature rises are not increased.

1309 The temperature limits in °C, assigned to each thermal class individually, form the basis for
1310 setting the temperature rise requirements, given in clause 5.4.3.

1311 Table 2, Table 3, Table 4, and Table 5 give the temperature limits for relevant transformer parts
1312 under different loading conditions and temperature of the external cooling medium.

1313 Where a metallic part outside the winding is in contact with insulation then the maximum
1314 temperature for that part is the lower of the requirement for a bare metallic part and the
1315 insulation class of the insulation minus 10K

1316 NOTE 2 Continuous service at rated load presumes cyclic temperature variation of the external cooling medium
1317 characterized by the rated ambient temperature and the maximum temperature at any time.

Table 2 – Maximum permissible temperatures of transformer windings for continuous service at rated load at rated temperature of external cooling medium

Insulation system thermal class	105	120
Average winding temperature in °C Natural or forced oil flow	85	95
Average winding temperature in °C Directed oil flow	90	100
Winding Hot-spot temperature in °C	98	110

1320 NOTE 3 Sufficient experience is available for transformers designed, tested and operated according the IEEE
1321 standard series with thermal class 120 using thermally kraft upgraded paper to introduce this thermal class here.

Table 3 - Maximum permissible temperatures of transformer windings when operating above rated power at maximum temperature of external cooling medium at any time

Insulation system thermal class	105	120
Winding Hot-spot temperature in °C (long time – emergency loading)	140	140