

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Power transformers –
Part 11: Dry-type transformers**

**Transformateurs de puissance –
Partie 11: Transformateurs de type sec**



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INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Power transformers –
Part 11: Dry-type transformers**

**Transformateurs de puissance –
Partie 11: Transformateurs de type sec**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

IEC 60076-11 Edition 2.0 2018-08

POWER TRANSFORMERS –

Part 11: Dry-type transformers

INTERPRETATION SHEET 1

This interpretation sheet has been prepared by IEC technical committee 14: Power transformers.

The text of this interpretation sheet is based on the following documents:

DISH	Report on voting
14/1052/DISH	14/1054/RVDISH

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

14.3.2 Temperature-rise test

Question

The independent certification body in Poland "Instytut Energetyki" carries out the testing of transformers or its inspectors witness this testing at the manufacturers' premises. The description of resistance measurement during the temperature rise test has caused a dispute between a manufacturer and the inspector on where exactly the resistance should be measured. The inspector requested that the resistance be measured on "winding lead exits" inside the enclosure, while the manufacturer argued for the measurement to be made on "winding terminals" which in its opinion were the bushings on the enclosure cover.

Subclause 14.3.2.1 General, states:

The winding temperature rise shall be established by the rise in resistance method or by superposition method. For the determination of the average winding temperature rise the measured temperatures of the cooling air or of the water intake of the cooling equipment shall be used.

For three-phase transformers, the resistance measurements shall be made between the central and an outer phase line terminals.

NOTE When the temperature rise is performed it is advisable to measure the windings resistance close to the windings.

Where should the measurements be made?

Interpretation

Testing of the winding resistance at transformer terminals (bushings) includes leadwork or busbars and often also multiple connections. Because of this, the tested winding resistance and its change due to heating is affected by the resistance of all these leads and connections. Consequently, the derived winding temperature rise if measured at the transformer terminals could be lower than if the winding resistance were tested directly on the winding lead exits. That is why the standard suggests (in the NOTE) that measurement of the windings' resistance be carried out close to the windings. That way, the accuracy of the indirect winding temperature measurement by resistance is higher.

In the case of dry-type transformers without enclosures, it is possible to have access close to the winding lead exits and not only to the transformer line terminals. Therefore, measurements shall normally be made at such locations.

On the other hand, if the dry-type transformer is equipped with an enclosure, the resistance measurement close to the winding lead exits requires opening the enclosure to have access to carry out the test (hence, affecting the normal cooling efficiency of the unit). Nevertheless, the advice to measure the resistance normally close to the winding lead exits holds. Limiting the enclosure opening by using special through elements for the cabling and/or by closing the required opening by temporary means as well as possible will minimize the impact on the normal cooling efficiency.

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POWER TRANSFORMERS –**Part 11: Dry-type transformers****FOREWORD**

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International Standard IEC 60076-11 has been prepared by IEC technical committee 14: Power transformers.

This second edition cancels and replaces the first edition published in 2004 and constitutes a technical revision.

The main changes with regard to the previous edition are as follows:

- Extension of the scope up to 72,5kV
- Enclosure management in regards of the performance
- Management of the dielectric and thermal features with altitude
- New climatic classes for a better adaptation of customers' need
- Establishment of the relation between location and environmental classes
- For fire behaviour classes, limitation at 1 000 kVA and process of test more robust

- Introduction of Seismic class
- Recommendations for amorphous transformers

The text of this International Standard is based on the following documents:

FDIS	Report on voting
14/964/FDIS	14/972/RVD

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

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

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

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

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

The contents of the corrigendum of March 2019 and Interpretation sheet 1 of July 2020 have been included in this copy.

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POWER TRANSFORMERS –

Part 11: Dry-type transformers

1 Scope

This part of IEC 60076 applies to dry-type power transformers (including auto-transformers) having values of highest voltage for equipment up to and including 72,5 kV and at least one winding operating at greater than 1,1 kV.

This document does not apply to:

- gas-filled dry-type transformers where the gas is not air;
- single-phase transformers rated at less than 5 kVA;
- polyphase transformers rated at less than 15 kVA;
- instrument transformers;
- starting transformers;
- testing transformers;
- traction transformers mounted on rolling stock;
- flameproof and mining transformers;
- welding transformers;
- voltage regulating transformers;
- small power transformers in which safety is a special consideration.

Where IEC standards do not exist for the transformers mentioned above or for other special transformers, this document may be applicable as a whole or in parts.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60068-3-3, *Environmental testing – Part 3-3: Guidance – Seismic test methods for equipments*

IEC 60071-1, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60071-2, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60076-1:2011, *Power transformers – Part 1: General*

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

IEC 60076-3:2013, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

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

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

IEC 60076-12:2008, *Power transformers – Part 12: Loading guide for dry-type power transformers*

IEC 60085, *Electrical insulation – Thermal evaluation and designation*

IEC 60270, *High-voltage test techniques – Partial discharge measurements*

IEC 60332-3-10, *Tests on electric cables under fire conditions – Part 3-10: Test for vertical flame spread of vertically-mounted bunched wires or cables – Apparatus*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

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

IEC TS 60815-1, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC 61378-1, *Converter transformers – Part 1: Transformers for industrial applications*

IEC 62271-202, *High-voltage switchgear and controlgear – Part 202: High-voltage/low-voltage prefabricated substation*

ISO 12944-6, *Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 6: Laboratory performance test methods*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

dry-type transformer

transformer of which the magnetic circuit and windings are not immersed in an insulating liquid

3.2

totally enclosed dry-type transformer

transformer in an un-pressurised enclosure cooled by the circulation of the internal air having no intentional exchange with external air

3.3

enclosed dry-type transformer

transformer in a ventilated enclosure cooled by the circulation of the external air

3.4

non-enclosed dry-type transformer

transformer supplied without a protective enclosure cooled by natural or forced air ventilation

4 Service conditions

4.1 General

The requirements of IEC 60076-1 apply to dry-type transformers only in so far as they are referred to in this document.

4.2 Normal service conditions

a) Altitude:

See IEC 60076-1.

b) Temperature of cooling air and water:

See IEC 60076-1.

For water cooled transformers, specification of the water (temperature, water flow, etc.) has to be defined by agreement between manufacturer and purchaser if the temperature of the water is different from that specified in IEC 60076-1 and IEC 60076-2

NOTE Liquids other than water can be used as a cooling medium then all technical data of the liquid has to be defined by agreement between manufacturer and purchaser

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 %.

The purchaser shall specify the magnitude and frequency of any harmonic voltages present in the supply that exceed these limits.

The manufacturer should take into account these harmonics in determination of additional core losses and also regarding the saturation of the core.

d) Load current harmonic content:

At the enquiry stage the purchaser shall specify the magnitude and frequency of each of the harmonic current components generated by the load.

The manufacturer shall consider the additional losses caused by harmonic currents in calculating the temperature rise of the windings and the effects on the other metallic parts of the transformer.

The manufacturer shall calculate the additional loss by using the method of IEC 61378-1 or by using a method like finite element by agreement between manufacturer and purchaser.

If the total harmonic content of the load current exceeds 5 %, then the extra losses due to these harmonic currents shall be taken into account by increasing the test current for the temperature rise test. The temperature rise with these losses shall not exceed the corresponding limit specified in Table 2 when tested in accordance with 14.3.2.

e) Symmetry of three-phase supply voltages:

See IEC 60076-1.

f) Installation environment:

This standard defines specific classes for environment:

- 1) for climatic conditions;
- 2) for humidity and pollution;
- 3) for fire behaviour;
- 4) for seismic disturbance;

- 5) environmental conditions within the following definitions according to IEC 60721-3-4:
- i) biological conditions 4B1;
 - ii) chemically active substances 4C2;
 - iii) mechanically active substances 4S3;
 - iv) mechanical conditions 4M4.
- g) For transformers intended to be installed indoors, some of these environmental conditions might not be applicable.
- h) Inrush current:
System inrush current limitations, if any, (maximum value, duration) shall be given at the enquiry stage by the purchaser.
- i) Frequency of energization:
If frequency of energization is greater than 24 times a year, then purchaser shall specify the number of energizations per year at the enquiry stage.
- j) Protection from water and liquids:
The transformer shall be protected against dripping water or flooding by water and other liquids.
- k) Special electrical and environmental conditions around the transformer:
IEC 60076-3 recommends general minimum clearances between transformer live parts and conductive parts in the installation.
Any part of the installation made of insulation material becomes conductive when moistened with rain water, salt water or other conductive liquids. Partial discharges in the surroundings of the transformer can decrease the dielectric strength of the air.
Therefore the clearances between these installations parts and the live parts of the transformer shall meet the clearances recommended in IEC 60076-3.
- NOTE An agreement between purchaser and manufacturer is needed to reduce the clearances between transformer live parts and conductive parts in the installation.
- l) Level of vibration:
Vibrations of the structure where the transformer is to be installed shall be taken into account when designing the transformer and special consideration shall be given in the stress transferred to connection terminals.
The purchaser shall specify vibration spectrum at the enquiry stage. The procedure of vibration test, if any, should be agreed at enquiry stage between purchaser and manufacturer.
- m) Corrosion protection:
Depending on the type of the installation, the purchaser should choose a protection class defined in ISO 12944 or as agreed between purchaser and manufacturer.
- n) Maintenance
The user shall follow the manufacturer guide line for maintenance and specially avoid an accumulation of dust or pollution on the transformer by a regular cleaning.

4.3 Electromagnetic compatibility (EMC)

Transformers shall be considered as passive elements in respect to emission and immunity to electromagnetic disturbances.

5 Rating and general requirements

5.1 General

The manufacturer shall assign ratings to the transformer, which shall be marked on the rating plate, see Clause 9. These ratings shall be such that the transformer can deliver its rated current under steady loading conditions without exceeding the limits of temperature rise specified in Clause 10, assuming that the applied primary voltage is equal to the rated voltage and that the supply is at rated frequency.

5.2 Rated power

5.2.1 General

The rated power refers to continuous loading. This is a reference value for guarantees and tests concerning load losses, temperature rises and short-circuit impedance.

NOTE A two-winding transformer has only one value of rated power, identical for both windings. When the transformer has rated voltage applied to the primary winding, and rated current flows through the terminals of that winding, the transformer receives the relevant rated power for both windings.

The rated power corresponds to continuous duty; nevertheless, dry-type transformers complying with this standard can be overloaded and guidance on overloads is given in IEC 60076-12.

5.2.2 Definition of the rated power with fans cooling or heat exchangers

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.

When additional cooling by means of fans is provided, the rated power without fans shall be subject to agreement between purchaser and supplier.

5.2.3 Transformer IP00 (without enclosure)

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

5.2.4 Transformer with enclosure

This subclause defines rated power and the distance between enclosures and live parts when the transformer is equipped with an enclosure.

Two cases are defined:

- a) The transformer in an enclosure is manufactured, tested in the enclosure and then delivered on site:
 - The clearances between the live parts and the enclosure shall be defined by the manufacturer. The dielectric tests shall be performed with the enclosure as a routine test.
 - If the clearance between the live part and the enclosure meets the requirement of IEC 60076-3 the dielectric routine test shall be performed either with enclosure or without enclosure.

- It is permitted to disassemble the enclosure for transportation reasons. In this case the dis-assembled clearances between the live parts and the enclosure shall meet the requirements of IEC 60076-3.
 - There shall be no reduction (de-rating) of the rated power.
- b) Transformer and enclosure are delivered on site separately, or later:
- There are two methods to determine the thermal performance of enclosure:
 - The de-rating of the rated power is determined by IEC 62271-202. Then the thermal class of enclosure shall be declared by the manufacturer of the enclosure (seller of the package).
 - The enclosure is calculated using Annex C of this document.
 - The clearance between the live part and the enclosure shall meet the requirement of IEC 60076-3.
 - Enclosure shall have a rating plate and the manufacturer of the enclosure or seller of the package is responsible for determining the rated power of the transformer with the enclosure.

5.2.5 Preferred values of rated power

The preferred values shall be in accordance with IEC 60076-1 starting from 50 kVA.

5.2.6 Loading beyond rated power

The loading guides for dry-type transformers in IEC 60076-12 and the requirements in IEC 60076-1 shall apply.

5.3 Provision for unusual service conditions

The purchaser shall identify in his enquiry any service conditions not covered by the normal service conditions in 4.2. Examples of such conditions are:

- high or low ambient 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;
- conductive pollution;
- excessive and abrasive dust;
- high harmonic content of the load current prescribed in 4.2;
- distortion of the supply voltage waveform prescribed in 4.2;
- fast transient overvoltage over the limits prescribed in 11.1;
- associated power factor correction and method of capacitor switching to limit inrush current;
- superimposed DC current;
- seismic qualification which would otherwise require special considerations in the design;
- extreme mechanical shock and vibrations;
- transport and storage conditions not covered by the normal condition described in 5.7;

- solar radiation;
- regular frequent energization in excess of 24 times per year;
- regular frequent short-circuits;
- V/Hz in excess of IEC 60076-1;
- 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 type of installation;
- environment (see 4.2), the purchaser should choose classes of protection in ISO12944 or by agreement between purchaser and manufacturer;
- load rejection conditions for generator transformers more severe than those given in IEC 60076-1.

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

Supplementary requirements, within defined limits, for the rating and testing of transformers designed for other than normal service conditions listed in 4.2, such as high temperature of cooling air or altitude above 1 000 m, are given in 10.2 and 10.3.

5.4 Transportation and storage

5.4.1 Transport limitation

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

If any other special conditions apply during transportation, they shall be stated in the enquiry.

5.4.2 Transport acceleration

The transformer shall be designed and manufactured to withstand a constant acceleration of at least 10 m/s^2 in all directions (in addition to the acceleration due to gravity in the vertical direction) without any damage. (See 4.2.f 5)

If the transport is not the responsibility of the manufacturer and an acceleration in excess of 10 m/s^2 is expected during transport, the accelerations and frequencies shall be defined at the enquiry stage. If higher accelerations are specified by the purchaser, the manufacturer should take them into account in the design and should give some advice for the transportation and packaging.

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 transformers is common practice.

5.4.3 Temperature and environment conditions for transport and storage

All transformers shall be suitable for transportation and storage at ambient temperatures down to $-25 \text{ }^{\circ}\text{C}$.

For storage and transportation with other ambient temperature see 12.1.

Transformers shall be protected during transportation and storage against contamination, water, etc.

5.5 Rated voltage and rated frequency

5.5.1 Rated voltage

The requirements in IEC 60076-1 apply.

5.5.2 Rated frequency

The requirements in IEC 60076-1 apply.

5.6 Operation at higher than rated voltage

The requirements in IEC 60076-1 apply.

NOTE 1 This requirement is not meant to be systematically utilised in normal service. The consequential increase in iron losses under these conditions will have adverse effects unless such operation is of limited duration. This condition is reserved for relatively rare cases of service under limited periods of time, for example emergency service or extreme peak loading.

NOTE 2 Under-fluxing will not increase the rated current.

5.7 Highest voltage for equipment U_m and dielectric tests levels

For line terminals, unless otherwise specified by the purchaser, U_m (highest voltage for equipment) shall be taken to be the lowest value that exceeds the rated voltage of each winding given in Table 3.

Unless otherwise specified by the purchaser, dielectric test levels shall be taken to be the highest applicable value corresponding to U_m , given in Table 3.

The purchaser can choose in alignment with insulation coordination one of the values of Table 3 or select higher value listed in IEC 60076-3.

5.8 Identification according to cooling method

5.8.1 General

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

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

5.8.2 Identification symbols

Transformers shall be identified according to the cooling method employed. Letter symbols for use in connection with each cooling method shall be as given in Table 1.

Table 1 – Letter symbols

		Symbol
Type of cooling medium	Air	A
	Water	W
Type of circulation	Natural	N
	Forced	F

5.8.3 Arrangement of symbols

Transformers shall be identified by two symbols for each cooling method for which a rating is assigned by the manufacturer, typically as follows:

- A transformer designed for natural air ventilation is designated AN.
- A transformer designed for natural air ventilation up to specified rating and with forced cooling to a higher rating is designated AN/AF.
- A transformer designed with forced cooling with a water heat exchanger is designated AFWF.
- A transformer designed with forced cooling water inside the coil is designated WF.

5.9 Guaranteed temperature rise at rated conditions

The design of the transformer shall be in accordance with the operating conditions (harmonic contents, ambient temperature etc.) stated by the purchaser at the enquiry stage.

The guaranteed temperature rise shall take into account the additional losses due to harmonics if specified, which increase eddy losses and stray losses in the windings and structural/frame parts.

If no harmonics are specified at the design stage but the real load current in service contains harmonics, the load on the transformer may need to be reduced or the cooling improved, to prevent the transformer temperature rise from exceeding the guaranteed limits.

5.10 Additional information required for enquiry

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

5.11 Sound level

See IEC 60076-1.

5.12 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.

6 Tappings

The requirements in IEC 60076-1 apply for de-energized tap changers (DETC) as well as on load tap changers (OLTC).

The preferred tapping range for DETC is either:

± 5 % in steps of 2,5 % (5 tap positions);

or

± 5 % (3 tap positions).

Tapping selection shall be made with de-energised transformers by the use of bolted links or DETC.

7 Connections

Unless otherwise specified by the purchaser, transformer connections shall be Dyn11 or Dyn5 in accordance with IEC 60076-1. The neutral connection shall be capable of carrying full rated phase current.

8 Ability to withstand short circuit

Transformers shall fulfil the requirements in IEC 60076-5. If the purchaser requires a test to demonstrate this fulfilment, this shall be stated in the contract.

9 Rating plate

9.1 Rating plate fitted to the transformer

Each transformer shall be provided with a rating plate of weatherproof material, fitted in a visible position, showing the items indicated below. The entries on the plate shall be indelibly marked (that is, by etching, engraving, stamping or by a photo-chemical process):

- a) dry-type transformer;
- b) number and year of this part of IEC 60076;
- c) manufacturer's name, country and town where the transformer was assembled;
- d) manufacturer's serial number;
- e) year of manufacture;
- f) thermal class of insulation system for each winding (either by temperature, letter or both – refer to IEC 60085). The first thermal class shall refer to the high voltage winding, the second thermal class shall refer to the low voltage winding. When more than two windings are present, the thermal classes shall be placed in the order of the windings from the high voltage to the low voltage;
- g) number of phases;
- h) rated power;
- i) apparent power for each cooling system;
- j) rated frequency;
- k) rated voltages, including tapping voltages, if any;
- l) rated currents for each kind of cooling;
- m) connection symbol;
- n) short-circuit impedance at rated current and at the appropriate reference temperature;
- o) type of cooling;
- p) total mass;
- q) insulation levels for each winding according to IEC 60076-3 standard notation;
- r) degree of protection;
- s) environmental class;
- t) climatic class;
- u) fire behaviour class;
- v) seismic class or floor accelerations if any;
- w) maximum altitude if exceeds 1 000 m;
- x) winding temperature rise for each winding if guaranteed values differ from Table 2.

9.2 Rating plate fitted to the transformer enclosure

Each transformer enclosure shall be provided with a rating plate of weatherproof material, fitted in a visible position, showing the items indicated in 9.1. The entries on the plate shall be indelibly marked (that is, by etching, engraving, stamping or by a photo-chemical process).

10 Temperature-rise limits

10.1 Normal temperature-rise limits

The temperature rise of each winding of the transformer, designed for operation at normal service conditions, shall not exceed the corresponding limit specified in Table 2 when tested in accordance with 14.3.2.

The average temperature rise of the winding is defined as the difference between the average temperature of the winding and the temperature of the cooling air or of the water at the intake of the cooling equipment, for air-cooled or water-cooled transformers.

The maximum temperature occurring in any part of the winding insulation system is called the hot-spot temperature. The hot spot temperature shall not exceed the rated value of the hot-spot winding temperature specified in Table 2 of IEC 60076-12:2008. This temperature could be measured, however an approximate value for practical purposes can be calculated by using equation 9 in 5.8 of IEC 60076-12:2008 with the values for Z and q given in equation 9 of IEC 60076-12:2008.

Components used as insulating material may be used separately or in combination, providing that their temperature does not exceed the values given for the appropriate insulation system temperature in accordance with the requirements as prescribed in the left hand column of Table 2.

The temperature of the core, metallic parts and adjacent materials shall not reach a value that will cause damage to any part of the transformer.

Table 2 – Winding temperature-rise limits

Insulation system thermal class (see Note 1) °C	Average winding temperature rise limits at rated current (see Note 2) K
105 (A)	60
120 (E)	75
130 (B)	80
155 (F)	100
180 (H)	125
200(N)	135
220(R)	150
250 (see Note 3)	175
NOTE 1 Letters refer to the temperature classifications given in IEC 60085.	
NOTE 2 Temperature rise measured in accordance with 14.3.2.	
NOTE 3 Designations of thermal classes over 250 shall increase by increments of 25 and be designated accordingly.	
NOTE 4 The values in this table are defined for normal ambient temperature: See IEC 60076-1.	

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

10.2 Reduced temperature rises for transformers designed for high cooling medium temperatures or special cooling medium conditions

When the transformer is designed for service where the temperature of the cooling medium exceeds one of the maximum values specified in 4.2, the temperature rise limits shall be reduced by the same amount as the excess. The values shall be rounded to the nearest whole number of K.

Any site conditions that may either impose restrictions on the cooling medium or produce high ambient medium temperatures should be stated by the purchaser.

10.3 High altitude temperature rise correction

Unless otherwise agreed upon between the supplier and the purchaser, for transformers designed for operation at an altitude greater than 1 000 m but tested at normal altitudes, the limits of temperature rise given in Table 2 shall be reduced by the following amounts for each 100 m by which the intended working altitude exceeds 1 000 m:

- natural-air-cooled transformers: 0,5 %;
- forced-air-cooled transformers: 1 %.

A corresponding reverse correction may be applied in cases where the altitude of the test room is above 1 000 m and the altitude of the installation site is below 1 000 m.

Any altitude correction shall be rounded to the nearest whole number of K.

11 Insulation levels

11.1 General

The test voltage levels (insulation levels) shall be those given in Table 3, list 1 or list 2.

Table 3 – Test voltage levels

Highest voltage for equipment U_m (r.m.s.) kV	Applied voltage AV (r.m.s.) kV	Full wave lightning impulse (peak value) kV	
		List 1	List 2
$\leq 1,1$	3	–	–
3,6	10	20	40
7,2	20	40	60
12,0	28	60	75
17,5	38	75	95
24,0	50	95	125
36,0	70	145	170
40,5	80	170	200
52,0	95	200	250
72,5	140	250	325

The choice between list 1 and list 2 should be made considering the degree of exposure to lightning and switching overvoltages, the type of system neutral earthing and, where applicable, the type of overvoltage protective device. See IEC 60071-1 and IEC 60071-2.

In some countries, different values of U_m are used. These values are normally close to those given in the Table 3 of this standard, e.g. 25 kV etc. In these cases, the insulation levels corresponding to the nearest U_m of the Table 3 of this standard shall be used if rated voltage is under the U_m value chosen.

NOTE It might happen that certain tapping voltages are chosen slightly higher than a standardized value of U_m , but the system to which the winding will be connected has a system highest voltage which stays within the standard value. The insulation requirements are to be coordinated with actual conditions, and therefore this standard value can be accepted as U_m for the transformer, and not the nearest higher value.

Example:

$U_r = 23,8 \text{ kV} \pm 5\%$ then the insulation levels of U_m 24 kV should apply

$U_r = 11,8 \text{ kV} \pm 5\%$ then the insulation levels of U_m 12 kV should apply

11.2 Transformers for use at high altitudes

The dielectric strength of the air decreases with the altitude. When the transformer is specified for operation at altitudes over 1 000 m above sea-level then the design shall take into account the reduction of the dielectric strength of the air.

When the transformers are specified for operation at altitudes between 1 000 m and 4 500 m above sea-level, but tested at another altitude, correction to the test voltages shall be applied according to Table 4. This correction shall apply only on applied voltage test and not on other dielectric tests.

When performing the applied voltage test, the value of the test voltage shall be multiplied by the coefficient Tcf:

$$Tcf = \frac{\text{Altitude correction factor for test site}}{\text{Altitude correction factor for installation site}}$$

Table 4 – Applied voltage level correction factor

Altitude in m	Installation altitude correction factor	Test altitude correction factor
<1 000	1,0	1,0
1 200	0,98	0,98
1 500	0,95	0,95
1 800	0,92	0,92
2 100	0,89	0,89
2 400	0,86	0,86
2 700	0,83	0,83
3 000	0,80	0,80
3 600	0,75	0,75
4 200	0,70	0,70
4 500	0,67	0,67

Above 4 500 m, the insulation level shall be defined by agreement between supplier and purchaser.

For an altitude not listed in Table 4 the correction factor can be defined by interpolation of the data of the table.

12 Climatic, environmental and fire behaviour classes

12.1 Climatic classes

Several climatic classes are defined:

- Class C1: The transformer is suitable for operation at ambient temperature not below $-5\text{ }^{\circ}\text{C}$ but may be exposed during transport and storage to ambient temperatures down to $-25\text{ }^{\circ}\text{C}$.
- Class C2: The transformer is suitable for operation, transport and storage at ambient temperatures down to $-25\text{ }^{\circ}\text{C}$.
- Class C3: The transformer is suitable for transport and storage at $-40\text{ }^{\circ}\text{C}$ and operation at $-25\text{ }^{\circ}\text{C}$.
- Class C4: The transformer is suitable for transport and storage at $-50\text{ }^{\circ}\text{C}$ and operation at $-40\text{ }^{\circ}\text{C}$.
- Class C5: The transformer is suitable for transport and storage at $-60\text{ }^{\circ}\text{C}$ and operation at $-50\text{ }^{\circ}\text{C}$.
- Class C_{xy} : The transformer is suitable for transport and storage at $-X\text{ }^{\circ}\text{C}$ and operation at $-Y\text{ }^{\circ}\text{C}$.

The Class C_{xy} shall be defined by agreement between the purchaser and the manufacturer who provide the temperature for the transportation, storage (X) and the temperature for operation (Y).

Special tests according to 14.4.4 shall confirm the conformity of transformers classes.

If a transformer meets one climatic class, it shall also be considered to meet less severe classes.

12.2 Environmental classes

12.2.1 Transformers for indoor application with or without enclosure and for outdoor application with enclosure

Environmental conditions for dry-type transformers are identified in terms of humidity, condensation, pollution and ambient temperature. Dripping of water or other conductive substances on the surface of the coils and active parts shall be prevented during storage and operation.

With regard to humidity, condensation and pollution, five different environmental classes are defined for transformers without special external protection measures:

- Class E0: No condensation occurs on the transformers and pollution is negligible. This is commonly achieved in a clean, dry indoor installation.
- Class E1: Occasional condensation can occur on the transformer (for example, when the transformer is de-energized). Limited pollution is possible.
- Class E2: Frequent condensation or light pollution or combination of both.

NOTE 1 Examples: Transformers are in direct access to the environment:

- area without industries and with low density of house equipped with heating plants;
- area with low density of industries or housing but subjected to frequent winds and/or rainfall;
- agricultural area;
- mountainous area.

All of these areas are situated at least at 15 km from the sea and are not exposed to winds directly from the sea.

Class E3: Frequent condensation or medium pollution or combination of both

NOTE 2 Examples: Transformers are in direct access to the environment:

- area with industries not producing particularly polluting smoke and/or with average density of houses equipped with heating plants
- area with high density of housing and/or industries but subjected to frequents winds and or rainfall
- areas exposed to wind from the sea but not too close to the coast(at least several kilometres distant)

Class E4: Frequent condensation or heavy pollution or combination of both

NOTE 3 Examples: Transformers are in direct access to the environment:

- area with high density of industries and suburbs of large cities with high density of heating plants producing pollution
- area close to the sea or in any case exposed to relatively strong wind from the sea

Special tests according to the procedure of 14.4.4 shall confirm the conformity of E1, E2, E3 or E4 class transformers.

If a transformer meets one environmental class, it shall also be considered to meet less severe classes.

For higher level of condensation as well as higher level of pollution, an agreement between manufacturer and purchaser is needed to provide suitable protective enclosure.

NOTE 4 Examples: Transformers are in direct access to the environment:

- area close to industry, subjected to conductive dusts and to industrial smoke producing particularly thick conductive deposit
- area close to the coast and exposed to salt spray or to very strong and polluting winds from the sea
- desert areas, characterised by no rain for long periods, exposed to strong winds carrying sand and salt, and subjected to regular condensation.

12.2.2 Dry-type transformers without enclosure for outdoor application

Environmental conditions for these dry-type transformers are identified in terms of humidity, condensation, pollution, ambient temperature and solar ultraviolet radiation (UV).

The transformer shall be installed outdoors without enclosure (IP00) and can be subjected to rain, snow or hail.

Class E-O-1: rural area or low pollution area.

Class E-O-2: urban area, industrial region or area with moderate pollution level.

Class E-O-3: coastal area or heavy pollution area.

Special tests according to the procedure of Annex B shall confirm the conformity of Class E-O-1, Class E-O-2, Class E-O-3 class transformers.

If a transformer meets one environmental class, it shall also be considered to meet less severe classes.

12.3 Fire behaviour classes

Two fire behaviour classes are defined:

Class F0: There is no special fire risk to consider. Except for the characteristics inherent in the design of the transformer, no special measures are taken to limit flammability. Nevertheless, the emission of toxic substances and opaque smoke shall be minimized.

Class F1: Transformers subject to a fire hazard. Restricted flammability is required. The emission of toxic substances and opaque smokes shall be minimised.

Special tests according to the procedure of 14.4.6 shall confirm the conformity of class F1 transformers.

12.4 Test criteria for climatic, environmental and fire behaviour classes

When a transformer is declared as suitable for a combination of climatic, environmental and fire behaviour classes, those tests which prove compliance with said classes, are to be carried out on one transformer in the sequence given in Table 5. This transformer or parts of the transformer depending on the individual test descriptions shall be used to carry out climatic, environmental and fire behaviour tests.

For the fire test, due to the criteria values (the temperature, smoke limits, etc.) linked with the calorific energy and laboratory limitations, the maximum rated power is 1000 kVA with insulation of 12 kV or 24 kV.

The transformers which are declared to comply with these classes shall be produced with the same conceptual design, rules, raw materials, and production process as the tested transformer. This transformer shall be taken from standard production and shall be suitable for energization and the supply of energy on the network as any other transformer.

The manufacturer shall be able to show to the purchasers the drawing, the bill of the raw material and the routine test done on the transformer that has passed the combination of climatic, environmental and fire tests. The criteria for equivalence are given in relevant clauses.

For transformers above a rated power of 1000 kVA or above an insulation level of 24 kV, climatic tests and environmental tests are valid only if the manufacturer has a certificate on complete test sequence described in Table 5 on rated power of 1000 kVA and an insulation level of 24 kV transformer. See in clause 14.4.4.4 and 14.4.5.3.

Table 5 – Sequence of tests

Classes			Climatic	Environmental		Fire behaviour	
Tests		Subclause	C1, C2, C3, C4, C5, Cxy	E0	E1, E2, E3, E4, E-O-1, E-O-2, E-O-3	F0	F1
1	Climatic test	14.4.4	Yes	-	-	-	-
2	Environmental test	14.4.5 Annex B	-	No	Yes	-	-
3	Fire behaviour test	14.4.6	-	-	-	No	Yes

The transformer subjected to the test sequence shall be transported to the climatic test chamber to carry out climatic test, then this transformer shall be transported to the environmental test chamber to carry out the environmental test and then relevant parts of this transformer shall be dismantled and transported in fire chamber to carry out the fire behaviour test. It is the responsibility of the laboratory, who issues the certificate, to ensure the correctness of the sequences above with the transformer tested

13 Seismic

13.1 General

A transformer in an environment exposed to seismic disturbance requires special consideration.

If the ground acceleration level (AG) is above or equal 2 m/s^2 or approximately $0,2 \text{ g}$, the transformer requires special consideration in the design, then the purchaser shall inform manufacturers regarding the installation area and seismic conditions.

The transformer shall be seismically qualified either by means of testing or by calculation based on a tested reference transformer(s).

General seismic performance levels given in this standard demonstrate the transformer withstand capability against seismic events.

In order to assess the transformer seismic capability, a representative ground acceleration spectrum shall be defined.

The choice of the most appropriate ground acceleration spectrum for seismic assessment for a transformer should include:

- the definition of the ground acceleration for the relevant geographical zone;
- the adjustment of the ground acceleration according to some parameters specific of the studied installation (type of soil, mass and elasticity of the supporting frame, superelevation, damping, etc.).

If detailed information for the determination of a specific ground acceleration spectrum is not available, the general seismic class approach shall be followed according to IEC 60068-3-3.

If detailed information for the determination of a specific ground acceleration spectrum is available, the specific seismic class approach shall be followed according to IEC 60068-3-3 based on agreement between manufacturer and purchaser.

13.2 General seismic class approach

13.2.1 Generalities

In case of general seismic class approach, two methods are possible for the determination of the applied excitation spectrum:

- 1) Standard amplitude method: if no information is available on the location of the transformer and on the characteristics of the supporting structure, see 13.2.2.
- 2) Calculated amplitude method: if sufficient information is available on the location of the transformer and on the characteristics of the supporting structure, see 13.2.3.

13.2.2 The standard amplitude method

This method allows the qualification of the transformer for seismic classes when no information is available on the location of the transformer and on the characteristics of the supporting structure.

The purchaser of the transformer shall specify the seismic performance level suitable for the considered application.

This shall be done with a simplified 4-step approach to associate the performance level to a different seismic zone or by choosing directly the seismic performance level in Table 6.

Step 1: The relevant zone of earthquake activity shall be identified according to IEC 60721-2-6:1990, Figure 5.

Step 2: An approximate acceleration level shall be obtained from IEC 60721-2-6:1990, Table 1 according to the relevant seismic zone.

Step 3: Identify the relevant performance levels according to the approximate acceleration level according to Table 6.

Step 4: Choose the floor acceleration vertical and horizontal in the Table 6 for calculation of the tests.

Table 6 – Approximate acceleration level and performance level

Approximate acceleration level [m/s ²]	Seismic classes (Performance level)	Floor acceleration A_f m/s ²	
		Horizontal	Vertical
2	S-I	6	3
3	S-II	9	4,5
5	S-III	15	7,5

NOTE The approximate acceleration levels do not include the unknown factors such as superelevation, direction, damping and others, therefore they are different compared to the floor acceleration.

13.2.3 The calculated amplitude method

This method allows qualification of the transformer for seismic classes when information is available on the location of the transformer and on the characteristics of the supporting structure. This method is based on IEC 60068-3-3.

In this case the performance level corresponds to the floor acceleration defined as:

$$Af_x = AG \times K \times D_x$$

$$Af_y = AG \times K \times D_y$$

$$Af_z = AG \times K \times D_z$$

The level is calculated taking into account:

AG ground acceleration level (Table 7)

K super elevation factor (Table 8)

D direction factor (Table 9)

A_f represents the acceleration of the floor.

The test and calculation shall be carried out with the value calculated with A_f .

It is the responsibility of the purchaser of the transformer to decide which acceleration level is most suitable for the considered application.

Table 7 – Ground acceleration level (*AG*)

Ground acceleration reference	Description of earthquake				
		AG m/s ²	For information only		
	General		Richter scale magnitude	UBC Zone 1	Intensity MSK
AG2	Light to medium earthquakes	2	< 5,5	1-2	< VIII
AG3	Medium to strong earthquakes	3	5,5 to 7,0	3	VIII to IX
AG5	Strong to very strong earthquakes	5	>7,0	4	>IX

Table 8 – Recommended super elevation factors (*K*)

K factor	Application
1,0	Mounting of equipment on rigid foundations or on structures of high rigidity
1,5	Installations rigidly connected to buildings
2,0	Installations on stiff structures connected rigidly to buildings
3,0	Installations on low rigidity structures connected to buildings

Table 9 – Direction factors (*D*)

Axis of vibration	D factor	Limitations
Horizontal, D x	Dx = 1	
Horizontal, D y	Dy = 1	
Vertical, D z	Dz = 0,5	Only with a specified vertical attitude
Vertical, D z	Dz = 1	When the mounting attitude is not specified*
* If the effect of the gravity does not influence the behavior of the transformer, these tests are carried out with each the three main axes of the transformer in turn in the vertical plane. The direction factors for each case are /Dx = 1, Dy = 1 ,Dz = 0,5		

Example:

If we consider the K factor, "installation on stiff structure connected rigidly to buildings" then it comes for the performance level in the worst case:

$$Af_x = AG \times K \times D_x = 2 \text{ m/s}^2 \times 2 \times 1 = 4 \text{ m/s}^2$$

$$Af_y = AG \times K \times D_y = 2 \text{ m/s}^2 \times 2 \times 1 = 4 \text{ m/s}^2$$

$$Af_z = AG \times K \times D_z = 2 \text{ m/s}^2 \times 2 \times 0,5 = 2 \text{ m/s}^2$$

NOTE Example: $1 \text{ m/s}^2 = 0,1g$

14 Test

14.1 General requirements for tests

New transformers shall be subjected to routine tests as specified in this standard.

Transformers which have been in service may be tested in accordance with this specification, but dielectric test levels should be reduced to 80 %.

Tests shall be made by the manufacturer or at an approved laboratory, unless otherwise agreed between the supplier and the purchaser at the tender stage.

Routine tests shall be made with the transformer at approximately the temperature of the test facility.

Tests shall be performed on a completely assembled transformer including relevant accessories supplied.

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

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

14.2 Routine tests

14.2.1 Measurement of winding resistance

The test described in 11.2 of IEC 60076-1:2011 applies.

14.2.2 Measurement of voltage ratio and check of phase displacement

The test described in 11.3 of IEC 60076-1:2011 applies.

14.2.3 Measurement of short-circuit impedance and load loss

The test described in 11.4 of IEC 60076-1:2011 applies.

For transformers with tapplings impedance and load losses values shall be measured at the principal tapping. Measurements at other tap positions and the extreme tapping(s) exceeding 5 % are necessary for each design and may be specified in the enquiry if carried out as routines test.

The reference temperature of the short-circuit impedance and load loss shall be the permitted average winding temperature rise limits at rated current as given in column 2 of Table 2 plus 20 °C.

If the guaranteed average winding temperature rise is different from the Table 2 then the reference temperature of the short-circuit impedance and load loss shall be the guaranteed average winding temperature rise plus yearly average temperature of the external cooling medium given by the purchaser.

If one of the three temperatures of cooling medium changes (see 4.2) and the other two temperatures are not specified by the purchaser, then the two other temperatures of cooling medium shall be changed accordingly. (See example below)

When a transformer has different guaranteed winding temperature rises, the reference temperature for the calculation of the I^2R loss shall be the winding-temperature rise for each winding plus 20 °C or plus yearly external temperature of the external cooling medium given by the purchaser whichever is higher. The reference temperature to evaluate all the other losses shall be the average of the winding temperature rises plus 20 °C or plus yearly external temperature of the external cooling medium given by the purchaser whichever is higher. In case of different winding material or/and different reference temperature, average value shall be taken for calculation of additional losses (see Annex D) and shall be the appropriate reference temperature for the rating plate and technical documentation.

Example 1:

If the temperature of the external cooling medium is 50 °C at any time, then the monthly average of the hottest month becomes 40 °C and the yearly average 30 °C.

If the monthly average of the hottest month is 35 °C, then temperature of the external cooling medium becomes 45 °C at any time and the yearly average 25 °C.

Example 2:

HV has class 180 insulation and temp rise of 125K.

LV has class 155 insulation and temp rise of 100K.

I²R for HV are calculated at Tref 145.

I²R for LV are calculated at Tref 120.

Additional losses are calculated using the average temperature rises $(125 + 100)/2 = 112,5 \text{ K} + 20 = 132,5 \text{ °C}$.

14.2.4 Measurement of no-load loss and current

The test described in 11.5 of IEC 60076-1:2011 applies.

14.2.5 Applied voltage test (AV)

The test described in Clause 10 of IEC 60076-3:2013 applies.

The test voltage shall be in accordance with Table 3 and clause 11.2 of this standard for the specified insulation level of the transformer.

The full test voltage shall be applied for 60 s between the winding under test and all the remaining windings, core, frame and transformer enclosure, connected to earth.

14.2.6 Induced voltage withstand test (IVW)

The test described in 11.2 of IEC 60076-3:2013 applies.

The test voltage shall be twice the rated voltage.

The duration of the test at full voltage shall be 60 s for any test frequency up to and including twice the rated frequency. When the test frequency exceeds twice the rated frequency, the duration of the test shall be:

$$120 \times \frac{\text{rated frequency}}{\text{test frequency}} \text{ s, but not less than 15 s}$$

14.2.7 Partial discharge measurement

14.2.7.1 General

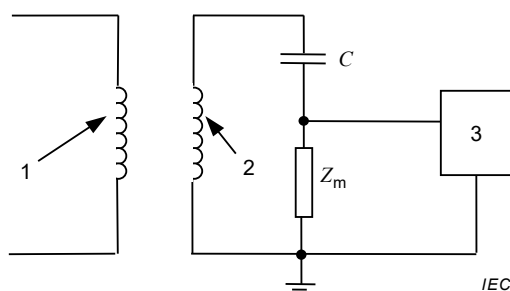
Partial discharge measurements shall be performed on all dry-type transformers. Measurement shall be made in accordance with IEC 60270 and with Annex A of IEC 60076-3:2013.

The partial discharge measurement shall be performed on transformer windings having $U_m \geq 3,6 \text{ kV}$.

14.2.7.2 Basic measuring circuit (typical only)

A basic measuring circuit for the partial discharge test is shown in Figure 1 and Figure 2.

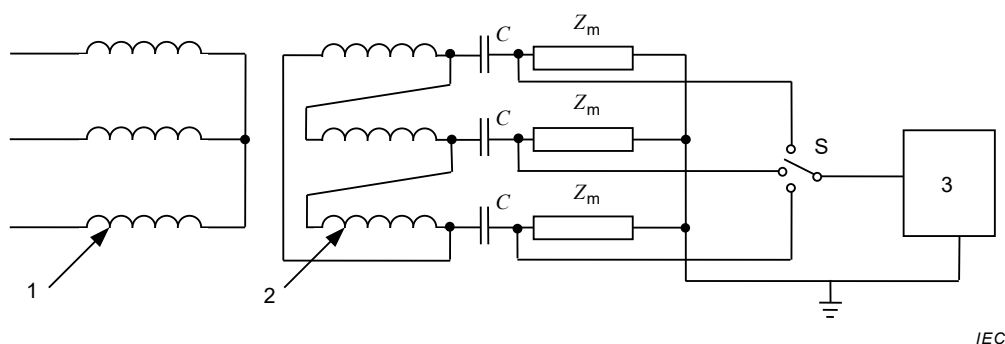
In the figures, a partial discharge-free high voltage capacitor, C , of suitable voltage rating (having a capacitance value large in comparison with the calibration generator capacitance, C_0) in series with a detection impedance, Z_m , is connected to each of the high-voltage winding terminals.



Key

- 1 Low-voltage winding
- 2 High-voltage winding
- 3 Measuring instrument

Figure 1 – Basic measuring circuit for the partial discharge test for a single-phase transformer



Key

- 1 Low-voltage winding
- 2 High-voltage winding, delta or star connected
- 3 Measuring instrument
- S Switch

Figure 2 – Basic measuring circuit for the partial discharge test for a three-phase transformer

14.2.7.3 Calibration of the measuring circuit

Attenuation of the discharge pulses occurs both within the windings and in the measuring circuit. Calibration is carried out as described in Annex A of IEC 60076-3:2013, by injecting simulated discharge pulses from a calibration generator at the transformer high voltage winding terminals. It is convenient if the calibration generator has a repetition frequency of the order of one impulse per half cycle of the power frequency used for the test on the transformer.

14.2.7.4 Voltage application

The partial discharge measurement shall be carried out after all dielectric tests are completed. The low-voltage winding shall be supplied from a three-phase or single-phase source, depending on whether the transformer itself is three-phase or single-phase. The voltage shall be as nearly as possible of sine-wave form and of a frequency suitably increased above the rated frequency to avoid excessive excitation current during the test. The procedure shall be as in 14.2.7.5 for three phase transformers or 14.2.7.6 for single phase transformers.

14.2.7.5 Three-phase transformers

The following test shall be performed on all dry-type transformers.

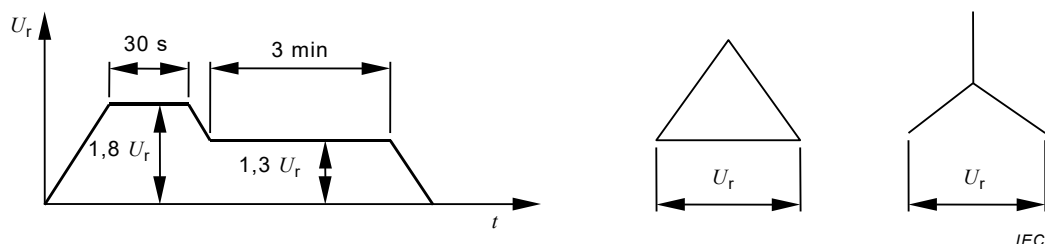


Figure 3 – Voltage application for routine partial discharge test

A phase-to-phase pre-stress voltage of $1,8 U_r$ shall be induced for 30 s where U_r is the rated voltage, followed without interruption by a phase-to-phase voltage of $1,3 U_r$ for 3 min, during which the partial discharge shall be measured.

14.2.7.6 Single-phase transformers

For single-phase transformers, U_r shall be the line-to-line or line-to-neutral voltage as appropriate. The voltage application shall be as for a three-phase transformer.

Three-phase transformers comprising of three single-phase transformers shall be tested as for three-phase transformers.

14.2.7.7 Partial discharge acceptance levels

The maximum level of partial discharges shall be 10 pC.

NOTE Transformers fitted with accessories, for example, surge arrestors are given special considerations. Partial discharge free means a level of PD measure less than 10pC.

14.3 Type tests

14.3.1 Full wave lightning impulse test (LI)

If not otherwise specified in this subclause, the relevant requirements of IEC 60076-3 apply.

If the tapping range is $\pm 5 \%$ or less, then the lightning impulse tests shall be made with the transformer connected on the principal tapping.

If the tapping range is larger than $\pm 5 \%$ then, unless otherwise agreed, the two extreme tapplings and the principal tapping shall be tested, one tapping for each of the three individual phases of a three-phase transformer or the three single-phase transformers designed to form a three-phase bank.

The test voltage shall be in accordance with Table 3 for the specified insulation level of the transformer.

The test impulse wave shape shall be 1 2 s 0 0 s 20 %.

The test voltage shall be of negative polarity. The test sequence per line terminal shall be one calibration impulse at a voltage between 50 % and 75 % of the full voltage followed by three impulses at full voltage.

By agreement between manufacturer and purchaser at enquiry stage, a special test with positive polarity can be defined.

If a chopped wave lightning impulse test (LIC) according to IEC 60076-3 is specified by the purchaser at the enquiry stage, the test voltage shall be the same magnitude as given in Table 3 of this standard for full wave.

NOTE In dry-type transformers, the lightning impulse test can give rise to capacitive partial discharges in the air which do not endanger the insulation. These partial discharges lead to changes in the current waveform, whilst the voltage waveform varies only slightly or not at all. Taking into account the above statement, slight deviations in current wave-form are not reasons for rejection.

14.3.2 Temperature-rise test

14.3.2.1 General

If not otherwise specified in this clause, the relevant requirements of IEC 60076-2 apply.

The temperature rise limits shall apply to the principal tapping corresponding to the rated voltage for a tapping range not exceed $\pm 5\%$.

If the tapping range exceeds $\pm 5\%$, the temperature rise limits shall apply to the minimum voltage tap at the appropriate tapping power. Tapping voltage and tapping current should be defined by agreement between manufacturer and purchaser in this case.

NOTE The load losses are different for different tapplings and sometimes also the no-load loss when variable flux voltage variation is specified.

A three-phase supply shall be used for the temperature rise test on three-phase transformers.

In case of harmonic content in the load current under normal service conditions, the value of the equivalent currents corresponding to the losses shall be determined by agreement between the manufacturer and the purchaser in accordance with 4.2.

The winding temperature rise shall be established by the rise in resistance method or by superposition method. For the determination of the average winding temperature rise the measured temperatures of the cooling air or of the water intake of the cooling equipment shall be used.

For three-phase transformers, the resistance measurements shall be made between the central and an outer phase line terminals.

NOTE When the temperature rise is performed it is advisable to measure the windings resistance close to the windings.

The location of the measuring points for ambient temperature and sensors on the transformer, if any, shall be the same for the reference and final measurements.

14.3.2.2 Methods of loading

14.3.2.2.1 General

Unless otherwise specified by the purchaser during the enquiry, the manufacturer may choose any of the following methods:

- simulated load method;
- back-to-back method;
- direct loading method.

These methods are applicable for an enclosed or non-enclosed or totally enclosed dry-type transformer(s) with natural air or forced air cooling or water force cooling.

14.3.2.2.2 Simulated load method

Temperature rise is established by combining the short-circuited test (load loss) and the open circuit test (no-load loss).

The short-circuited test shall be performed with rated current flowing in one winding and the other winding short-circuited and shall continue until the steady state condition of the windings and magnetic core are reached, see 14.3.2.4.

The open-circuit test, at rated voltage and rated frequency, shall be continued until steady-state condition of the winding and magnetic core is reached, see 14.3.2.4. The temperature rise of each winding, θ_e , shall then be measured.

The test procedure shall be performed in two steps in any sequence:

- the winding short-circuited test is carried out until stabilisation of the core and the winding temperature;
- the open-circuit test is carried out until stabilisation of the core and the winding temperature.

The total winding temperature rise, θ'_c , of each winding, with rated current in the winding and normal excitation of the core, is calculated by the following formula:

$$\Delta\theta'_c = \Delta\theta_c \left[1 + \left(\frac{\Delta\theta_e}{\Delta\theta_c} \right)^{1/K1} \right]^{K1}$$

where:

θ'_c is the total winding temperature rise;

θ_c is the winding temperature rise at the short-circuited test

θ_e is the winding temperature rise at the open-circuited test;

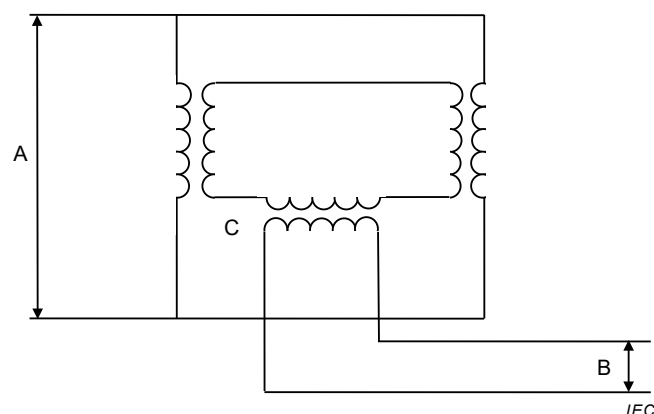
$K1 = 0,8$ for natural air cooling and $0,9$ for forced air cooling.

14.3.2.2.3 Back-to-back method

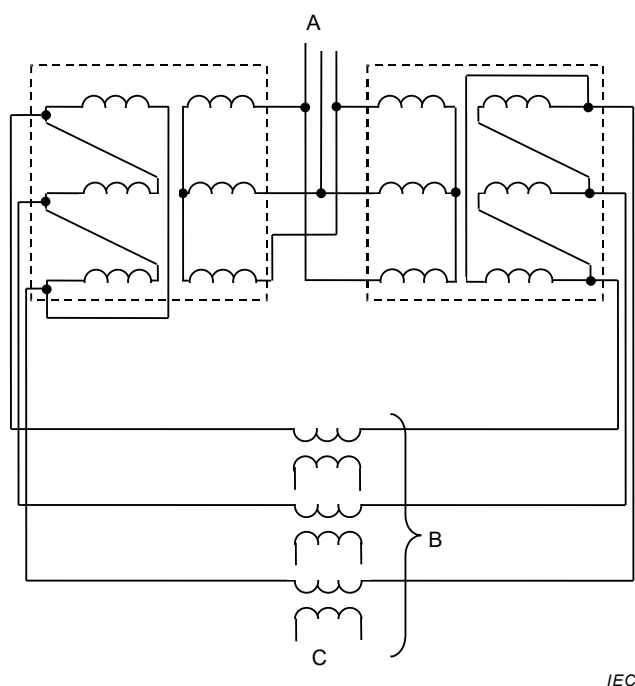
This method is appropriate when there are two suitable transformers and the necessary test equipment is available.

Two transformers, one of which is the transformer under test, are connected in parallel, and preferably the inner windings are excited at the rated voltage of the transformer under test. By means of different voltage ratios or an injected voltage, the rated current is made to flow in the transformer under test until stabilisation of the core and winding temperatures. See Figure 4 and Figure 5.

NOTE The duration of the test can be reduced by exciting the core for a period of time (preferably not less than 12 h) prior to the application of test current to the windings.

**Key**

- A Voltage source at rated frequency for no-load losses
- B Source for rated current at rated frequency for load losses
- C Booster transformer

Figure 4 – Example of back-to-back method – Single phase**Key**

- A Voltage source at rated frequency for no-load losses
- B Source for rated current at rated frequency for load losses
- C Booster transformer

Figure 5 – Example of back-to-back method – Three-phase**14.3.2.2.4 Direct loading method**

This method is only applicable for small transformers due to the limitation of the test laboratory power.

One winding, preferably the inner winding, of the transformer is excited at rated voltage with the other connected to a suitable load such that rated currents flow in both windings.

14.3.2.3 Winding temperature-rise correction for reduced current

When the input test current I_t is below the rated value of current I_N , but not less than 90 % I_N , the temperature rises θ_t , of the windings, shall be measured by the resistance method when steady-state conditions of the winding and magnetic core have been reached, and corrected to rated load conditions θ_N , by the formula:

$$\Delta\theta_N = \Delta\theta_t \left[\frac{I_N}{I_t} \right]^q$$

where:

θ_N is the temperature rise of the winding at the rated load condition;

θ_t is the temperature rise of the winding at the test current;

I_N is the rated value of current;

I_t is the input test current.

The value of q shall be taken as:

1,6 for AN transformers;

1,8 for AF transformers.

The value of q for other cooling system shall be defined by agreement between manufacturer and purchaser.

14.3.2.4 Determination of steady state conditions

The ultimate temperature rise is reached when the temperature rise becomes constant; this is considered to have been achieved when the temperature rise does not vary by more than 1 K per hour.

To determine when steady state conditions have been achieved, thermocouples or thermometers shall be applied on the centre of top yoke and as close as possible to low-voltage winding conductors at the top of the winding, the measurement being on the centre leg of a three-phase unit.

For other special cases, the determination of the steady state conditions process shall be agreed between manufacturer and purchaser.

14.4 Special tests

14.4.1 Partial discharge measurement for transformers operated under a single phase line-to-earth fault condition

Partial discharge measurement of single phase line-to-earth fault condition.

This special test is for transformers connected to systems which are isolated or earthed through a high value impedance and which can continue to be operated under a single phase line-to-earth fault condition. The test shall be performed when specified by the purchaser.

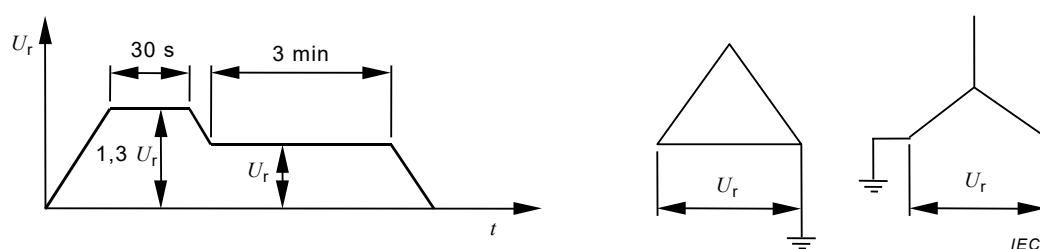


Figure 6 – Voltage application for special partial discharge test

A phase-to-phase voltage of $1,3 U_r$ shall be induced for 30 s, with one line terminal earthed, followed without interruption by a phase-to-phase voltage of U_r for 3 min during which the partial discharge shall be measured (see Figure 6). This test shall be repeated with another line terminal earthed.

All other criteria refer to 14.2.7.

14.4.2 Measurement of sound level

The relevant requirements in IEC 60076-10 apply.

NOTE Sound level guarantees are based on free field conditions and apparent increase in sound level can be noted on site due to reflections from the hard building walls, floor and ceiling.

14.4.3 Short-circuit test

If not otherwise specified in this standard, the relevant requirements of IEC 60076-5 apply.

14.4.4 Climatic tests

14.4.4.1 Test procedure

This test will determine the suitability of transformers for climatic classes.

The test is divided into two steps:

- storage test step;
- energizing test step.

For each climatic class, the ambient temperatures for these test steps are defined in Table 10.

Table 10 – Climatic class features

Climatic class	Storage ambient temperature (SAT) In °C	Energize ambient temperature(EAT) In °C
C1	–25	–5
C2	–25	–25
C3	–40	–25
C4	–50	–40
C5	–60	–50
C _{xy}	–x	–y

14.4.4.2 Test method

The test shall be carried out on a complete transformer without enclosure, if any. The transformer shall be placed in a test chamber.

The ambient temperature in the chamber shall be measured at a minimum of 3 positions located 0,1 m from the external surface and at half the height of the test object. The mean values of the readings shall be taken as the reference air temperature.

By agreement between supplier and purchaser, the test may be carried out on all coils removed from the core. The final dielectric checks should be carried out after reassembling the tested coils on the transformer.

The following test procedure shall be applied:

- a) The air temperature in the test chamber shall be gradually decreased to the storage ambient temperature (SAT) $\pm 3\text{ }^{\circ}\text{C}$ in 8 h and then maintained at this value for at least 12 h until steady state condition have been reached at less than 1 K per hour.
- b) The temperature shall then be gradually increased up to energize ambient temperature (EAT) $\pm 3\text{ }^{\circ}\text{C}$ in about 4 h. This temperature shall be maintained for at least 12 h until steady state condition have been reached. If EAT is equal to SAT, this step is deleted.
- c) A thermal shock shall then be performed by applying a current equal to twice the rated current to the winding under test (contained in solid insulation such as cast coil or open wound vacuum impregnated). The current shall be maintained until the winding under test reaches a mean temperature corresponding to the average winding temperature rise, according to Table 2, plus $40\text{ }^{\circ}\text{C}$ (maximum ambient temperature in normal service conditions). In case this temperature limit is not reached after 12 h, the test is considered as completed. The mean temperature reached by the windings shall be determined by resistance variation. The thermal shock should be performed by applying one of the following methods.

1) Test with DC supply:

The prescribed thermal shock shall be performed by applying a DC current of the specified value to the winding to be tested. In case of multiphase transformers, the test current should be applied to all phase coils connected in series.

NOTE 1 To put the coils in series, it might be necessary to remove the winding connections.

The monitoring of the winding mean temperature for the duration of the test can be made directly by the volt-ampere method measuring the test current and the relevant voltage drop.

2) Test with AC supply:

The prescribed thermal shock shall be performed by applying an AC current of the specified value to the winding to be tested, with the other winding(s) short-circuited. In case of multiphase transformers, a symmetrical system of currents should be applied. The monitoring of the winding mean temperature for the duration of the test should be performed in DC by superimposing the measuring current to the AC test current, or according to another equivalent method.

The coil not under the test can be overheated.

3) Test with AC supply, alternative method:

Twice the rated current shall be supplied to the transformer with one of the windings short-circuited. The temperature in each of the windings is monitored by readings of temperature sensors fixed near the bottom and top of the winding surface. The sensors are calibrated by a calibration test with twice the rated current carried out at normal ambient temperature before the actual test.

The sensors are calibrated by comparing the sensor readings with the winding temperature rise as measured by change in winding resistance. In this way, the sensor reading corresponding to an average winding temperature rise according to Table 2