



IEC 60076-11

Edition 2.0 2018-08
REDLINE VERSION

INTERNATIONAL STANDARD



Power transformers –
Part 11: Dry-type transformers

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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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INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 11: Dry-type transformers

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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

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- withdrawn,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

The contents of the corrigendum of March 2019 and the 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 ~~36~~ 72,5 kV and at least one winding operating at greater than 1,1 kV. ~~The standard applies to all construction technologies.~~

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 (~~see IEC 60044 and IEC 60186~~);
- 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 60050 (all parts), International electrotechnical vocabulary (IEV)~~

IEC 60068-3-3, *Environmental testing – Part 3-3: Guidance – Seismic test methods for equipments*

~~IEC 60071 (all parts), Insulation co-ordination~~

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: ~~1993~~ 2011, *Power transformers – Part 1: General Amendment 1 (1999)*

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 classification of electrical insulation 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 60905:1987, *Loading guide for dry-type power transformers*~~

~~IEC 61330, *High-voltage/low-voltage prefabricated substations*~~

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

~~4.2.1 General~~

~~Unless otherwise stated, the service conditions in 4.2.2 to 4.2.6 apply. When transformers are required to operate outside the normal service conditions, de-rating in accordance with 11.2 and/or 11.3 applies.~~

a) Altitude:

~~A height above sea level not exceeding 1 000 m. See IEC 60076-1.~~

b) Temperature of cooling air and water:

~~The temperature of cooling air not exceeding:~~

- ~~40 °C at any time;~~
- ~~30 °C monthly average of the hottest month;~~
- ~~20 °C yearly average.~~

~~and not below:~~

- ~~–25 °C in the case of outdoor transformers;~~
- ~~–5 °C in the case of indoor transformers.~~

~~where the monthly and yearly averages are as defined in 3.12 of IEC 60076-1.~~

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 supply voltage of which the waveshape is approximately sinusoidal.~~

~~NOTE This requirement is normally not critical in public supply systems but may have to be considered in installations with considerable converter loading. In such cases, there is a conventional rule that the deformation shall neither exceed 5 % total harmonic content nor 1 % even harmonic content, see IEC 61000-2-4. Also note the importance of current harmonics for load loss and temperature rise, see IEC 61378-1.~~

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 ~~polyphase~~ three-phase supply voltages:

~~For three phase transformers, a set of three phase supply voltages which are approximately symmetrical.~~

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.

~~4.2.6 Humidity~~

~~The relative humidity of the surrounding air shall be less than 93 %. No drops of water shall be present on the surface of the coils.~~

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 60905~~ IEC 60076-12.

5.2.2 ~~Operation~~ 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 transformer shall be fully rated when supplied in an enclosure.~~ The rated power refers to continuous loading. This is a reference value for guarantees and tests concerning load losses and temperature rises ~~and short-circuit impedance.~~

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 ~~nominal~~ rated power ~~rating with and~~ without fans shall be subject to agreement between purchaser and supplier.

~~The rating plate shall indicate both the power rating without fans and the maximum power rating with fan cooling.~~

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 ~~Operation in an~~ Transformer with enclosure

~~For operation in an enclosure that is not provided or later provided by the manufacturer of the transformer, see Annex D of IEC 61330 and IEC 60905.~~

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 ~~supplier~~ 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 ~~conditions~~

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/s² 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/s² 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 °C.

~~The supplier shall be informed of anticipated high levels of shock, vibration and inclination during transportation to site.~~

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

~~Within the prescribed value of U_m , a transformer shall be capable of service without damage under conditions of overfluxing where the ratio of voltage over frequency exceeds the corresponding ratio at rated voltage and rated frequency by no more than 5 %.~~

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 ~~and~~ unless such operation ~~should be~~ is of limited duration. This condition ~~should be~~ 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 ~~off-circuit~~ with de-energised transformers by the use of bolted links or ~~off-circuit tap changers~~ DETC.

7 Connections

Unless otherwise specified by the purchaser, transformer connections shall be Dyn11 or Dyn5 ~~with clock hour figure 5 or 11~~ 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 ~~temperature~~ for each winding (either by temperature, letter or both – refer to IEC 60085). The first ~~letter~~ thermal class shall refer to the high voltage winding, the second ~~letter~~ thermal class shall refer to the low voltage winding. When more than two windings are present, the ~~letters~~ 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 ~~for each kind of cooling~~;
- 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.

~~The rated withstand voltages for all windings shall appear on the rating plate. The principles of the standard notation are illustrated in Clause 5 of IEC 60076-3.~~

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 1 of IEC 60905~~ 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 ~~4 in 4.2.4 of IEC 60905~~ 9 in 5.8 of IEC 60076-12:2008 with the values for Z and q given in ~~7.2 of IEC 60905~~ 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-air medium temperatures or special-air cooling medium conditions

When the transformer is designed for service where the temperature of the cooling-air 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-air medium or produce high ambient-air 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 ~~500~~ 100 m by which the intended working altitude exceeds 1 000 m:

- natural-air-cooled transformers: ~~2,5~~ 0,5 %;
- forced-air-cooled transformers: ~~5~~ 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

~~When transformers are intended for general power distribution in public or industrial systems, the insulation levels shall be those given in Table 3, list 1 or list 2.~~

~~Table 3 – Insulation levels based on European practice~~

Highest voltage for equipment U_m (r.m.s.) kV	Rated short duration separate-source AC withstand voltage (r.m.s.) kV	Rated lightning impulse withstand voltage (peak value) kV	
		List 1	List 2
≤1,4	3	–	–
3,6	40	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

~~Table 4 – Insulation levels based on North American practice~~

Dielectric insulation levels for dry type transformers used on system with BILs 200 kV and below													
Max LL system voltage kV	Nominal LL system voltage kV	Low frequency voltage insulation level kV r.m.s.	Basic Lightning Impulse Insulation Levels (BILs) in common use (peak value 1,2 μs)										
			10	20	30	45	60	95	110	125	150	200	
0,25	0,25	2,5	None										
0,6	0,6	3	S	1	1								
1,2	1,2	4	S	1	1								
2,75	2,5	10		S	1	1							
5,6	5	12			S	1	1						
9,52	8,7	19				S	1	1					
15,5	15	34					S	1	1				
18,5	18	40						S	1	1			
25,5	25	50							2	S	1	1	
36,5	34,5	70									2	S	1
Impulse chopped wave: minimum time to flash over (μs)			1	1	1	1,3	2	2	1,8	2	2,3	2,7	
S – Standard values.													
1 – Optional higher levels where exposure to overvoltage occurs and higher protective margins are required.													
2 – Lower levels where surge arrester protective devices can be applied with lower spark over levels.													

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
≤ 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:

$U_r = 23,8$ kV +/-5 % then the insulation levels of U_m 24 kV should apply

$U_r = 11,8$ kV +/-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 ~~3 000~~ 4 500 m above sea-level, but tested at ~~normal~~ another altitude, ~~the rated short duration separate source AC withstand voltage shall be increased by 1 % for each 100 m above 1 000 m, correction to the test voltages shall be applied according to Table 4. Above 3 000 m, the insulation level shall be defined by agreement between supplier and purchaser.~~ 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:

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

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

~~Two~~ 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 ~~Clause 27~~ 14.4.4 shall confirm the conformity of ~~C1 and C2 class~~ transformers classes.

~~NOTE Transformers for outdoor operation should normally be provided with an enclosure or be given other suitable protection.~~

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.

~~NOTE These are important not only during service but also during storage before installation.~~

With regard to humidity, condensation and pollution, ~~three~~ 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 ~~heavy~~ 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 ~~Clause 26~~ 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 ~~Clause 28~~ 14.4.6 shall confirm the conformity of class F1 transformers.

~~NOTE – Measurements made in conformity with Clause 28 tend to result in a standard deviation ≤ 10 K.~~

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 ~~the same~~ 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.

~~The tests specified in Clauses 26, 27 and 28 shall be carried out as specified on one transformer being representative of the design type.~~

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		SubClause	Climatic		Environmental			Fire behaviour	
Tests			C1, C2, C3, C4, C5, Cxy		E0	E1, E2, E3, E4, E-O-1, E-O-2, E-O-3	F0	F1	
4	Thermal shock at -5 °C	27.3	Yes	No	-	-	-	-	
2	Thermal shock at -25 °C	27.4	No	Yes	-	-	-	-	
3	Condensation test	26.3.1	-	-	No	Yes	No	-	
4	Condensation and humidity penetration test	26.3.2	-	-	No	No	Yes	-	
5	Fire behaviour test	28.3	-	-	-	-	No	Yes	
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/s² or approximately 0,2 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 <i>A_f</i> 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				
	General	AG m/s ²	For information only		
			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	D y = 1	
Vertical, D z	D z = 0,5	Only with a specified vertical attitude
Vertical, D z	D z = 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 %, ~~however, the guarantee levels of the transformer when new do not apply.~~

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.

~~Dielectric tests in accordance with Clauses 19, 20 and 21~~ Routine tests shall be made with the transformer at approximately the temperature of the test ~~house~~ 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 ~~supplier~~ 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.

~~When a transformer has windings of different insulation system temperatures, the reference temperature relating to the winding having the higher insulation system temperature shall be used.~~

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.

I^2R for HV are calculated at Tref 145.

I^2R 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 ~~Separate source AC withstand voltage test~~ 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 ~~or Table 4~~ 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 AC withstand voltage test~~ 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

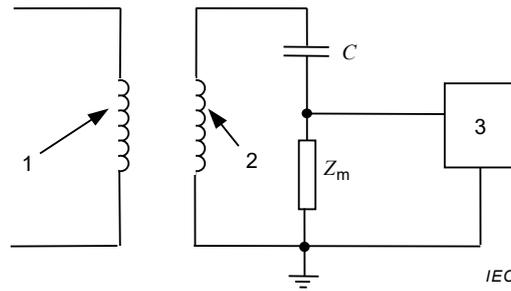
Partial discharge measurements shall be performed on all dry-type transformers. Measurement shall be made in accordance with IEC 60270 and with Annex A of IEC 60076-3:2013.

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.

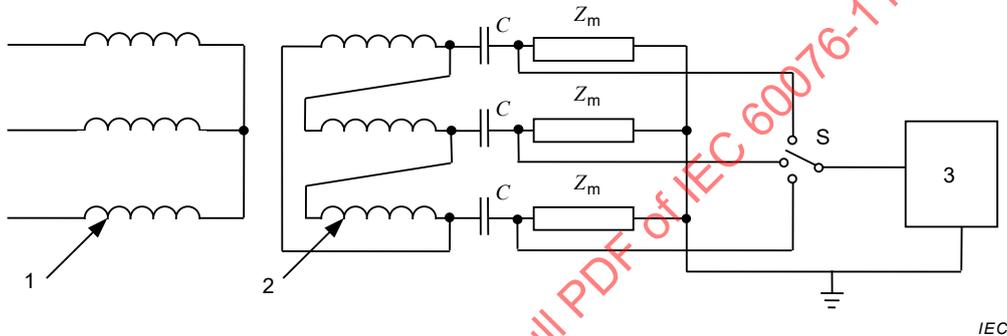
In the figures, a partial discharge-free high voltage capacitor, C , of suitable voltage rating (having a capacitance value large in comparison with the calibration generator capacitance, C_0) in series with a detection impedance, Z_m , is connected to each of the high-voltage winding terminals.



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 ~~standard discharge calibrator~~ 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.

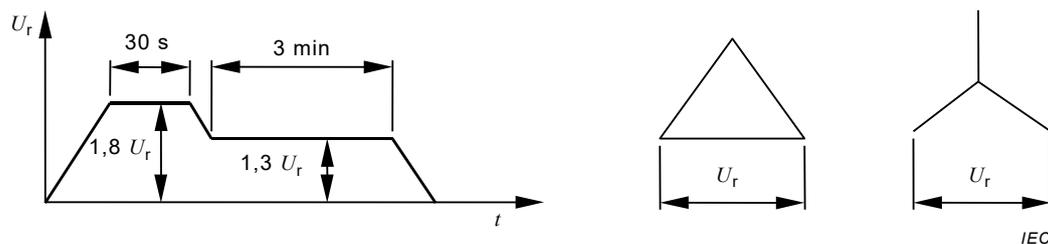


Figure 3 – Voltage application for routine partial discharge test

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 ~~Special considerations should be given to transformers fitted with accessories, for example, surge arrestors.~~ 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 ~~test described in Clause 13~~ 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 tappings 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 ~~or Table 4~~ for the specified insulation level of the transformer.

The test impulse wave shape shall be $1,2 \mu\text{s} \pm 30\%$ / $50 \mu\text{s} \pm 20\%$.

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. ~~In this case, the separate source voltage withstand test and induced overvoltage withstand test should be repeated.~~ 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

~~The relevant requirements in 5.1, 5.2.3, 5.4, 5.5 and 5.6 of IEC 60076-2 apply. A three phase supply shall be used for the temperature rise test on three phase transformers.~~

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 tappings 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

~~The manufacturer may choose any of the following methods may be applied.~~

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

~~This method is applicable for an enclosed or non-enclosed or totally enclosed dry type unit with natural air or forced air cooling.~~

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

~~The temperature of the transformer shall be stabilised with that of the test laboratory environment. The resistance of the high voltage and low voltage windings shall be measured, these values will be used as reference values for the calculation of the temperature rise of the two windings. The ambient temperature of the test laboratory shall also be measured and registered.~~

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

~~The location of the measuring points (that is, the ambient temperature thermometers and sensors on the transformer, if any), shall be the same for the reference and final measurements.~~

~~The winding 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 winding temperature rise, $\Delta\theta_e$, shall be established by the rise in resistance method or by superposition.~~

The open-circuit test, at rated voltage and rated frequency, shall be continued until steady-state condition of the winding and magnetic core is ~~obtained, individual winding temperature rises, $\Delta\theta_e$, shall then be measured~~ reached, see 14.3.2.4. The temperature rise of each winding, $\Delta\theta_e$, shall then be measured.

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

- the winding short-circuited test is carried out until stabilisation of the core and the winding temperature. ~~Subsequently, an open-circuit test shall be carried out until stabilisation of the core and winding temperature is reached;~~

or

- the open-circuit test is carried out until stabilisation of the core and the winding temperature. ~~Subsequently, the winding short-circuited test shall be carried out until stabilisation of the core and winding temperature is reached.~~

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

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

where:

$\Delta\theta'_c$ is the total winding temperature rise;

$\Delta\theta_c$ is the winding temperature rise at the short-circuited test

$\Delta\theta_e$ is the ~~individual~~ 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 ~~similar~~ suitable transformers and the necessary test equipment is available. ~~It is applicable for enclosed or non enclosed dry type units with natural air or forced air cooling.~~

~~The temperature of the transformer shall be stabilised with that of the test laboratory environment. The resistance of the high voltage and low voltage windings shall be measured, these values will be used as reference values for the calculation of the temperature rise of the two windings. The ambient temperature of the test laboratory shall also be measured and registered.~~

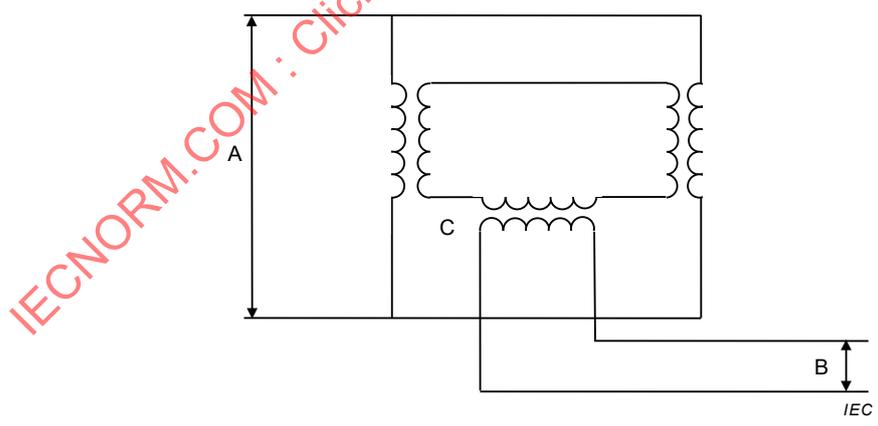
~~The location of the measuring points shall be the same for the reference and final measurements.~~

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

~~In a three phase transformer, the measurement should preferably associated with the middle limb in case of star connected winding.~~

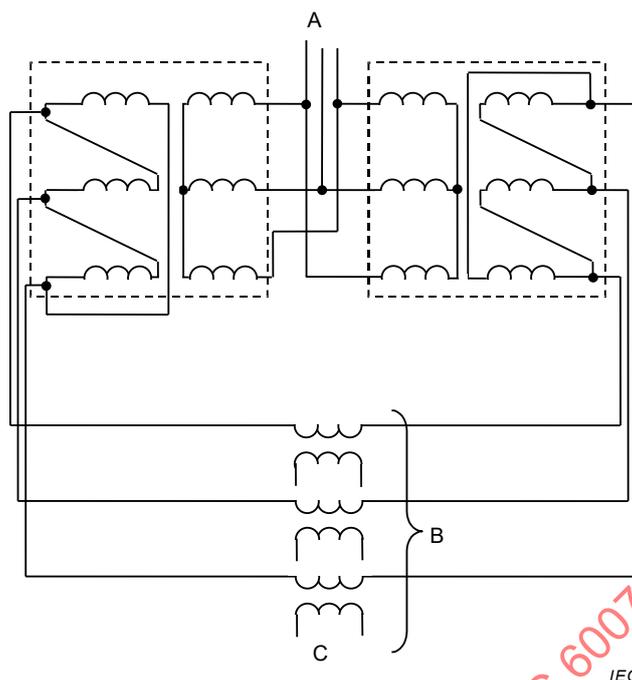
Two transformers, one of which is the transformer under test, are connected in parallel, and preferably the inner windings are excited at the rated voltage of the transformer under test. By means of different voltage ratios or an injected voltage, the rated current is made to flow in the transformer 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 method⁴

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 rise, $\Delta\theta_t$, 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, $\Delta\theta_N$, by the formula:

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

where:

$\Delta\theta_N$ is the temperature rise of the winding at the rated load condition;

$\Delta\theta_t$ 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:

⁴—The duration of the test may 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.

- 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 ~~to the following surfaces~~ 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 all types of transformers defined in Clause 3: centre of top yoke and as close as practicable to the innermost 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 Additional procedure test (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 ~~additional~~ 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.

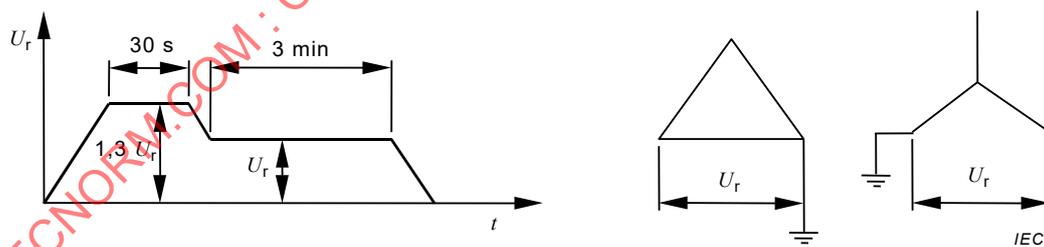


Figure 6 – Voltage application for special partial discharge test

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 ~~may~~ can be noted on site due to reflections from the hard building walls, floor and ceiling.

14.4.3 Short-circuit test

~~The relevant requirements in IEC 60076-5 apply.~~

~~The partial discharge test shall be repeated after the short-circuit test. The final values shall not exceed the limits given in 22.5.~~

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

~~27.1 Thermal shock test (special test)~~

This test will determine the suitability of transformers for climatic classes ~~as defined in 13.1. For the test sequence, see 13.4.~~

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

~~27.3 Thermal shock test for C1 class transformers~~

14.4.4.2 Test method

The test shall be carried out on a complete transformer² 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.

²~~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 unit.~~

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 ~~$(-25 \pm 3)^\circ\text{C}$~~ the storage ambient temperature (SAT) $\pm 3^\circ\text{C}$ 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 ~~$(-5 \pm 3)^\circ\text{C}$~~ energize ambient temperature (EAT) $\pm 3^\circ\text{C}$ 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°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 ~~could~~ 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 ~~over-positioning~~ 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 plus 40°C is determined. The same sensor reading shall be obtained in the test, which starts at low ambient temperature.

The coil not under the test can be overheated.

NOTE 2 Care ~~should~~ needs to be taken to prevent thermally overstressing some windings because of the different thermal transient behaviour of the transformer parts.

- d) After the thermal shock, the transformer shall be brought back to a temperature of $(25 \pm 10)^\circ\text{C}$.

14.4.4.3 Test criteria

~~At least 12 h after the end of~~ After the thermal shock test, the transformer shall be submitted to the dielectric routine tests (~~separate source~~ applied voltage test and induced ~~over~~voltage withstand tests), in accordance with the insulation level of the windings, but at voltages reduced to 80 % of the standard values.

~~In addition, for transformers having windings contained within solid insulation,~~ Partial discharge measurements shall be carried out ~~according to Clause 22~~. The test voltage shall not exceed the test voltage of the reduced induced overvoltage withstand test (160 % of the rated value) and the measured values shall not exceed those prescribed for routine tests.

When visually inspected, the windings shall show no visible abnormality, such as cracks or slits.

14.4.4.4 Validity of the test

The validity of the results of a climatic test carried out on ~~a~~ the reference tested transformer can be extended to other transformers ~~based on the same design criteria, such as~~ which have:

- the same or lower current density (A/mm²);
- the same or lower insulation level for HV winding;
- for insulation level HV over 24kV or for rated power above 1000kVA the extension of the validity is subject of an agreement between purchaser and manufacturer. (by calculation or tests);

The transformer shall have the same criteria as the reference tested transformer for:

- ~~same~~ conceptual design ~~(for example, windings contained in solid insulation or not, winding type, degree of protection, etc.)~~ and design rules;
- ~~same~~ conducting materials;
- ~~same~~ main insulating materials;
- raw materials;
- production process;
- same or lower average temperature rise for the windings ~~(according to Table 2)~~.

~~27.4 Thermal shock test for C2 class transformers~~

~~27.4.1 Test method~~

~~The test methods are the same as in 27.3.1 with the following modification:~~

~~Step b) is deleted in order to carry out the thermal shock test from –25 °C.~~

~~27.4.2 Test criteria~~

~~The test criteria are the same described in 27.3.2.~~

14.4.5 Environmental test

14.4.5.1 General

This test establishes the suitability of transformers for environmental classes as defined in 13. ~~For the test sequence, see 13.4.~~

If not otherwise specified, the tests shall be performed on one transformer completely assembled, fitted with its accessories (if relevant for the test).

The transformer and its accessories shall be new and clean without any additional surface treatment ~~of the insulating parts.~~

14.4.5.2 Test procedure for classes E1, E2, E3, E4

~~26.3.1 Class E1 transformers~~

~~This test is a condensation test.~~

~~The transformer shall be placed in a test chamber in which temperature and humidity are kept under control.~~

~~The volume of the chamber shall be at least five times that of the rectangular box circumscribing the transformer. The clearances from any part of the transformer to walls, ceiling and spraying nozzles shall be not less than the smallest phase to phase clearance between live parts of the transformer and not less than 150 mm.~~

~~The temperature of the air in the test chamber shall be such as to ensure condensation on the transformer.~~

~~The humidity in the chamber shall be maintained above 93 %. This may be achieved by periodically or continuously atomising a suitable amount of water.~~

~~The conductivity of the water shall be in the range of 0,1 S/m to 0,3 S/m.~~

~~The position of the mechanical atomisers shall be chosen in such a way that the transformer is not directly sprayed.~~

~~No water shall drop from the ceiling upon the transformer under test.~~

~~The transformer shall be kept in air having a relative humidity above 93 % for not less than 6 h, without being energised.~~

~~Within 5 min thereafter the transformer shall be submitted to a test with induced voltage as follows:~~

- ~~— Transformers with windings intended for connection to a system which are solidly earthed or earthed through a low impedance shall be energised at a voltage of 1,1 times the rated voltage for a period of 15 min.~~
- ~~— Transformers with windings intended for connection to systems which are isolated or earthed through a considerable impedance shall be submitted to a test with induced voltage for 3 successive periods of 5 min. During the test, each high voltage terminal in turn shall be connected to earth and a voltage of 1,1 times the rated voltage shall be applied between the other terminals and earth. The three phase test can be replaced by single phase tests with the two non-earthed phase terminals being interconnected.~~

~~Preferably, the above test should be made in the test chamber.~~

~~During the voltage application, no flashover shall occur and visual inspection shall not show any serious tracking.~~

~~26.3.2 Class E2 transformers~~

~~This test procedure includes a condensation test and a humidity penetration test. The condensation test shall be the same as described under 26.3.1, except for the conductivity of water which shall be in the range of 0,5 S/m to 1,5 S/m.~~

~~At the beginning of the humidity penetration test, the transformer shall be in a dry condition. It shall be installed in a de-energised condition and held in the climatic chamber for 144 h. The temperature of the climatic chamber shall be held at $(50 \pm 3)^\circ\text{C}$ and the relative humidity held at $(90 \pm 5)\%$. At the end of this period and after 3 h in normal ambient conditions at the latest, the transformer shall be subjected to the separate source AC withstand voltage test and the induced AC withstand voltage test, but at voltages reduced to 80 % of the standardised values.~~

~~There should be neither flashover nor breakdown during the dielectric tests and visual inspection shall not show any serious tracking.~~

This test procedure includes a condensation test for all classes and followed by a humidity penetration test for classes E2, E3 and E4.

Table 11 – Environmental classes

Class	Conductivity range S/m	Humidity value for condensation test	Humidity penetration tests
E1	0,1 to 0,3	>93 %	NO
E2	0,5 to 1,5	>93 %	YES
E3	3,6 to 4,0	>95 %	YES
E4	5,6 to 6,0	>95 %	YES

For the condensation test the transformer shall be placed in a test chamber in which temperature and humidity are kept under control.

- The volume of the chamber shall be at least five times that of the rectangular box circumscribing the transformer. The clearances from any part of the transformer to walls, ceiling, spraying nozzles and temperature sensors shall be not less than the smallest phase-to-phase clearance between live parts of the transformer and not less than 150 mm.
- The position of the mechanical atomisers shall be chosen in such a way that the transformer is not directly sprayed.
- The temperature of the air in the test chamber shall be such as to ensure condensation on the transformer. The surface of the transformer shall be at least 10 K colder than the temperature in the test chamber at the beginning of the test.
- The humidity in the chamber shall be increased in less than one hour up to the value given in Table 11 and then maintained above this value. This shall be achieved by periodically or continuously atomising a suitable amount of water.
- The transformer shall be kept in air having a relative humidity as defined in Table 11 for not less than 2 h, without being energised
- The temperature of the water basin shall be between 8 K and 10 K higher than the temperature in the test chamber during the test.
- No water shall drip from the ceiling upon the transformer under test.
- The conductivity of the water shall be in the range defined in Table 11.
- Within 5 min after stopping the atomiser spray and while the transformer remains in the test chamber, the transformer shall be submitted to a test with induced voltage as follows:

- Transformers with windings intended for connection to a system, which are solidly earthed or earthed through a low impedance, shall be energised at a voltage of 1,1 times the rated voltage for a period of 15 min.
- Transformers with windings intended for connection to systems which are isolated or earthed through considerable impedance shall be submitted to a test with induced voltage for three successive periods of 5 min. During the test, each high voltage terminal in turn shall be connected to earth and a voltage of 1,1 times the rated voltage shall be applied between the other terminals and earth. The three-phase test can be replaced by single-phase tests with the two non-earthed phase terminals being interconnected. The time between each of the three tests shall be less than 3 min.

In case both of the above tests are to be carried out, the test sequence shall start with the test for transformers with windings intended for connection to systems which are isolated or earthed through considerable impedance.

- During the voltage application, no collapse of voltage and no flashover shall occur. Visual inspection shall not show any serious tracking (no carbonised or no erosion trace not removable by wiping on the insulation surfaces)

For the humidity penetration test:

- At the beginning, the transformer shall be in a dry condition but not wiped to eliminate the remaining condensation from the condensation test.

NOTE The transformer could be dried in a climatic chamber.

- Transformers shall be installed in a de-energised condition and held in the climatic chamber for 144 h.
- The temperature of the climatic chamber shall be held at $(50 \pm 3) ^\circ\text{C}$ and the relative humidity held at $(90 \pm 5) \%$.
- Within 3 h after ending the humidity penetration period and in normal ambient conditions, the transformer shall have completed the applied voltage test (AV) and the induced withstand voltage test, but at voltages reduced to 80 % of the standardised values.
- During the voltage application, no collapse of voltage and no flashover shall occur. Visual inspection shall not show any serious tracking (no carbonised or no erosion trace not removable by wiping on the insulation surfaces).

14.4.5.3 Validity of the test

The validity of the results of an environmental test carried out on ~~a~~ the reference tested transformer can be extended to other transformers based on the same ~~design criteria, such as~~ or lower insulation level for HV winding and the same or lower rated voltage for HV winding.

- for insulation level HV over 24kV or for rated power above 1000kVA the extension of the validity is subject of an agreement between purchaser and manufacturer. (by calculation or tests);

The transformer should have the same criteria as the reference tested transformer for:

- ~~same conceptual design (for example, windings contained in solid insulation or not, winding type, degree of protection, etc.)~~ and design rules;
- ~~same main insulating materials.~~
- raw materials;
- production process.

14.4.6 Fire behaviour test

14.4.6.1 General

To optimise the behaviour of a transformer, it is necessary to minimise its emission of toxic substances and opaque smoke in the event of burning. The use of halogenic materials should

be avoided. Checking of corrosive and harmful gas emission shall be made as described below. Moreover, the transformer shall not contribute significantly to the thermal energy of an external fire. The fire behaviour shall be assessed by the test procedure in 14.4.6.2.

~~28.2 — Checking of corrosive and harmful gases emission~~

The emission of corrosive and harmful gases shall be checked on small quantities of the combustible materials present in the transformer.

In principle, the tests should be able to detect the presence of components such as hydrogen chloride (HCl), hydrogen cyanide (HCN), hydrogen bromide (HBr), hydrogen fluoride (HF), sulfur dioxide (SO₂), formaldehyde (HCHO).

~~The details of test procedures and acceptable limits for gas emission may be agreed between purchaser and supplier unless~~ specified in national regulations if any.

14.4.6.2 Fire behaviour test for F1 class transformer

14.4.6.2.1 Test object

The test shall be carried out on one complete phase of a transformer comprising HV and LV coils, core leg and insulation components, without enclosure ~~if any~~. The core leg may be replaced by material of approximately similar dimensions and thermal behaviour as the original core leg. The yoke shall not be considered and the LV terminal leads shall be cut at the upper and lower end coil level.

The outer coil diameter of circular windings or the maximum cross dimension for non-circular windings to be tested shall be between 400 mm and 500 mm ~~of a standard transformer~~. The minimum dimension is given to keep the test relevant regarding the calorific value of the coil during the test.

~~NOTE — Windings with larger or smaller dimensions may be tested by agreement.~~

14.4.6.2.2 Validity of the test

The validity of the results of a fire test carried out on a transformer can be extended to ~~other~~ different transformers (rated power, voltage, etc.) based on the same design criteria, such as:

- ~~same~~ similar conceptual design (for example, windings contained in solid insulation or not, winding type, degree of protection, etc.);
- ~~same average temperature rise for the windings (according to Table 2);~~
- identical thermal insulation class;
- same main insulating materials;
- Identical formula and composition for casting system or impregnation system.

14.4.6.3 Testing installation

14.4.6.3.1 Test chamber

The test chamber shall be based on that described in IEC 60332-3-10 (related to cables), see Figure 7. The walls shall be made of heat resistant steel with a thickness of 1,5 mm to 2,0 mm, thermally insulated, so as to give a heat transfer of approximately 0,7 W/(m²K). A fire resistant window should be fitted if possible. The dimensions of the test chamber are shown in Table 12.

All dimensions in mm.

Table 12 – Dimension of the chamber

A ^a	B		C	D	E	F		G Diameter	H Diameter
	Minimum	Maximum				Minimum	Maximum		
9 000	3 500	4 000	2 000	1 000	600	1 500	2 000	500	500
J	K Minimum	L Diameter	M	N	P	Q	R	S	T
300	400	350	800	400	800	500	900	400	1 200
U	V	W	X	Y	Z	AA	AB^b	AC^b	
500	175	300	30	40	20	50	1 000	1 000	

^a Approximate height.
^b Minimum dimension.

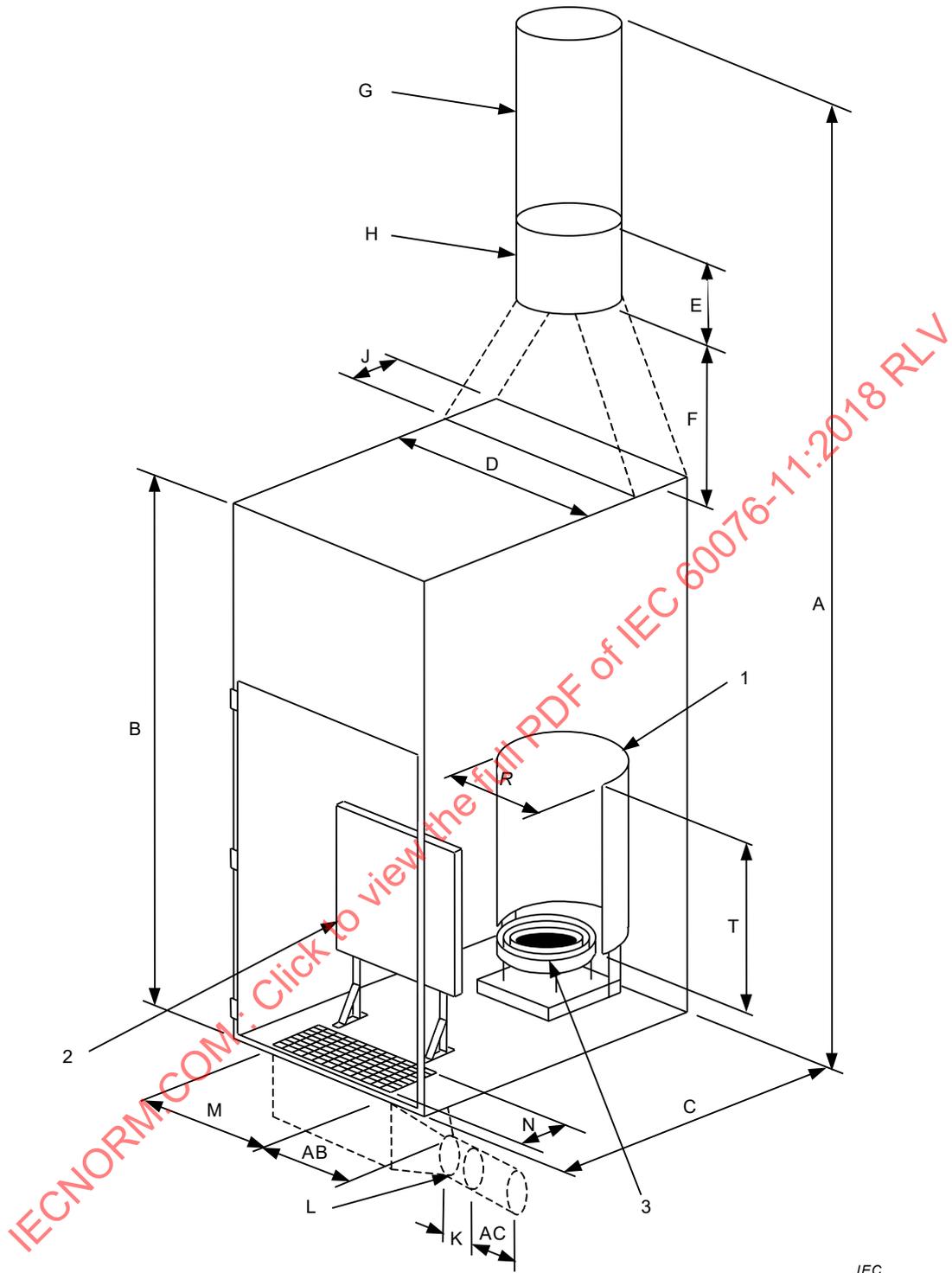
The chamber shall be equipped with a chimney of approximately 500 mm inner diameter and an air-inlet duct of approximately 350 mm inner diameter. The difference in level between the air inlet into the test-chamber and gas outlet at the chimney shall be approximately 9 m. The air is admitted under the test chamber through a grating (400 × 800) mm² and escapes through an opening of approximately 0,3 m² into the chimney.

Within the chimney, there shall be a measuring section of 500 mm diameter and a length of at least 600 mm, the lower end of which is situated 1,5 m to 2,0 m above the level of the roof of the test-chamber.

Within the air-inlet duct there shall be a measuring section of 350 mm diameter and a length of at least 400 mm at a distance of at least 1 m from the air inlet into the test chamber and to the air-inlet to the duct.

A throttle valve shall be provided ~~in the chimney and/or~~ in the air inlet unless forced airflow is provided so the airflow can be kept temperature-dependent as it would be the case of natural chimney effect. The test-chamber should be built in such a way that the influence of wind on the amount of entering air is negligible.

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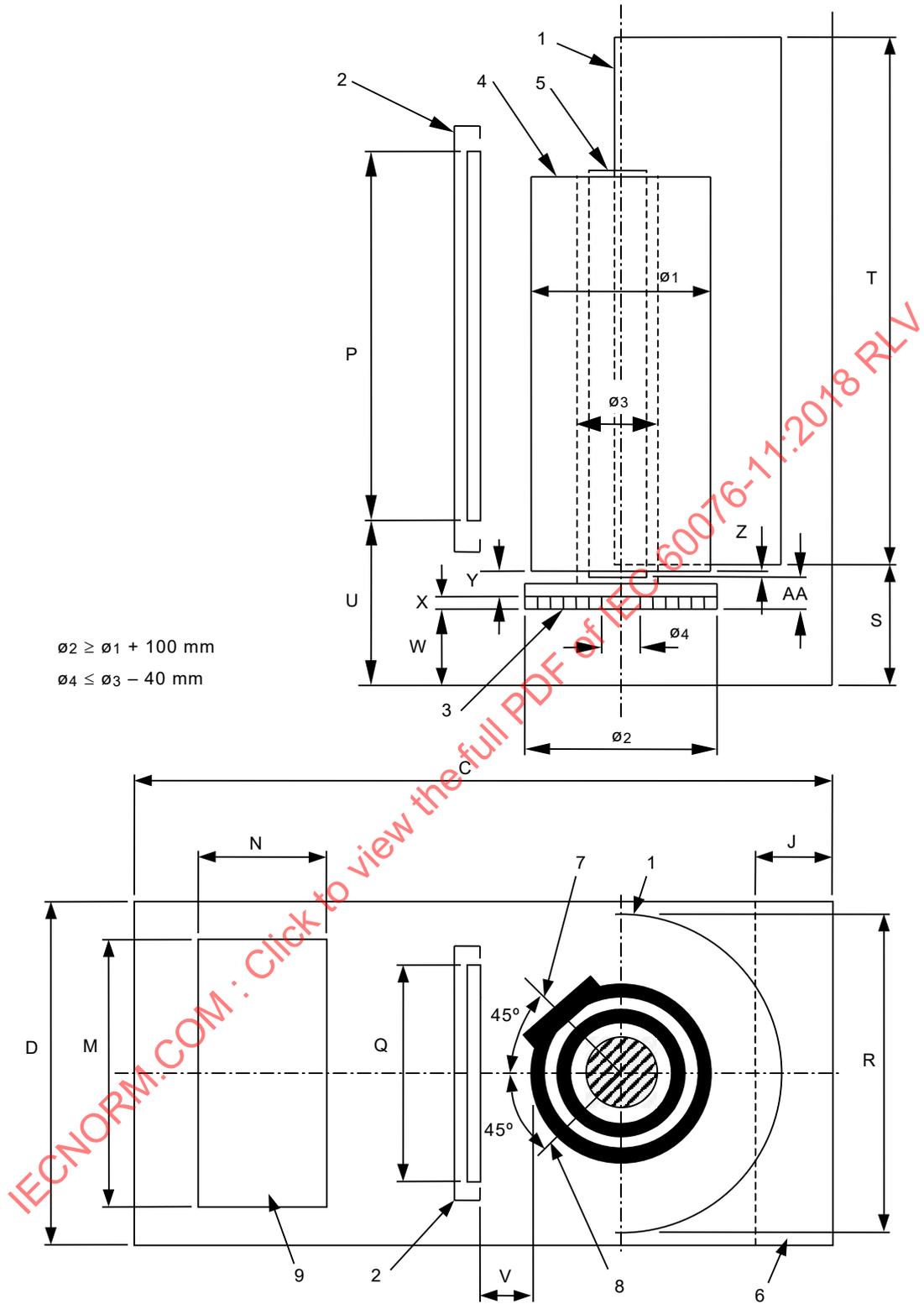


Key

- 1 Shield
- 2 Radiant panel
- 3 Alcohol container

NOTE See Table 12 for dimensions A to Z and AA to AC.

Figure 7 – Test chamber



$\varnothing 2 \geq \varnothing 1 + 100 \text{ mm}$
 $\varnothing 4 \leq \varnothing 3 - 40 \text{ mm}$

Key

- | | | |
|---------------------|--------------|--|
| 1 Shield | 4 Coils | 7 Position of terminals of test object |
| 2 Radiant panel | 5 Core | 8 Measuring sensors |
| 3 Alcohol container | 6 Air outlet | 9 Air inlet |

NOTE See Table 12 for dimensions A to Z and AA to AC.

Figure 8 – Test chamber details

14.4.6.4 Ignition sources (see Figure 7)

The main source of heat is ethyl alcohol (caloric value 27 MJ/kg) burning in a container which may be subdivided by concentric rings. The outer diameter of the container in use shall be at least 100 mm larger than the external diameter of the outer coil. The inner diameter of the container shall be at least 40 mm smaller than the inner diameter of the inner coil.

The initial level of the alcohol in the container shall be (30 ± 1) mm which corresponds to a burning time of approximately 20 min.

A second source of heat is a vertically placed flat radiant electrical panel, approximately 800 mm in height and 500 mm in width, made of heating resistors totalling 24 kW with an adjustable power source to maintain the panel at $750\text{ °C} \pm 5\text{ °C}$. The top and bottom temperature of the radiant panel shall be measured and the average temperature shall be used for the temperature regulation of the panel. A hemicylindrical metal shield, 900 mm in diameter and 1,2 m in height, shall be placed opposite the panel.

~~NOTE — When testing windings with an outer dimension larger than 500 mm, the shield may be omitted.~~

14.4.6.5 ~~Quantities Values to be measured and measuring values~~

~~28.4.1 Temperatures~~

The following temperatures shall be measured by means of thermocouples or equivalent devices:

- air inlet;
- air outlet;
- top and bottom temperature of the radiant panel;
- surface of LV-coil at top (optional);
- surface of HV-coil at top (optional);
- core leg or part simulating it, at bottom and top (optional);
- duct between core and LV-coil in the middle (optional);
- duct between LV- and HV-coil in the middle (optional).

NOTE 1 The location of the measuring sensors on the test object is indicated in Figure 8.

~~28.4.2 Other quantities to be measured~~

The other characteristics and parameters here below shall be measured:

- transmission of visible light in the measuring section; this measurement shall be carried out along an optical path through the smoke of at least 500 mm;

NOTE 2 The optical transmission factor being X and the actual length of the optical path being p (expressed in metres), the value of the transmission factor referred to a 1 m path is: $\tau = X^{1/p}$.

- air flow rate in the air inlet;
- gas flow rate in the chimney (optional).

14.4.6.6 ~~Calibration Preparation procedure of the test chamber without test object~~

Set up of the chamber shall be ~~calibrated~~ done after energising the radiant panel with 24 kW constantly for not less than 40 min.

The air-flow rate measured in the inlet section shall be adjusted in such a way that in steady state conditions it will be $0,21\text{ m}^3/\text{s} \pm 15\%$ at 20 °C . When the testing installation is based on natural airflow, the flow-rate may be modified by acting on the throttle valve or equivalent

device. In the case of testing installations operating with forced air, the flow-rate may be adjusted by acting on the fan system.

This fan system has to be free-wheeling to allow the development of airflow which will become stronger later during the test. The using of the throttle valve is preferred over the using of the fan system.

The location of the radiant panel as well as settings of the throttle valve and if used of the fan system shall be the same for preparation procedure and testing and shall remain unchanged during the testing.

NOTE More adjustments ~~may~~ can be needed to obtain the required air-flow-rate in steady-state conditions.

14.4.6.7 Test method

The test object shall be installed in the test chamber as indicated in Figure 8 respecting the following conditions:

- The distance between the radiant panel and the outer winding surface shall be approximately 175 mm. The location of the radiant panel shall be the same as for preparation procedure.
- The initial level of alcohol in the container shall be approximately 40 mm under the transformer winding level.

NOTE In some cases, agreement between purchaser and supplier is necessary depending upon the design of the test object.

- The test object shall be placed concentric with the chamber axis and 500 mm between his centre line and the back wall of the chamber.
- The hemicylindrical metal shield shall be opposite to the heating panel and concentric with the test object and chamber axis so that equal distances to the side walls and the back wall are reached, which means 50 mm away from the side walls and the back wall of the chamber.
- The temperature in the test chamber, of the inlet air, and of the test object at the beginning of the test shall be between 15 °C and 30 °C.
- The container is filled with alcohol just before starting (in practice, within 5 min).

The test starts at the moment the alcohol is ignited and the radiant panel (24 kW) switched on. The radiant panel shall be switched off 40 min later. The quantities listed in the subclauses of 14.4 shall be recorded for at least 60 min from the beginning of the test or for the total duration of the test.

The test object shall be weighed before and after the test with an accuracy of $\pm 0,5$ % or better. The material representing the core leg and the coils with insulation parts may be weighed separately.

14.4.6.8 Test report

The test report shall contain the following information:

- a) result of the test performed on samples of material (if required by the purchaser);
- b) total calculated mass and thermal energy of burnable materials (if possible) and measured weight of the tested object;
- c) result of the test-chamber ~~calibration~~ preparation procedure (air flow-rate, temperatures in the measuring sections, adjustment of the throttle valve or gas extraction system, etc.);
- d) full description of the method of carrying out the test, including the time periods during which alcohol burns and electrical energy is applied;

- e) loss of mass of burnable materials during the test (accuracy of $\pm 10\%$) and calculated heat release (MJ) (if possible);
- f) temperatures recorded throughout the test at intervals of 2 min or less, starting from the beginning of the test (ignition of the alcohol);
- g) visible light transmitted in the measuring section continuously recorded throughout the test (in %);
- h) inlet airflow rate throughout the test, measured at intervals of 2 min or less in the measuring section (m^3/s);
- i) visible fire behaviour of the object under test;
- j) documentation on the test chamber including settings, method of air flow adjustment, precise dimension of the chamber and test object.

14.4.6.9 Criteria for evaluating the test results

The test object shall be considered to have passed the test if it meets the following criteria:

- a) The temperature rise above the ambient temperature of the gases in the measuring section in the chimney shall not exceed 420 K throughout the test.
- b) 5 min after the radiant panel is switched off (45 min after the beginning of the test), the temperature rise above the ambient temperature of the gases in the measuring section in the chimney shall not exceed 140 K ~~and it shall decrease when measured over time periods of 10 min~~. The temperature trend measured each 10 min interval shall be linear and negative. Transient temperature readings above and below trend line are permitted to be ignored.
- c) The temperature rise of the gases in the measuring section in the chimney shall not exceed 80 K after 60 min from the beginning of the test. ~~These conditions are assumed to demonstrate that the fire had ceased to burn~~. This criterion is valid independent of whether flames are visible or not.

~~NOTE – A higher temperature rise may be allowed if the stored thermal energy prevents the temperature drop with natural airflow.~~
- d) The arithmetic mean of the optical transmission factor of light in the measuring section, referred to an optical path through smoke of 1 m, between 20 min and 60 min after the beginning of the test, shall be not less than 20 % (indicative).

NOTE Temperature measurements made in conformity with 14.4.6.9 tend to result in a tolerance of 10%.

14.4.7 Seismic test

14.4.7.1 Validity of the test

This test determines the suitability of transformers for seismic classes as defined in Clause 13.

The validity of the results of a seismic test carried out on a transformer can be extended to other transformers based on the identical mechanical structure and some design criteria:

- similar conceptual design (winding type, enclosure, etc.);
- identical mechanical structure (same clamping, same support, winding support, at least identical number and type of anchor points, etc.);
- weight of the transformer not exceeding $-30\%/+15\%$ of the tested transformer;
- similar proportion of the dimension ($\pm 10\%$) in all axis;
- having the same structural strength of connections between parts (for example coil block supports, connections between frame parts, terminal bars etc.)

If these criteria are not met, then by agreement between manufacturer and purchaser the extension can be done by using an analytic method or finite element analysis calculation following either the manufacturer's method or another standardised method.

For extension of the validity of the test IEEE 693 should be used.

14.4.7.2 Test procedure and test method and acceptance criteria

The acceptance criteria given in IEC 60068-3-3 may be additionally applied based on agreement between manufacturer and purchaser.

The transformer shall be inspected and the state of the core and windings shall be compared with their state before the test, in order to reveal possible apparent defects such as changes in lead position, displacements, etc. which, in spite of successful routine tests, might endanger the safe operation of the transformer.

All the routine tests, including dielectric tests at 80 % of the prescribed test value (see Table 3), shall be repeated. If a lightning impulse test is specified, it shall be performed at this stage.

In order to consider the transformer as having passed the seismic test, the following conditions shall be fulfilled:

- a) The routine tests have been successfully repeated and the lightning impulse test, if specified, successfully performed.
- b) The inspection does not reveal any defects such as displacements, shifting of laminations, deformation of windings, connections or supporting structures, so significant that they might endanger the safe operation of the transformer.
- c) No traces of internal electrical discharge are found after dielectric tests.
- d) The short-circuit impedance values, in ohms, evaluated for each phase at the end of the tests do not differ from the original values by more than 1 %. Based on agreement between purchaser and manufacturer a difference of up to 3 % can be acceptable.

14.4.8 Special test for transformers equipped with amorphous core

Amorphous core transformers should be manufactured with material known or under development.

To ensure reliability of these transformers, before installing on the network, manufacturers shall be able to prove their long term reliability either:

- by a short circuit withstand test;
- or
- by providing certificates of this test for similar (see IEC 60076-5 rules) transformers;

The rules in IEC 60076-5 regarding similarity between transformers and related to absorbed power, axial forces and winding stresses at short circuit shall be applied to determine the validity of the test.

The procedure of test shall be as prescribed by IEC 60076-1, IEC 60076-3 and IEC 60076-5, respecting in particular the following requirements:

- All the routine tests, including dielectric tests at 100 % of the test value prescribed in Clause 15, shall be repeated. A lightning impulse test shall be performed at this stage.

In addition to IEC 60076-5 criteria the value of measured no load loss before and after the short circuit test shall not deviated by more than 12 %. This measurement shall be done in the same laboratory.

15 Tolerances

Tolerances shall be as specified in IEC 60076-1.

16 Protection against direct contact

Transformers in which constructive features do not provide for protection against direct contact shall be supplied with a visible element (warning plate or special mark) indicating the danger, according to national rules.

17 Degrees of protection provided by enclosures

The design of an enclosure will be dependent upon the location and environmental conditions in which the transformer is installed. The enclosure shall be specified by reference to IEC 60529.

18 Earthing terminal

Transformers shall be fitted with an earth terminal for the connection of a protective conductor. All exposed metallic conductive non-live parts shall be connected to the earth terminal by construction or otherwise.

19 Information required with enquiry and order

The requirements in IEC 60076-1:2011, Annex A, apply.

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Annex A (informative)

Installation and safety of dry-type transformers

A.1 Manuals

Instruction manuals concerning installation requirements, transport requirements, erection, maintenance and operation should be given to the purchaser by the supplier, in particular for the supply of a prototype for a given purchaser. Unless otherwise specified in the contract, it is considered a good practice to transmit these manuals in advance, in order to enable the purchaser to check the correctness of the installation and the steps taken to organise transport and erection, if applicable.

A.2 Installation

A.2.1 General

Safety in the transformer use can be considered from different points of view:

- a) intrinsic safety of the transformer in order to be free from dangerous events arising from internal failure;
- b) safety deriving from steps taken in the installation precautions against unavoidable events;
- c) limitation of consequences of external events.

National laws and regulations ~~shall~~ govern the steps to be taken to improve safety in b) and c) above.

National standards specify installation requirements to be observed.

~~NOTE National laws and regulations prevail on the contents of this informative Annex.~~

Subclauses A.2.2 to A.2.4 give some examples of the steps to be taken both by the supplier and the purchaser to assure an acceptable degree of safety.

A.2.2 Intrinsic safety

The fulfilment of the requirements contained in this standard gives the necessary reliability against dangerous failures inside the transformer. For main fittings, the relevant standards are applicable. The manufacturer's instructions on loading capabilities should be followed and loading guides are available in national standards.

The following particular points ~~may~~ might be applicable:

- insulation levels and tests;
- maximum heat generation resulting from the guaranteed and tested losses;
- maximum temperature in service;
- systematic maintenance of the transformer, its accessories and protection. The manual should address these points;
- the manual should give guidance on condition based maintenance;
- use of an F1 class transformer in case of danger of fire (external or internal).

A.2.3 Installation precautions

Installation precautions are given in national laws and regulations and in national standards.

Installation designers should consider the following, non-exhaustive, list of points:

- whether the cooling system ~~should be~~ is sufficient to keep the temperature of the ambient air below the specified maximum limits;
- whether adequate protection against transient overvoltages generated by the system or by lightning;
- the overcurrent protection and inherent short-circuit withstand capability of the transformer;
- other protections on the transformer (contacts on temperature-indicating devices, etc.) and in the installation (relays, fuses, etc.);
- risk and consequences of and precautions against fire originating in the transformer itself or originating elsewhere;
- restricted access to avoid contact with live parts or hot parts and to limit the presence of persons in the case of failure;
- limitation of the noise emission outside the installation;
- for busbars or cables, whether control of the emission of the magnetic field ~~may be~~ is necessary;
- provisions to prevent ambient air contamination;
- prevention of generation and accumulation of gases;
- prohibition of an obstructed ventilation in protective enclosure;
- provision of sufficient ventilation to the electrical equipment room indicated in the purchaser manufacturer manual.

A.2.4 Installation design

Installation designers should provide the following:

- sufficient ventilation to keep the air temperature around the transformer below the limits given in 4.2 unless otherwise agreed between supplier and purchaser;
- adequate measures to keep the ambient air temperature above the lower limits in 4.2 unless otherwise specified;
- adequate protection against transient overvoltages;

NOTE ~~Careful attention should be given to the~~ Fast transient overvoltages ~~occurring~~ can occur when the circuit breaker interrupts the magnetising current prior to its reaching a natural current zero. Such transients are often repeated several times with escalating peak value during one circuit breaker operation.

- a device or system that immediately disconnects the transformer from the energy source in case of large over-currents;
- protection against heat from nearby heat sources;
- minimum retention pockets for combustible smokes and gases;
- restricted accessibility for safety reasons;
- limitation of sound outside the installation, if necessary;
- control of emission of magnetic fields (mainly due to connections or busbars) outside the installation by means of screens in the installation or adequate distances.

Annex B (informative)

Environmental test for evaluation of outdoor transformers without enclosure

B.1 General

The test consists of two parts:

- testing of a set of primary and secondary windings under applied voltage in a salt-fog chamber and under application of intensive UV radiation. In this test well-defined conditions are applied and varied. The test allows achieving results within a short testing period under accelerated conditions;
- testing for corrosion of the transformer core and constructive parts.

It is highly recommended to energise a transformer in an outdoor installation with demanding environmental conditions continuously during a one year period to check the reliability of the transformers. Reliability criteria of the field test are given in this annex.

The following table gives test parameters for the tests described in Clauses B.2 to B.4.

Table B.1 – Outdoor environmental classes

	E-Outdoor-1	E-Outdoor-2	E-Outdoor-3
Salt-fog and UV-radiation chamber test	25 cycles/300 h	50 cycles/600 h	100 cycles/1200 h
Core and Clamp Coating Test (ISO12944 with durability range "high")	C2	C4	C5-M
Field test (IEC 60815)	Light	Medium	Very heavy

B.2 Salt-fog and UV-radiation chamber test

B.2.1 Test description

A low and a high voltage winding, either integrated in a common coil or assembled as two separate coils in the same way as in the transformer, shall be tested. In case the coil has taps, they shall be prepared in the same way as for a transformer. The coil(s) shall be new and clean without any additional surface treatment of the insulating parts.

These windings shall be placed in a test chamber in which the temperature is kept under control. The volume of the chamber shall be at least five times that of the rectangular box circumscribing the coil(s). The clearances from any part of the coil(s) to walls, ceiling and spraying nozzles shall be not less than the smallest phase-to-phase clearance between live parts of the transformer (see IEC 60076-3) and not less than 150 mm.

An applied voltage shall be permanently applied to the HV winding. The windings shall prove to withstand a multi-parameter, environmental chamber test. The chamber shall be equipped to expose the windings through a cycle of salted fog (2 h), clean fog (4 h), ultraviolet radiation (4 h), and cooling (2 h) periods. The total duration of one cycle is 12 h.

The cycle time and the respective periods are accelerated compared to a 24 h day cycle. The salt-fog period represents a period where winds bring salt-fog from the coast or another conductive pollution. The clean fog represents condensation during the night. The increased temperature during the UV irradiation represents on one hand the temperature increase due to sun irradiation and on the other hand an increased load during the day period. The cooling period represents calm evening hours with decreasing load.

During the salt- and clean-fog application a minimum of 1 l/h/m³ has to be introduced as a fog with droplet size up to 50 µm.

The fog distribution inside the chamber shall be approximately homogeneous.

The temperature in the chamber shall be between 50 °C and 100 °C during the UV radiation application. During the cooling period and the salt fog periods the temperature in the chamber shall drop to room temperature within 2 h.

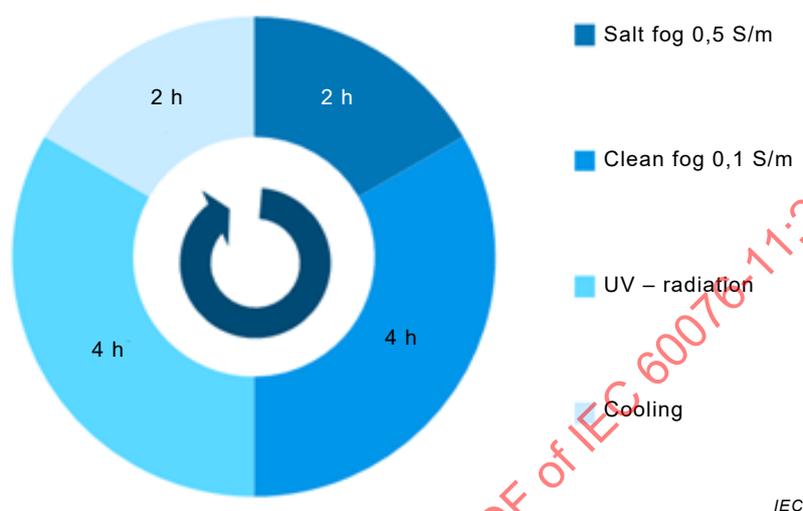


Figure B.1 – Salt fog multi-parameter ageing cycle

The schedule is applied in a clockwise sequence: 4 h UV, 2 h cooling down period, 2 h of salt fog, 4 h of clean fog (see Figure B.1). Voltage is applied continuously throughout the cycle.

Test shall be conducted for a number of cycles/a duration specified in Table B.1 for different E-outdoor levels.

The conductivity of the sprayed water for the salt fog shall be a minimum of 0,5 S/m (NaCl).

The conductivity of the sprayed water for the clean fog shall be about 0,1 S/m (NaCl).

Ultraviolet lamps shall be used on two sides of the windings (front and back side of the windings, which comprises the tapping and the connections) during the testing.

The front side of the windings shall be positioned at an angle of 20° to the axis of the opposite UV lamps.

The spectrum of the UV light shall be representative of the solar UV spectrum (in the range 280 nm to 340 nm).

The UV lamps shall have a total minimum power rating of 1 200 W per front- and back-site.

The UV lamps should be placed maximum in 1m distance from the winding surface.

The low voltage winding shall be short circuited and grounded.

The high voltage winding shall be short circuited and applied with 1,1 times the rated phase to ground voltage.

The windings shall be placed on a grounded plate having the coil support insulators between the windings and the grounded plate, as they are used in the transformer assembly.

The windings shall be applied with voltage during all periods of all test cycles.

B.2.2 Acceptance criteria:

During the voltage application, no flash over shall occur, and visual inspection shall not show:

- any tracking;
- erosion that is deeper than 2 mm;
- any significant change in surface appearance (discoloration, swollen parts, falling-off parts, etc.).

B.3 Core and clamp coating test

B.3.1 Test description

The core and clamp protection system shall be proven to withstand a corrosion protection test. The conditions of test shall be as follows:

- The test shall be done with a sample of core steel sheets of the same quality and thickness as used in a transformer, at least 50 mm stacking height, 150 mm core sheet width and 500 mm length, including the core bolts and the corresponding press construction.
- The protection system has to be applied on the core sheets, as it is used also for the full transformer.
- The clamps shall be protected as used in the full transformer design.
- The test procedure shall be followed in accordance with ISO 12944-6, with a minimum requirement of corrosivity category specified in Table B.1 for different E-outdoor levels. Higher corrosivity categories can be specified based on agreement between manufacturer and purchaser based on ISO 12944-2.
- Since in reality the core is energized and vibrating, it has to be ensured that the core- and clamp-coating can withstand it.
- In case of no field test (see B.4) is performed, the core and clamping test as described in this clause has to be done with an energized core at 1,5...1,7 T.

B.3.2 Acceptance criteria

For the protection of the clamps, ISO 12944-6 shall be followed.

For the protection of the core sheets, ISO 12944-6 shall be followed. In addition, no corrosion is allowed on the surface between the core-sheets, except for up to 5 mm from the edge.

B.4 Field test

B.4.1 Test description

A field test is recommended on a full transformer for at least one year. The transformer and its accessories shall be new and clean without any additional surface treatment of the insulating parts. No maintenance or cleaning shall occur during the test period. The transformer shall be placed at a location where it is exposed to sun radiation for the majority of the daytime. No additional structure for shading or roofing not forming part of the transformer shall be placed above or besides the transformer. It is recommended to perform the test at a testing site qualified for testing of electric outdoor equipment.

The transformer has to be energized in the field installation during at least a one-year test period. A voltage corresponding to the rated voltage of the transformer shall be used. The transformer can be operated under no-load condition.

The environment of the outdoor test place shall correspond at least to a site pollution severity class specified in Table B.1 for different E-outdoor levels in accordance with IEC TS 60815-1.

B.4.2 Acceptance criteria

The test is passed if no flashover and no transformer failure occurred during this time.

No tracking or erosion shall be visible on the coils.

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Annex C
(normative)

Cooling of transformer in naturally ventilated room

C.1 Assumptions

The room is cooled by natural air circulation, therefore:

Q_{AF} is the heat dissipation by forced air circulation (kW).

$$Q_{AF} = 0 \tag{C.1}$$

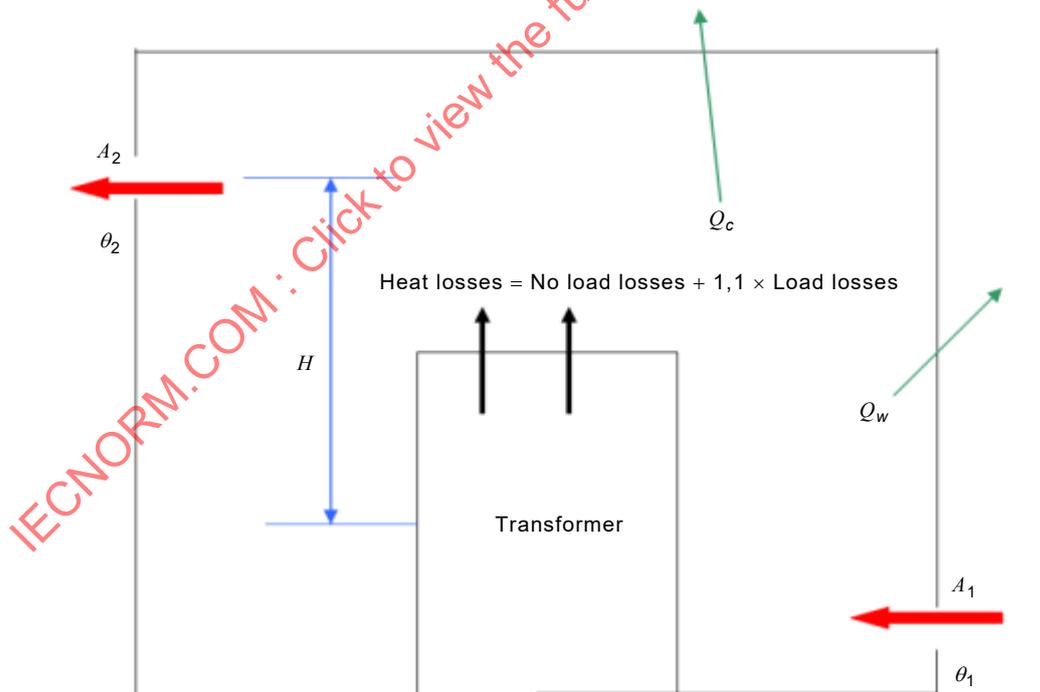
Q_C, Q_W are losses dissipated respectively through ceiling and the walls (kW).

$$Q_C, Q_W = 0 \tag{C.2}$$

In case of harmonics in load current, special considerations shall be taken into account.

The heat dissipation through ceiling and the walls is generally low. This quantity depends on the heat transfer coefficients of the materials of the walls and ceiling, the surface area of the ceiling and the walls and the difference between indoor and outdoor temperatures.

See Figure C.1.



IEC

A_1 is the air inlet effective cross section (m²)

A_2 is the air outlet effective cross section (m²)

θ_1, θ_2 are the air temperatures of inlet and outlet (°C)

H is the difference in height between mid-outlet surface and mid-height of transformer (m)

Q_C, Q_W are losses dissipated respectively through the ceiling and the walls (kW)

Figure C.1 – Heat dissipation in a natural ventilated room

C.2 Data for the calculation of ventilation

The transformer produces losses that are dissipated in the room. This subclause gives the calculation of these losses.

$\Delta\theta_a$ = air temperature rise (K):

$$\Delta\theta_a = \theta_2 - \theta_1 \text{ approximate value} = 15 \text{ K} \quad (\text{C.3})$$

NLL is the transformer no load losses (kW);

LL are the transformer nominal load losses at reference temperature (kW);

HL are the transformer heat losses in the room (kW);

$$HL = NLL + 1,1 \times LL \text{ (kW)} \quad (\text{C.4})$$

NOTE the value 15 K indicated above is the common empirical value from the experience of the manufacturers.

C.3 Output

Losses produced by the transformers should be dissipated outside the room. This annex allows to give the surface of the air inlet.

A_1 is the air inlet effective cross section (m²).

A_2 is the air outlet effective cross section (m²).

$$A_2 / A_1 > 1,1 \text{ (minimum 10 \% more)} \quad (\text{C.5})$$

Q_{tot} is the heat dissipation in the transformer's room (kW),

$$Q_{\text{tot}} = Q_{\text{nac}} + Q_{\text{WC}} + Q_{\text{AF}} \text{ (kW)} \quad (\text{C.6})$$

Q_{nac} is the dissipation by natural air circulation (kW)

$$Q_{\text{nac}} = 0,1 \times A_1 \times \sqrt{H \times \Delta\theta_a^3} \text{ (kW)} \quad (\text{C.7})$$

$\Delta\theta_a$ is the air temperature rise (K).

Q_{WC} is the heat dissipation through the walls and ceiling (kW).

$$Q_{\text{WC}} = Q_{\text{W}} + Q_{\text{C}} = 0 \text{ (see assumption)} \quad (\text{C.8})$$

Q_{AF} is the heat dissipation by forced air circulation (kW).

$$Q_{\text{AF}} = 0 \text{ (see assumption)}$$

To assure a good ventilation of the room:

$$HL = Q_{\text{nac}} + Q_{\text{WC}} \text{ (kW)} \quad (\text{C.9})$$

The required air inlet section A_1 is then given by:

$$A_1 = \frac{HL}{0,1 \sqrt{H \times \Delta\theta_a^3}} \quad (\text{m}^2) \quad (\text{C.10})$$

Calculation of air outlet section A_2 :

See formula (C.5).

C.4 Numerical application for a 1 000 kVA transformer

In this example, harmonics are not considered.

$NLL = 2,3 \text{ kW}$

$LL = 11 \text{ kW}$

The heat losses HL in the room are:

$$HL = NLL + 1,1 \times LL = 2,3 + 1,1 \times 11 = 14,4 \text{ kW}$$

$H = 4,6 \text{ m}$

Finally it comes:

$$A_1 = \frac{14,4}{0,1 \times \sqrt{4,6 \times 15^3}} = 1,155 \text{ m}^2$$

The effective cross section of the air inlet shall be at least of 1,155 m² to assure a correct cooling of the transformer in its naturally ventilated room.

Calculation of air outlet section A_2 :

$A_2 \text{ minimum} = 1,1 \times 1,155 = 1,271 \text{ (m}^2\text{)}$

The effect of the transformer installed in a natural ventilated room increases the temperature rises of the transformer by approximately half of the air-increased temperature between inlet and outlet (IEC 62271-202).

Annex D (normative)

Calculation of the losses with different reference temperatures and/or winding material

List of symbols

Index 1	refers to measurement of 'cold winding resistance';
Index 2	indicates conditions during measurement of load loss;
r	indicates conditions at 'reference temperature';
R	resistance;
θ	winding temperature in °C;
P	load loss;
I	specified load current for loss determination (rated current, tapping current, other specified value related to a particular loading case);
P_a	'additional loss'
Index A, B	System designation;
ϑ_0	material constant (copper = 235, aluminum = 225).

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

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

$$R_2 = R_1 \frac{\vartheta_0 + \theta_2}{\vartheta_0 + \theta_1}$$

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

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

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

$$R_r = R_1 \frac{\vartheta_0 + \theta_r}{\vartheta_0 + \theta_1}$$

$$P_{ar} = P_{a2} \frac{\vartheta_0 + \theta_2}{\vartheta_0 + \theta_r}$$

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

Subclause 14.2.3 describes furthermore that the reference temperatures of the transformer systems can be different. Therefore the different materials and reference temperatures need to be considered in the correction. For the calculation of the additional losses P_{ar} the mean value of the reference temperatures θ_r is used. Additionally the mean value of the material constants ϑ_0 needs to be considered in these cases.

$$\theta_{r,Pa} = \frac{\theta_{rA} + \theta_{rB}}{2}$$

$$\vartheta_{0Pa} = \frac{\vartheta_{0A} + \vartheta_{0B}}{2}$$

Example 1: For cast resin transformers with the identical reference temperature for all systems of 120 °C, the formula become as follows according to the materials used:

$$R_r = R_1 \frac{235+120}{235+\theta_1} \text{ (Copper)}$$

$$R_r = R_1 \frac{225+120}{225+\theta_1} \text{ (Aluminum)}$$

$$R_r = R_1 \frac{355}{235+\theta_1} \text{ (Copper)}$$

$$R_r = R_1 \frac{345}{225+\theta_1} \text{ (Aluminum)}$$

$$P_{ar} = P_{a2} \frac{235+\theta_2}{120+235}$$

$$P_{ar} = P_{a2} \frac{225+\theta_2}{120+225}$$

$$P_{ar} = P_{a2} \frac{235+\theta_2}{355}$$

$$P_{ar} = P_{a2} \frac{225+\theta_2}{345}$$

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

Example 2: A cast resin transformer with

System A (e.g. HV)

System B (e.g. LV)

Thermal class: F

Thermal class: H

Average winding temperature rise: 100 K

Average winding temperature rise: 125 K

Reference temperature: 120 °C

Reference temperature: 145 °C

Material: aluminum

Material: copper

Correction between the temperature θ_1 at resistance measurement and the temperature θ_2 at loss measurement

$$R_{2A} = R_{1A} \frac{\vartheta_{0A} + \theta_2}{\vartheta_{0A} + \theta_1}$$

$$R_{2B} = R_{1B} \frac{\vartheta_{0B} + \theta_2}{\vartheta_{0B} + \theta_1}$$

$$P_{a2} = P_2 - (I^2 R_{2A} + I^2 R_{2B})$$

Winding resistances R_r , at particular reference temperatures θ_r :

$$R_{rA} = R_1 \frac{225+120}{225+\theta_1} = R_1 \frac{345}{225+\theta_1}$$

$$R_{rB} = R_1 \frac{235+145}{235+\theta_1} = R_1 \frac{380}{235+\theta_1}$$

Additional loss P_r , at medium reference temperature θ_r :

$$\theta_{r,Pa} = \frac{120 + 145}{2} = 132,5$$

$$\vartheta_{Pa} = \frac{225 + 235}{2} = 230$$

$$P_{ar} = P_{a2} \frac{\vartheta_{0P_a} + \theta_2}{\vartheta_{0P_a} + \theta_{r,P_a}} = P_{a2} \frac{230 + \theta_2}{230 + 132,5} = P_{a2} \frac{230 + \theta_2}{362,5}$$

Finally: $P_r = (I^2 R_{2A} + I^2 R_{2B}) + P_{ar}$

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Bibliography

IEC 60721-2-6:1990, *Classification of environmental conditions – Part 2: Environmental conditions appearing in nature – Earthquake vibration and shock*

ISO 12944 (all parts), *Paints and varnishes – Corrosion protection of steel structures by protective paint systems*

ISO 12944-2, *Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 2: Classification of environments*

IEEE 693, *IEEE Recommended Practice for Seismic Design of Substations*

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

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

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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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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

- reconfirmed,
- 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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
≤ 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 °C but may be exposed during transport and storage to ambient temperatures down to -25 °C .
- Class C2: The transformer is suitable for operation, transport and storage at ambient temperatures down to -25 °C .
- Class C3: The transformer is suitable for transport and storage at -40 °C and operation at -25 °C .
- Class C4: The transformer is suitable for transport and storage at -50 °C and operation at -40 °C .
- Class C5: The transformer is suitable for transport and storage at -60 °C and operation at -50 °C .
- Class C_{xy} : The transformer is suitable for transport and storage at $-X\text{ °C}$ and operation at $-Y\text{ °C}$.

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:

$$A_{f_x} = AG \times K \times D_x$$

$$A_{f_y} = AG \times K \times D_y$$

$$A_{f_z} = AG \times K \times D_z$$

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				
	General	AG m/s ²	For information only		
			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 m/s² = 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 tappings 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.

I^2R for HV are calculated at Tref 145.

I^2R 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

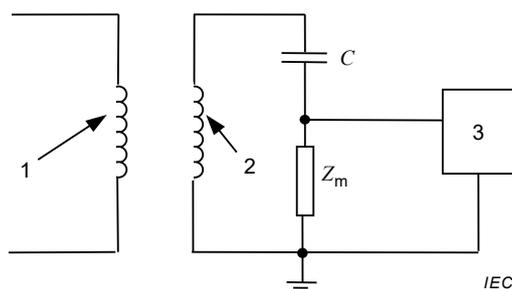
Partial discharge measurements shall be performed on all dry-type transformers. Measurement shall be made in accordance with IEC 60270 and with Annex A of IEC 60076-3:2013.

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.

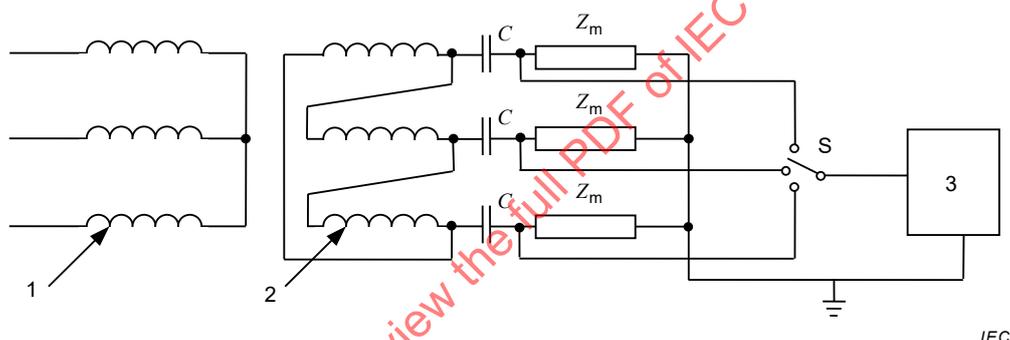
In the figures, a partial discharge-free high voltage capacitor, C , of suitable voltage rating (having a capacitance value large in comparison with the calibration generator capacitance, C_0) in series with a detection impedance, Z_m , is connected to each of the high-voltage winding terminals.



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.

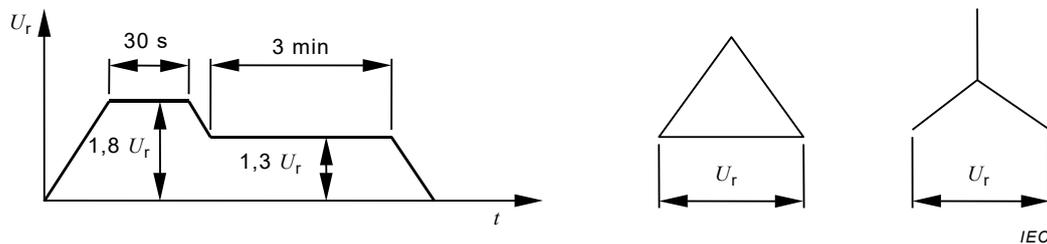


Figure 3 – Voltage application for routine partial discharge test

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 tappings 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 $1,2 \mu\text{s} \pm 30\%$ / $50 \mu\text{s} \pm 20\%$.

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 tappings 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, $\Delta\theta_e$, 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, $\Delta\theta'_c$, 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:

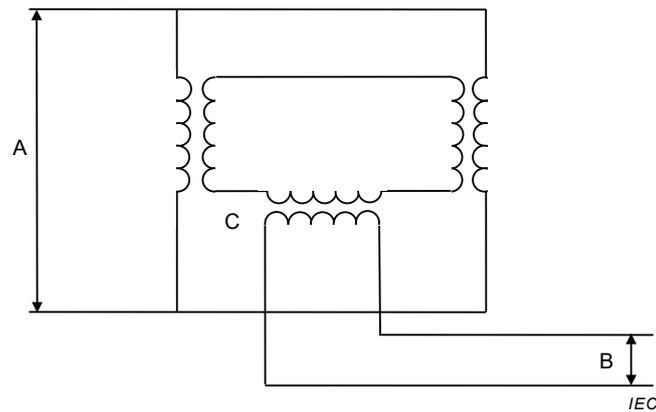
- $\Delta\theta'_c$ is the total winding temperature rise;
- $\Delta\theta_c$ is the winding temperature rise at the short-circuited test
- $\Delta\theta_e$ is the winding temperature rise at the open-circuited test;
- $K1 = 0,8$ for natural air cooling and $0,9$ for forced air cooling.

14.3.2.2.3 Back-to-back method

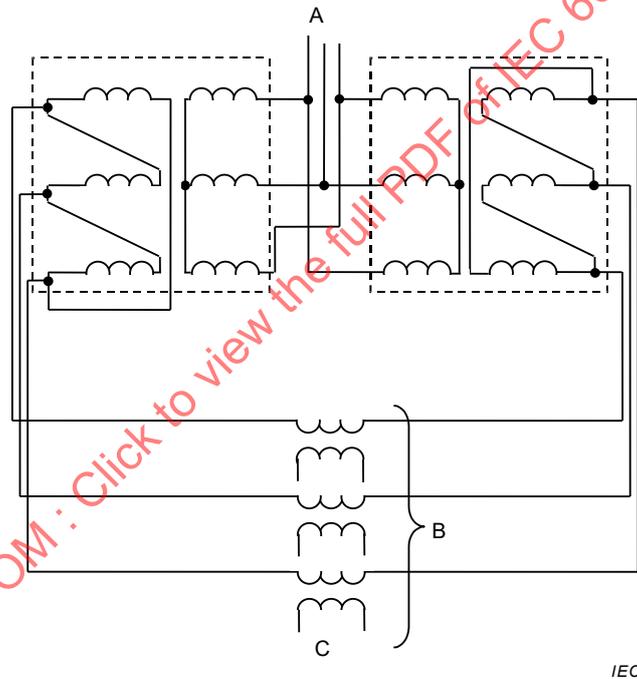
This method is appropriate when there are two suitable transformers and the necessary test equipment is available.

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, $\Delta\theta_t$, 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, $\Delta\theta_N$, by the formula:

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

where:

$\Delta\theta_N$ is the temperature rise of the winding at the rated load condition;

$\Delta\theta_t$ 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.

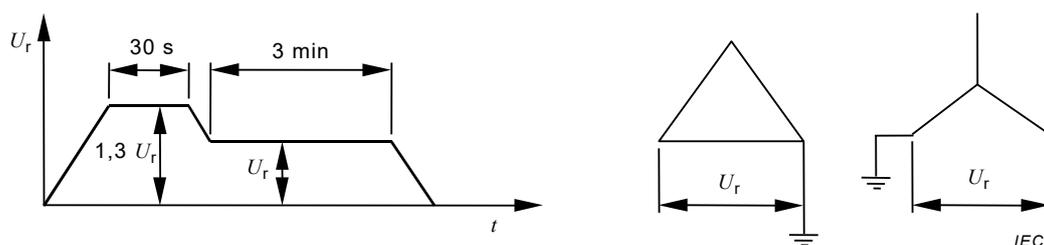


Figure 6 – Voltage application for special partial discharge test

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)	Energize ambient temperature(EAT)
	In °C	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) ± 3 °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) ± 3 °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 °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

plus 40 °C is determined. The same sensor reading shall be obtained in the test, which starts at low ambient temperature.

The coil not under the test can be overheated.

NOTE 2 Care needs to be taken to prevent thermally overstressing some windings because of the different thermal transient behaviour of the transformer parts.

- d) After the thermal shock, the transformer shall be brought back to a temperature of (25 ± 10) °C.

14.4.4.3 Test criteria

After the thermal shock test, the transformer shall be submitted to the dielectric routine tests (applied voltage test and induced voltage withstand tests), in accordance with the insulation level of the windings, but at voltages reduced to 80 % of the standard values.

Partial discharge measurements shall be carried out. The test voltage shall not exceed the test voltage of the reduced induced overvoltage withstand test (160 % of the rated value) and the measured values shall not exceed those prescribed for routine tests.

When visually inspected, the windings shall show no visible abnormality, such as cracks or slits.

14.4.4.4 Validity of the test

The validity of the results of a climatic test carried out on the reference tested transformer can be extended to other transformers which have:

- the same or lower current density (A/mm^2);
- the same or lower insulation level for HV winding;
- for insulation level HV over 24kV or for rated power above 1000kVA the extension of the validity is subject of an agreement between purchaser and manufacturer. (by calculation or tests);

The transformer shall have the same criteria as the reference tested transformer for:

- conceptual design and design rules;
- raw materials;
- production process;
- same or lower average temperature rise for the windings.

14.4.5 Environmental test

14.4.5.1 General

This test establishes the suitability of transformers for environmental classes as defined in 13.

If not otherwise specified, the tests shall be performed on one transformer completely assembled, fitted with its accessories (if relevant for the test).

The transformer and its accessories shall be new and clean without any additional surface treatment.

14.4.5.2 Test procedure for classes E1, E2, E3, E4

This test procedure includes a condensation test for all classes and followed by a humidity penetration test for classes E2, E3 and E4.

Table 11 – Environmental classes

Class	Conductivity range S/m	Humidity value for condensation test	Humidity penetration tests
E1	0,1 to 0,3	>93 %	NO
E2	0,5 to 1,5	>93 %	YES
E3	3,6 to 4,0	>95 %	YES
E4	5,6 to 6,0	>95 %	YES

For the condensation test the transformer shall be placed in a test chamber in which temperature and humidity are kept under control.

- The volume of the chamber shall be at least five times that of the rectangular box circumscribing the transformer. The clearances from any part of the transformer to walls, ceiling, spraying nozzles and temperature sensors shall be not less than the smallest phase-to-phase clearance between live parts of the transformer and not less than 150 mm.
- The position of the mechanical atomisers shall be chosen in such a way that the transformer is not directly sprayed.
- The temperature of the air in the test chamber shall be such as to ensure condensation on the transformer. The surface of the transformer shall be at least 10 K colder than the temperature in the test chamber at the beginning of the test.
- The humidity in the chamber shall be increased in less than one hour up to the value given in Table 11 and then maintained above this value. This shall be achieved by periodically or continuously atomising a suitable amount of water.
- The transformer shall be kept in air having a relative humidity as defined in Table 11 for not less than 2 h, without being energised.
- The temperature of the water basin shall be between 8 K and 10 K higher than the temperature in the test chamber during the test.
- No water shall drip from the ceiling upon the transformer under test.
- The conductivity of the water shall be in the range defined in Table 11.
- Within 5 min after stopping the atomiser spray and while the transformer remains in the test chamber, the transformer shall be submitted to a test with induced voltage as follows:
 - Transformers with windings intended for connection to a system, which are solidly earthed or earthed through a low impedance, shall be energised at a voltage of 1,1 times the rated voltage for a period of 15 min.
 - Transformers with windings intended for connection to systems which are isolated or earthed through considerable impedance shall be submitted to a test with induced voltage for three successive periods of 5 min. During the test, each high voltage terminal in turn shall be connected to earth and a voltage of 1,1 times the rated voltage shall be applied between the other terminals and earth. The three-phase test can be replaced by single-phase tests with the two non-earthed phase terminals being interconnected. The time between each of the three tests shall be less than 3 min.

In case both of the above tests are to be carried out, the test sequence shall start with the test for transformers with windings intended for connection to systems which are isolated or earthed through considerable impedance.
- During the voltage application, no collapse of voltage and no flashover shall occur. Visual inspection shall not show any serious tracking (no carbonised or no erosion trace not removable by wiping on the insulation surfaces)

For the humidity penetration test:

- At the beginning, the transformer shall be in a dry condition but not wiped to eliminate the remaining condensation from the condensation test.

NOTE The transformer could be dried in a climatic chamber.

- Transformers shall be installed in a de-energised condition and held in the climatic chamber for 144 h.
- The temperature of the climatic chamber shall be held at $(50 \pm 3) ^\circ\text{C}$ and the relative humidity held at $(90 \pm 5) \%$.
- Within 3 h after ending the humidity penetration period and in normal ambient conditions, the transformer shall have completed the applied voltage test (AV) and the induced withstand voltage test, but at voltages reduced to 80 % of the standardised values.
- During the voltage application, no collapse of voltage and no flashover shall occur. Visual inspection shall not show any serious tracking (no carbonised or no erosion trace not removable by wiping on the insulation surfaces).

14.4.5.3 Validity of the test

The validity of the results of an environmental test carried out on the reference tested transformer can be extended to other transformers based on the same or lower insulation level for HV winding and the same or lower rated voltage for HV winding.

- for insulation level HV over 24kV or for rated power above 1000kVA the extension of the validity is subject of an agreement between purchaser and manufacturer. (by calculation or tests);

The transformer should have the same criteria as the reference tested transformer for:

- conceptual design and design rules;
- raw materials;
- production process.

14.4.6 Fire behaviour test

14.4.6.1 General

To optimise the behaviour of a transformer, it is necessary to minimise its emission of toxic substances and opaque smoke in the event of burning. The use of halogenic materials should be avoided. Checking of corrosive and harmful gas emission shall be made as described below. Moreover, the transformer shall not contribute significantly to the thermal energy of an external fire. The fire behaviour shall be assessed by the test procedure in 14.4.6.2.

The emission of corrosive and harmful gases shall be checked on small quantities of the combustible materials present in the transformer.

In principle, the tests should be able to detect the presence of components such as hydrogen chloride (HCl), hydrogen cyanide (HCN), hydrogen bromide (HBr), hydrogen fluoride (HF), sulfur dioxide (SO₂), formaldehyde (HCHO).

The acceptable limits for gas emission may be specified in national regulations if any.

14.4.6.2 Fire behaviour test for F1 class transformer

14.4.6.2.1 Test object

The test shall be carried out on one complete phase of a transformer comprising HV and LV coils, core leg and insulation components, without enclosure. The core leg may be replaced by material of approximately similar dimensions and thermal behaviour as the original core leg. The yoke shall not be considered and the LV terminal leads shall be cut at the upper and lower end coil level.

The outer coil diameter of circular windings or the maximum cross dimension for non-circular windings to be tested shall be between 400 mm and 500 mm. The minimum dimension is given to keep the test relevant regarding the calorific value of the coil during the test.

14.4.6.2 Validity of the test

The validity of the results of a fire test carried out on a transformer can be extended to different transformers (rated power, voltage, etc.) based on the same design criteria, such as:

- similar conceptual design (for example, windings contained in solid insulation or not, winding type, degree of protection, etc.);
- identical thermal insulation class;
- same main insulating materials;
- Identical formula and composition for casting system or impregnation system.

14.4.6.3 Testing installation

14.4.6.3.1 Test chamber

The test chamber shall be based on that described in IEC 60332-3-10 (related to cables), see Figure 7. The walls shall be made of heat resistant steel with a thickness of 1,5 mm to 2,0 mm, thermally insulated, so as to give a heat transfer of approximately 0,7 W/(m²K). A fire resistant window should be fitted if possible. The dimensions of the test chamber are shown in Table 12.

All dimensions in mm.

Table 12 – Dimension of the chamber

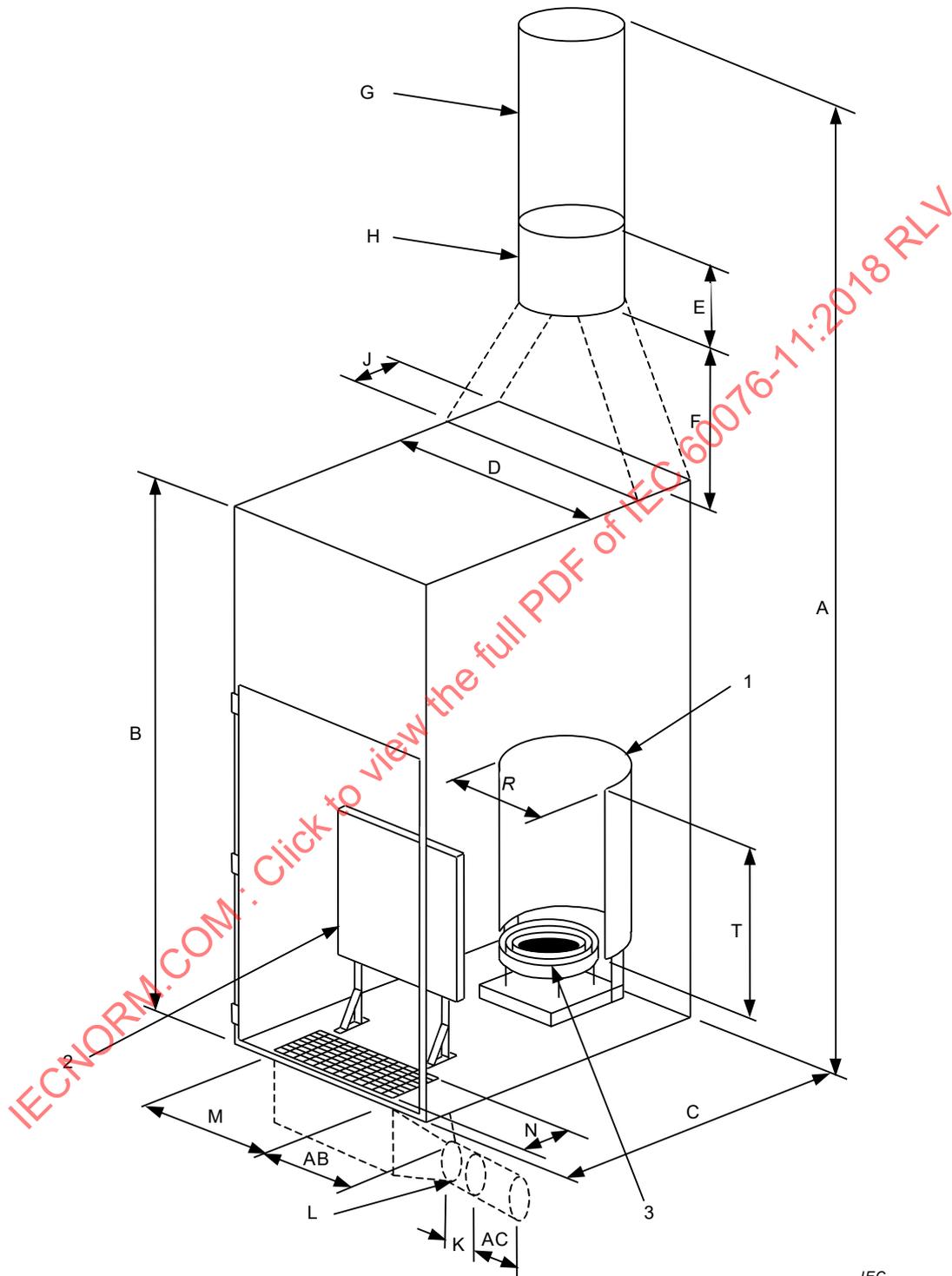
A ^a	B		C	D	E	F		G Diameter	H Diameter
	Minimum	Maximum				Minimum	Maximum		
9 000	3 500	4 000	2 000	1 000	600	1 500	2 000	500	500
J	K Minimum	L Diameter	M	N	P	Q	R	S	T
300	400	350	800	400	800	500	900	400	1 200
U	V	W	X	Y	Z	AA	AB^b	AC^b	
500	175	300	30	40	20	50	1 000	1 000	
^a Approximate height.									
^b Minimum dimension.									

The chamber shall be equipped with a chimney of approximately 500 mm inner diameter and an air-inlet duct of approximately 350 mm inner diameter. The difference in level between the air inlet into the test-chamber and gas outlet at the chimney shall be approximately 9 m. The air is admitted under the test chamber through a grating (400 × 800) mm² and escapes through an opening of approximately 0,3 m² into the chimney.

Within the chimney, there shall be a measuring section of 500 mm diameter and a length of at least 600 mm, the lower end of which is situated 1,5 m to 2,0 m above the level of the roof of the test-chamber.

Within the air-inlet duct there shall be a measuring section of 350 mm diameter and a length of at least 400 mm at a distance of at least 1 m from the air inlet into the test chamber and to the air-inlet to the duct.

A throttle valve shall be provided in the air inlet unless forced airflow is provided so the airflow can be kept temperature-dependent as it would be the case of natural chimney effect. The test-chamber should be built in such a way that the influence of wind on the amount of entering air is negligible.

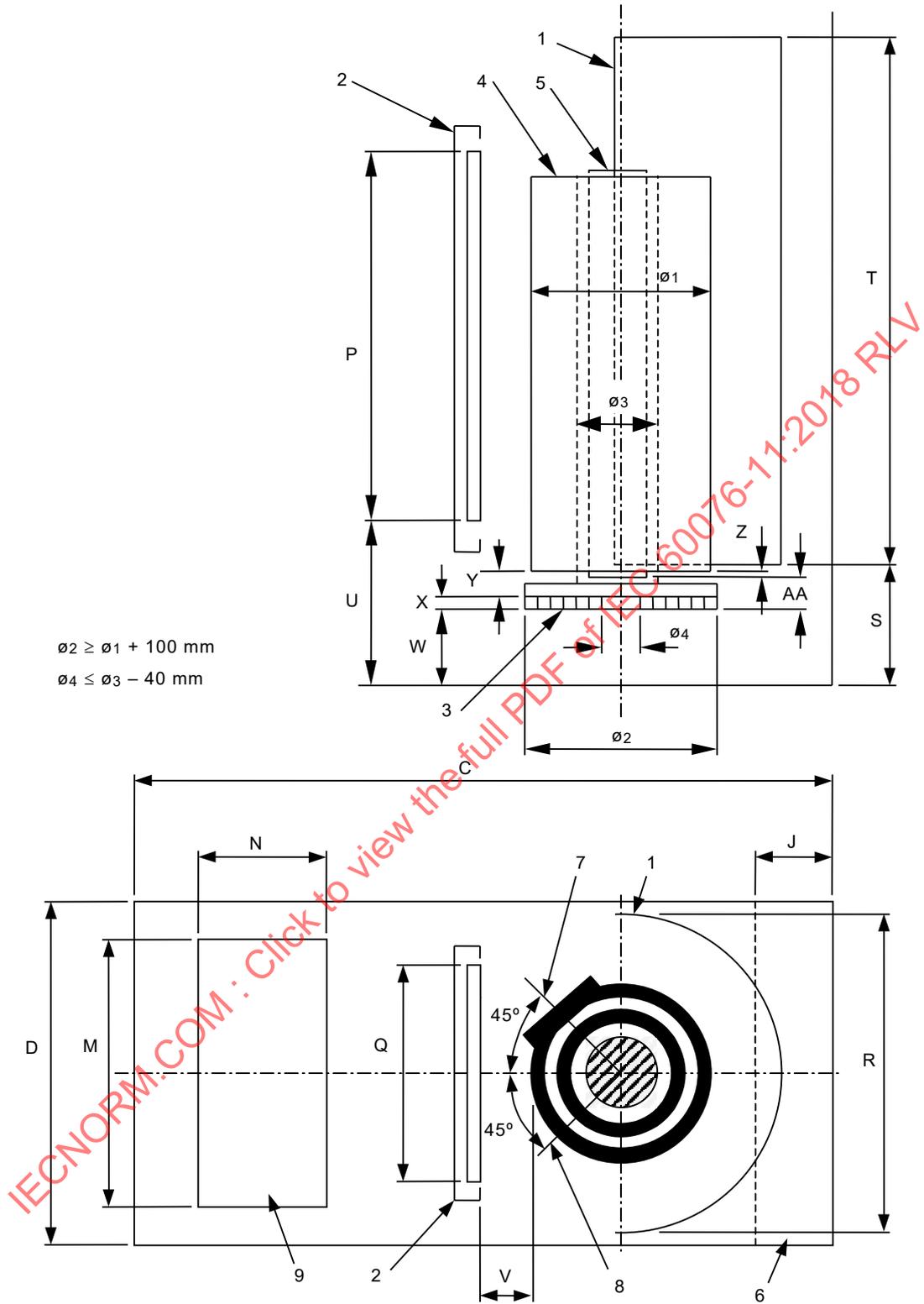


Key

- 1 Shield
- 2 Radiant panel
- 3 Alcohol container

NOTE See Table 12 for dimensions A to Z and AA to AC.

Figure 7 – Test chamber



$\varnothing 2 \geq \varnothing 1 + 100 \text{ mm}$
 $\varnothing 4 \leq \varnothing 3 - 40 \text{ mm}$

Key

- | | | |
|---------------------|--------------|--|
| 1 Shield | 4 Coils | 7 Position of terminals of test object |
| 2 Radiant panel | 5 Core | 8 Measuring sensors |
| 3 Alcohol container | 6 Air outlet | 9 Air inlet |

NOTE See Table 12 for dimensions A to Z and AA to AC.

Figure 8 – Test chamber details

14.4.6.4 Ignition sources (see Figure 7)

The main source of heat is ethyl alcohol (caloric value 27 MJ/kg) burning in a container which may be subdivided by concentric rings. The outer diameter of the container in use shall be at least 100 mm larger than the external diameter of the outer coil. The inner diameter of the container shall be at least 40 mm smaller than the inner diameter of the inner coil.

The initial level of the alcohol in the container shall be (30 ± 1) mm which corresponds to a burning time of approximately 20 min.

A second source of heat is a vertically placed flat radiant electrical panel, approximately 800 mm in height and 500 mm in width, made of heating resistors totalling 24 kW with an adjustable power source to maintain the panel at $750\text{ °C} \pm 5\text{ °C}$. The top and bottom temperature of the radiant panel shall be measured and the average temperature shall be used for the temperature regulation of the panel. A hemicylindrical metal shield, 900 mm in diameter and 1,2 m in height, shall be placed opposite the panel.

14.4.6.5 Values to be measured

The following temperatures shall be measured by means of thermocouples or equivalent devices:

- air inlet;
- air outlet;
- top and bottom temperature of the radiant panel;
- surface of LV-coil at top (optional);
- surface of HV-coil at top (optional);
- core leg or part simulating it, at bottom and top (optional);
- duct between core and LV-coil in the middle (optional);
- duct between LV- and HV-coil in the middle (optional).

NOTE 1 The location of the measuring sensors on the test object is indicated in Figure 8.

The other characteristics and parameters here below shall be measured:

- transmission of visible light in the measuring section; this measurement shall be carried out along an optical path through the smoke of at least 500 mm;

NOTE 2 The optical transmission factor being X and the actual length of the optical path being p (expressed in metres), the value of the transmission factor referred to a 1 m path is: $\tau = X^{1/p}$.

- air flow rate in the air inlet;
- gas flow rate in the chimney (optional).

14.4.6.6 Preparation procedure of the test chamber without test object

Set up of the chamber shall be done after energising the radiant panel with 24 kW constantly for not less than 40 min.

The air-flow rate measured in the inlet section shall be adjusted in such a way that in steady state conditions it will be $0,21\text{ m}^3/\text{s} \pm 15\%$ at 20 °C . When the testing installation is based on natural airflow, the flow-rate may be modified by acting on the throttle valve or equivalent device. In the case of testing installations operating with forced air, the flow-rate may be adjusted by acting on the fan system.

This fan system has to be free-wheeling to allow the development of airflow which will become stronger later during the test. The using of the throttle valve is preferred over the using of the fan system.

The location of the radiant panel as well as settings of the throttle valve and if used of the fan system shall be the same for preparation procedure and testing and shall remain unchanged during the testing.

NOTE More adjustments can be needed to obtain the required air-flow-rate in steady-state conditions.

14.4.6.7 Test method

The test object shall be installed in the test chamber as indicated in Figure 8 respecting the following conditions:

- The distance between the radiant panel and the outer winding surface shall be approximately 175 mm. The location of the radiant panel shall be the same as for preparation procedure.
- The initial level of alcohol in the container shall be approximately 40 mm under the transformer winding level.

NOTE In some cases, agreement between purchaser and supplier is necessary depending upon the design of the test object.

- The test object shall be placed concentric with the chamber axis and 500 mm between his centre line and the back wall of the chamber.
- The hemicylindrical metal shield shall be opposite to the heating panel and concentric with the test object and chamber axis so that equal distances to the side walls and the back wall are reached, which means 50 mm away from the side walls and the back wall of the chamber.
- The temperature in the test chamber, of the inlet air, and of the test object at the beginning of the test shall be between 15 °C and 30 °C.
- The container is filled with alcohol just before starting (in practice, within 5 min).

The test starts at the moment the alcohol is ignited and the radiant panel (24 kW) switched on. The radiant panel shall be switched off 40 min later. The quantities listed in the subclauses of 14.4 shall be recorded for at least 60 min from the beginning of the test or for the total duration of the test.

The test object shall be weighed before and after the test with an accuracy of $\pm 0,5$ % or better. The material representing the core leg and the coils with insulation parts may be weighed separately.

14.4.6.8 Test report

The test report shall contain the following information:

- a) result of the test performed on samples of material (if required by the purchaser);
- b) total calculated mass and thermal energy of burnable materials (if possible) and measured weight of the tested object;
- c) result of the test-chamber preparation procedure (air flow-rate, temperatures in the measuring sections, adjustment of the throttle valve or gas extraction system, etc.);
- d) full description of the method of carrying out the test, including the time periods during which alcohol burns and electrical energy is applied;
- e) loss of mass of burnable materials during the test (accuracy of ± 10 %) and calculated heat release (MJ) (if possible);
- f) temperatures recorded throughout the test at intervals of 2 min or less, starting from the beginning of the test (ignition of the alcohol);

- g) visible light transmitted in the measuring section continuously recorded throughout the test (in %);
- h) inlet airflow rate throughout the test, measured at intervals of 2 min or less in the measuring section (m^3/s);
- i) visible fire behaviour of the object under test;
- j) documentation on the test chamber including settings, method of air flow adjustment, precise dimension of the chamber and test object.

14.4.6.9 Criteria for evaluating the test results

The test object shall be considered to have passed the test if it meets the following criteria:

- a) The temperature rise above the ambient temperature of the gases in the measuring section in the chimney shall not exceed 420 K throughout the test.
- b) 5 min after the radiant panel is switched off (45 min after the beginning of the test), the temperature rise above the ambient temperature of the gases in the measuring section in the chimney shall not exceed 140 K. The temperature trend measured each 10 min interval shall be linear and negative. Transient temperature readings above and below trend line are permitted to be ignored
- c) The temperature rise of the gases in the measuring section in the chimney shall not exceed 80 K after 60 min from the beginning of the test. This criterion is valid independent of whether flames are visible or not.
- d) The arithmetic mean of the optical transmission factor of light in the measuring section, referred to an optical path through smoke of 1 m, between 20 min and 60 min after the beginning of the test, shall be not less than 20 % (indicative).

NOTE Temperature measurements made in conformity with 14.4.6.9 tend to result in a tolerance of 10%.

14.4.7 Seismic test

14.4.7.1 Validity of the test

This test determines the suitability of transformers for seismic classes as defined in Clause 13.

The validity of the results of a seismic test carried out on a transformer can be extended to other transformers based on the identical mechanical structure and some design criteria:

- similar conceptual design (winding type, enclosure, etc.);
- identical mechanical structure (same clamping, same support, winding support, at least identical number and type of anchor points, etc.);
- weight of the transformer not exceeding -30 %/+15 % of the tested transformer;
- similar proportion of the dimension (+/- 10 %) in all axis;
- having the same structural strength of connections between parts (for example coil block supports, connections between frame parts, terminal bars etc.)

If these criteria are not met, then by agreement between manufacturer and purchaser the extension can be done by using an analytic method or finite element analysis calculation following either the manufacturer's method or another standardised method.

For extension of the validity of the test IEEE 693 should be used.

14.4.7.2 Test procedure and test method and acceptance criteria

The acceptance criteria given in IEC 60068-3-3 may be additionally applied based on agreement between manufacturer and purchaser.

The transformer shall be inspected and the state of the core and windings shall be compared with their state before the test, in order to reveal possible apparent defects such as changes in lead position, displacements, etc. which, in spite of successful routine tests, might endanger the safe operation of the transformer.

All the routine tests, including dielectric tests at 80 % of the prescribed test value (see Table 3), shall be repeated. If a lightning impulse test is specified, it shall be performed at this stage.

In order to consider the transformer as having passed the seismic test, the following conditions shall be fulfilled:

- a) The routine tests have been successfully repeated and the lightning impulse test, if specified, successfully performed.
- b) The inspection does not reveal any defects such as displacements, shifting of laminations, deformation of windings, connections or supporting structures, so significant that they might endanger the safe operation of the transformer.
- c) No traces of internal electrical discharge are found after dielectric tests.
- d) The short-circuit impedance values, in ohms, evaluated for each phase at the end of the tests do not differ from the original values by more than 1 %. Based on agreement between purchaser and manufacturer a difference of up to 3 % can be acceptable.

14.4.8 Special test for transformers equipped with amorphous core

Amorphous core transformers should be manufactured with material known or under development.

To ensure reliability of these transformers, before installing on the network, manufacturers shall be able to prove their long term reliability either:

- by a short circuit withstand test;

or

- by providing certificates of this test for similar (see IEC 60076-5 rules) transformers;

The rules in IEC 60076-5 regarding similarity between transformers and related to absorbed power, axial forces and winding stresses at short circuit shall be applied to determine the validity of the test.

The procedure of test shall be as prescribed by IEC 60076-1, IEC 60076-3 and IEC 60076-5, respecting in particular the following requirements:

- All the routine tests, including dielectric tests at 100 % of the test value prescribed in Clause 15, shall be repeated. A lightning impulse test shall be performed at this stage.

In addition to IEC 60076-5 criteria the value of measured no load loss before and after the short circuit test shall not deviated by more than 12 %. This measurement shall be done in the same laboratory.

15 Tolerances

Tolerances shall be as specified in IEC 60076-1.

16 Protection against direct contact

Transformers in which constructive features do not provide for protection against direct contact shall be supplied with a visible element (warning plate or special mark) indicating the danger, according to national rules.

17 Degrees of protection provided by enclosures

The design of an enclosure will be dependent upon the location and environmental conditions in which the transformer is installed. The enclosure shall be specified by reference to IEC 60529.

18 Earthing terminal

Transformers shall be fitted with an earth terminal for the connection of a protective conductor. All exposed metallic conductive non-live parts shall be connected to the earth terminal by construction or otherwise.

19 Information required with enquiry and order

The requirements in IEC 60076-1:2011, Annex A, apply.

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Annex A (informative)

Installation and safety of dry-type transformers

A.1 Manuals

Instruction manuals concerning installation requirements, transport requirements, erection, maintenance and operation should be given to the purchaser by the supplier, in particular for the supply of a prototype for a given purchaser. Unless otherwise specified in the contract, it is considered a good practice to transmit these manuals in advance, in order to enable the purchaser to check the correctness of the installation and the steps taken to organise transport and erection, if applicable.

A.2 Installation

A.2.1 General

Safety in the transformer use can be considered from different points of view:

- a) intrinsic safety of the transformer in order to be free from dangerous events arising from internal failure;
- b) safety deriving from steps taken in the installation precautions against unavoidable events;
- c) limitation of consequences of external events.

National laws and regulations govern the steps to be taken to improve safety in b) and c) above.

National standards specify installation requirements to be observed.

Subclauses A.2.2 to A.2.4 give some examples of the steps to be taken both by the supplier and the purchaser to assure an acceptable degree of safety.

A.2.2 Intrinsic safety

The fulfilment of the requirements contained in this standard gives the necessary reliability against dangerous failures inside the transformer. For main fittings, the relevant standards are applicable. The manufacturer's instructions on loading capabilities should be followed and loading guides are available in national standards.

The following particular points might be applicable:

- insulation levels and tests;
- maximum heat generation resulting from the guaranteed and tested losses;
- maximum temperature in service;
- systematic maintenance of the transformer, its accessories and protection. The manual should address these points;
- the manual should give guidance on condition based maintenance;
- use of an F1 class transformer in case of danger of fire (external or internal).

A.2.3 Installation precautions

Installation precautions are given in national laws and regulations and in national standards.

Installation designers should consider the following, non-exhaustive, list of points:

- whether the cooling system is sufficient to keep the temperature of the ambient air below the specified maximum limits;
- whether adequate protection against transient overvoltages generated by the system or by lightning;
- the overcurrent protection and inherent short-circuit withstand capability of the transformer;
- other protections on the transformer (contacts on temperature-indicating devices, etc.) and in the installation (relays, fuses, etc.);
- risk and consequences of and precautions against fire originating in the transformer itself or originating elsewhere;
- restricted access to avoid contact with live parts or hot parts and to limit the presence of persons in the case of failure;
- limitation of the noise emission outside the installation;
- for busbars or cables, whether control of the emission of the magnetic field is necessary;
- provisions to prevent ambient air contamination;
- prevention of generation and accumulation of gases;
- prohibition of an obstructed ventilation in protective enclosure;
- provision of sufficient ventilation to the electrical equipment room indicated in the purchaser manufacturer manual.

A.2.4 Installation design

Installation designers should provide the following:

- sufficient ventilation to keep the air temperature around the transformer below the limits given in 4.2 unless otherwise agreed between supplier and purchaser;
- adequate measures to keep the ambient air temperature above the lower limits in 4.2 unless otherwise specified;
- adequate protection against transient overvoltages;

NOTE Fast transient overvoltages can occur when the circuit breaker interrupts the magnetising current prior to its reaching a natural current zero. Such transients are often repeated several times with escalating peak value during one circuit breaker operation.

- a device or system that immediately disconnects the transformer from the energy source in case of large over-currents;
- protection against heat from nearby heat sources;
- minimum retention pockets for combustible smokes and gases;
- restricted accessibility for safety reasons;
- limitation of sound outside the installation, if necessary;
- control of emission of magnetic fields (mainly due to connections or busbars) outside the installation by means of screens in the installation or adequate distances.

Annex B (informative)

Environmental test for evaluation of outdoor transformers without enclosure

B.1 General

The test consists of two parts:

- testing of a set of primary and secondary windings under applied voltage in a salt-fog chamber and under application of intensive UV radiation. In this test well-defined conditions are applied and varied. The test allows achieving results within a short testing period under accelerated conditions;
- testing for corrosion of the transformer core and constructive parts.

It is highly recommended to energise a transformer in an outdoor installation with demanding environmental conditions continuously during a one year period to check the reliability of the transformers. Reliability criteria of the field test are given in this annex.

The following table gives test parameters for the tests described in Clauses B.2 to B.4.

Table B.1 – Outdoor environmental classes

	E-Outdoor-1	E-Outdoor-2	E-Outdoor-3
Salt-fog and UV-radiation chamber test	25 cycles/300 h	50 cycles/600 h	100 cycles/1200 h
Core and Clamp Coating Test (ISO12944 with durability range "high")	C2	C4	C5-M
Field test (IEC 60815)	Light	Medium	Very heavy

B.2 Salt-fog and UV-radiation chamber test

B.2.1 Test description

A low and a high voltage winding, either integrated in a common coil or assembled as two separate coils in the same way as in the transformer, shall be tested. In case the coil has taps, they shall be prepared in the same way as for a transformer. The coil(s) shall be new and clean without any additional surface treatment of the insulating parts.

These windings shall be placed in a test chamber in which the temperature is kept under control. The volume of the chamber shall be at least five times that of the rectangular box circumscribing the coil(s). The clearances from any part of the coil(s) to walls, ceiling and spraying nozzles shall be not less than the smallest phase-to-phase clearance between live parts of the transformer (see IEC 60076-3) and not less than 150 mm.

An applied voltage shall be permanently applied to the HV winding. The windings shall prove to withstand a multi-parameter, environmental chamber test. The chamber shall be equipped to expose the windings through a cycle of salted fog (2 h), clean fog (4 h), ultraviolet radiation (4 h), and cooling (2 h) periods. The total duration of one cycle is 12 h.

The cycle time and the respective periods are accelerated compared to a 24 h day cycle. The salt-fog period represents a period where winds bring salt-fog from the coast or another conductive pollution. The clean fog represents condensation during the night. The increased temperature during the UV irradiation represents on one hand the temperature increase due

to sun irradiation and on the other hand an increased load during the day period. The cooling period represents calm evening hours with decreasing load.

During the salt- and clean-fog application a minimum of 1 l/h/m^3 has to be introduced as a fog with droplet size up to $50 \mu\text{m}$.

The fog distribution inside the chamber shall be approximately homogeneous.

The temperature in the chamber shall be between $50 \text{ }^\circ\text{C}$ and $100 \text{ }^\circ\text{C}$ during the UV radiation application. During the cooling period and the salt fog periods the temperature in the chamber shall drop to room temperature within 2 h.

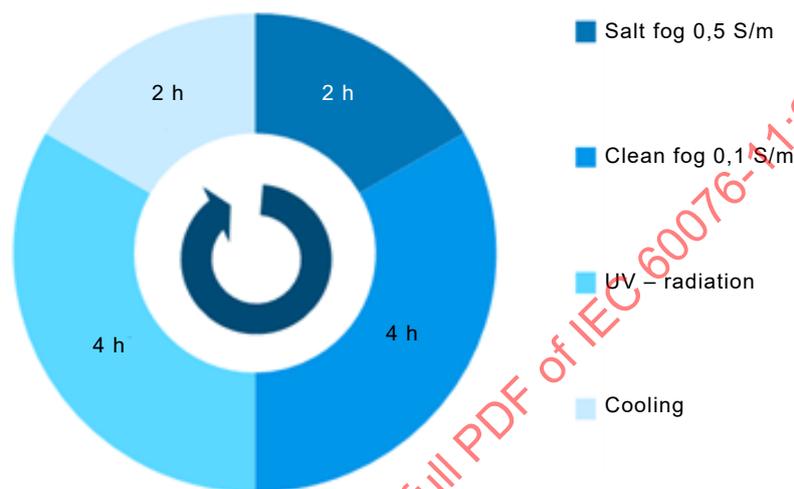


Figure B.1 – Salt fog multi-parameter ageing cycle

The schedule is applied in a clockwise sequence: 4 h UV, 2 h cooling down period, 2 h of salt fog, 4 h of clean fog (see Figure B.1). Voltage is applied continuously throughout the cycle.

Test shall be conducted for a number of cycles/a duration specified in Table B.1 for different E-outdoor levels.

The conductivity of the sprayed water for the salt fog shall be a minimum of $0,5 \text{ S/m}$ (NaCl).

The conductivity of the sprayed water for the clean fog shall be about $0,1 \text{ S/m}$ (NaCl).

Ultraviolet lamps shall be used on two sides of the windings (front and back side of the windings, which comprises the tapping and the connections) during the testing.

The front side of the windings shall be positioned at an angle of 20° to the axis of the opposite UV lamps.

The spectrum of the UV light shall be representative of the solar UV spectrum (in the range 280 nm to 340 nm).

The UV lamps shall have a total minimum power rating of $1\ 200 \text{ W}$ per front- and back-site.

The UV lamps should be placed maximum in 1 m distance from the winding surface.

The low voltage winding shall be short circuited and grounded.

The high voltage winding shall be short circuited and applied with 1,1 times the rated phase to ground voltage.

The windings shall be placed on a grounded plate having the coil support insulators between the windings and the grounded plate, as they are used in the transformer assembly.

The windings shall be applied with voltage during all periods of all test cycles.

B.2.2 Acceptance criteria:

During the voltage application, no flash over shall occur, and visual inspection shall not show:

- any tracking;
- erosion that is deeper than 2 mm;
- any significant change in surface appearance (discoloration, swollen parts, falling-off parts, etc.).

B.3 Core and clamp coating test

B.3.1 Test description

The core and clamp protection system shall be proven to withstand a corrosion protection test. The conditions of test shall be as follows:

- The test shall be done with a sample of core steel sheets of the same quality and thickness as used in a transformer, at least 50 mm stacking height, 150 mm core sheet width and 500 mm length, including the core bolts and the corresponding press construction.
- The protection system has to be applied on the core sheets, as it is used also for the full transformer.
- The clamps shall be protected as used in the full transformer design.
- The test procedure shall be followed in accordance with ISO 12944-6, with a minimum requirement of corrosivity category specified in Table B.1 for different E-outdoor levels. Higher corrosivity categories can be specified based on agreement between manufacturer and purchaser based on ISO12944-2.
- Since in reality the core is energized and vibrating, it has to be ensured that the core- and clamp-coating can withstand it.
- In case of no field test (see B.4) is performed, the core and clamping test as described in this clause has to be done with an energized core at 1,5...1,7 T.

B.3.2 Acceptance criteria

For the protection of the clamps, ISO 12944-6 shall be followed.

For the protection of the core sheets, ISO 12944-6 shall be followed. In addition, no corrosion is allowed on the surface between the core-sheets, except for up to 5 mm from the edge.

B.4 Field test

B.4.1 Test description

A field test is recommended on a full transformer for at least one year. The transformer and its accessories shall be new and clean without any additional surface treatment of the insulating parts. No maintenance or cleaning shall occur during the test period. The transformer shall be placed at a location where it is exposed to sun radiation for the majority of the daytime. No

additional structure for shading or roofing not forming part of the transformer shall be placed above or besides the transformer. It is recommended to perform the test at a testing site qualified for testing of electric outdoor equipment.

The transformer has to be energized in the field installation during at least a one-year test period. A voltage corresponding to the rated voltage of the transformer shall be used. The transformer can be operated under no-load condition.

The environment of the outdoor test place shall correspond at least to a site pollution severity class specified in Table B.1 for different E-outdoor levels in accordance with IEC TS 60815-1.

B.4.2 Acceptance criteria

The test is passed if no flashover and no transformer failure occurred during this time.

No tracking or erosion shall be visible on the coils.

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Annex C
(normative)

Cooling of transformer in naturally ventilated room

C.1 Assumptions

The room is cooled by natural air circulation, therefore:

Q_{AF} is the heat dissipation by forced air circulation (kW).

$$Q_{AF} = 0 \tag{C.1}$$

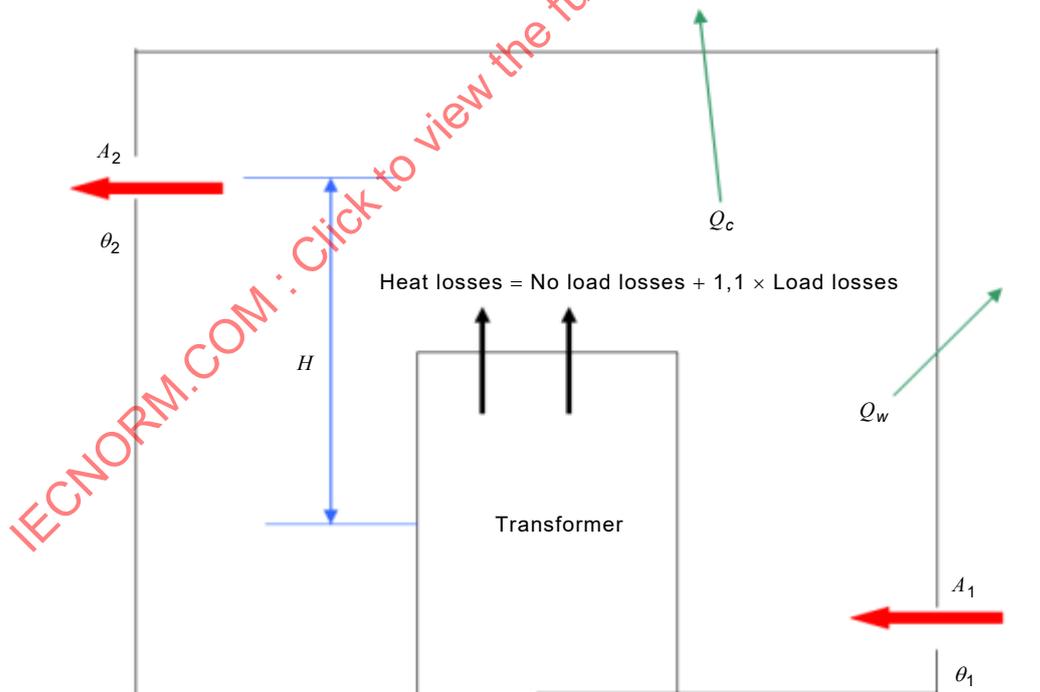
Q_C, Q_W are losses dissipated respectively through ceiling and the walls (kW).

$$Q_C, Q_W = 0 \tag{C.2}$$

In case of harmonics in load current, special considerations shall be taken into account.

The heat dissipation through ceiling and the walls is generally low. This quantity depends on the heat transfer coefficients of the materials of the walls and ceiling, the surface area of the ceiling and the walls and the difference between indoor and outdoor temperatures.

See Figure C.1.



IEC

A_1 is the air inlet effective cross section (m²)

A_2 is the air outlet effective cross section (m²)

θ_1, θ_2 are the air temperatures of inlet and outlet (°C)

H is the difference in height between mid-outlet surface and mid-height of transformer (m)

Q_C, Q_W are losses dissipated respectively through the ceiling and the walls (kW)

Figure C.1 – Heat dissipation in a natural ventilated room

C.2 Data for the calculation of ventilation

The transformer produces losses that are dissipated in the room. This subclause gives the calculation of these losses.

$\Delta\theta_a$ = air temperature rise (K):

$$\Delta\theta_a = \theta_2 - \theta_1 \text{ approximate value} = 15 \text{ K} \quad (\text{C.3})$$

NLL is the transformer no load losses (kW);

LL are the transformer nominal load losses at reference temperature (kW);

HL are the transformer heat losses in the room (kW);

$$HL = NLL + 1,1 \times LL \text{ (kW)} \quad (\text{C.4})$$

NOTE the value 15 K indicated above is the common empirical value from the experience of the manufacturers.

C.3 Output

Losses produced by the transformers should be dissipated outside the room. This annex allows to give the surface of the air inlet.

A_1 is the air inlet effective cross section (m²).

A_2 is the air outlet effective cross section (m²).

$$A_2 / A_1 > 1,1 \text{ (minimum 10 \% more)} \quad (\text{C.5})$$

Q_{tot} is the heat dissipation in the transformer's room (kW),

$$Q_{\text{tot}} = Q_{\text{nac}} + Q_{\text{WC}} + Q_{\text{AF}} \text{ (kW)} \quad (\text{C.6})$$

Q_{nac} is the dissipation by natural air circulation (kW)

$$Q_{\text{nac}} = 0,1 \times A_1 \times \sqrt{H \times \Delta\theta_a^3} \text{ (kW)} \quad (\text{C.7})$$

$\Delta\theta_a$ is the air temperature rise (K).

Q_{WC} is the heat dissipation through the walls and ceiling (kW).

$$Q_{\text{WC}} = Q_{\text{W}} + Q_{\text{C}} = 0 \text{ (see assumption)} \quad (\text{C.8})$$

Q_{AF} is the heat dissipation by forced air circulation (kW).

$$Q_{\text{AF}} = 0 \text{ (see assumption)}$$

To assure a good ventilation of the room:

$$HL = Q_{\text{nac}} + Q_{\text{WC}} \text{ (kW)} \quad (\text{C.9})$$

The required air inlet section A_1 is then given by:

$$A_1 = \frac{HL}{0,1 \sqrt{H \times \Delta\theta_a^3}} \quad (\text{m}^2) \quad (\text{C.10})$$

Calculation of air outlet section A_2 :

See formula (C.5).

C.4 Numerical application for a 1 000 kVA transformer

In this example, harmonics are not considered.

$NLL = 2,3 \text{ kW}$

$LL = 11 \text{ kW}$

The heat losses HL in the room are:

$$HL = NLL + 1,1 \times LL = 2,3 + 1,1 \times 11 = 14,4 \text{ kW}$$

$H = 4,6 \text{ m}$

Finally it comes:

$$A_1 = \frac{14,4}{0,1 \times \sqrt{4,6 \times 15^3}} = 1,155 \text{ m}^2$$

The effective cross section of the air inlet shall be at least of 1,155 m² to assure a correct cooling of the transformer in its naturally ventilated room.

Calculation of air outlet section A_2 :

$A_2 \text{ minimum} = 1,1 \times 1,155 = 1,271 \text{ (m}^2\text{)}$

The effect of the transformer installed in a natural ventilated room increases the temperature rises of the transformer by approximately half of the air-increased temperature between inlet and outlet (IEC 62271-202).

Annex D (normative)

Calculation of the losses with different reference temperatures and/or winding material

List of symbols

Index 1	refers to measurement of 'cold winding resistance';
Index 2	indicates conditions during measurement of load loss;
r	indicates conditions at 'reference temperature';
R	resistance;
θ	winding temperature in °C;
P	load loss;
I	specified load current for loss determination (rated current, tapping current, other specified value related to a particular loading case);
P_a	'additional loss'
Index A, B	System designation;
ϑ_0	material constant (copper = 235, aluminum = 225).

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

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

$$R_2 = R_1 \frac{\vartheta_0 + \theta_2}{\vartheta_0 + \theta_1}$$

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

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

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

$$R_r = R_1 \frac{\vartheta_0 + \theta_r}{\vartheta_0 + \theta_1}$$

$$P_{ar} = P_{a2} \frac{\vartheta_0 + \theta_2}{\vartheta_0 + \theta_r}$$

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

Subclause 14.2.3 describes furthermore that the reference temperatures of the transformer systems can be different. Therefore the different materials and reference temperatures need to be considered in the correction. For the calculation of the additional losses P_{ar} the mean value of the reference temperatures θ_r is used. Additionally the mean value of the material constants ϑ_0 needs to be considered in these cases.

$$\theta_{r,Pa} = \frac{\theta_{rA} + \theta_{rB}}{2}$$

$$\vartheta_{0Pa} = \frac{\vartheta_{0A} + \vartheta_{0B}}{2}$$

Example 1: For cast resin transformers with the identical reference temperature for all systems of 120 °C, the formula become as follows according to the materials used:

$$R_r = R_1 \frac{235+120}{235+\theta_1} \text{ (Copper)}$$

$$R_r = R_1 \frac{225+120}{225+\theta_1} \text{ (Aluminum)}$$

$$R_r = R_1 \frac{355}{235+\theta_1} \text{ (Copper)}$$

$$R_r = R_1 \frac{345}{225+\theta_1} \text{ (Aluminum)}$$

$$P_{ar} = P_{a2} \frac{235+\theta_2}{120+235}$$

$$P_{ar} = P_{a2} \frac{225+\theta_2}{120+225}$$

$$P_{ar} = P_{a2} \frac{235+\theta_2}{355}$$

$$P_{ar} = P_{a2} \frac{225+\theta_2}{345}$$

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

Example 2: A cast resin transformer with

System A (e.g. HV)

System B (e.g. LV)

Thermal class: F

Thermal class: H

Average winding temperature rise: 100 K

Average winding temperature rise: 125 K

Reference temperature: 120 °C

Reference temperature: 145 °C

Material: aluminum

Material: copper

Correction between the temperature θ_1 at resistance measurement and the temperature θ_2 at loss measurement

$$R_{2A} = R_{1A} \frac{\vartheta_{0A} + \theta_2}{\vartheta_{0A} + \theta_1}$$

$$R_{2B} = R_{1B} \frac{\vartheta_{0B} + \theta_2}{\vartheta_{0B} + \theta_1}$$

$$P_{a2} = P_2 - (I^2 R_{2A} + I^2 R_{2B})$$

Winding resistances R_r , at particular reference temperatures θ_r :

$$R_{rA} = R_1 \frac{225+120}{225+\theta_1} = R_1 \frac{345}{225+\theta_1}$$

$$R_{rB} = R_1 \frac{235+145}{235+\theta_1} = R_1 \frac{380}{235+\theta_1}$$

Additional loss P_r , at medium reference temperature θ_r :

$$\theta_{r,Pa} = \frac{120 + 145}{2} = 132,5$$

$$\vartheta_{Pa} = \frac{225 + 235}{2} = 230$$

$$P_{ar} = P_{a2} \frac{\vartheta_{0P_a} + \theta_2}{\vartheta_{0P_a} + \theta_{r,P_a}} = P_{a2} \frac{230 + \theta_2}{230 + 132,5} = P_{a2} \frac{230 + \theta_2}{362,5}$$

Finally: $P_r = (I^2 R_{2A} + I^2 R_{2B}) + P_{ar}$

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ISO 12944-2, *Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 2: Classification of environments*

IEEE 693, *IEEE Recommended Practice for Seismic Design of Substations*

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

TRANSFORMATEURS DE PUISSANCE –

Partie 11: Transformateurs de type sec

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La Norme internationale IEC 60076-11 a été établie par le comité d'études 14 de l'IEC: Transformateurs de puissance.

Cette deuxième édition annule et remplace la première édition publiée en 2004 dont elle constitue une révision technique.

Les principales modifications par rapport à l'édition précédente sont les suivantes:

- Extension du domaine d'application jusqu'à 72,5 kV
- Prise en compte des enveloppes en ce qui concerne les performances
- Prise en compte des caractéristiques diélectriques et thermiques en fonction de l'altitude
- Nouvelles classes climatiques pour une meilleure adaptation des besoins des clients

- Établissement de la relation entre l'emplacement et les classes d'environnement
- Pour les classes de comportement au feu, limitation à 1 000 kVA et processus d'essai plus robuste
- Introduction d'une classe sismique
- Recommandations pour les transformateurs amorphes

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
14/964/FDIS	14/972/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 60076, publiée sous le titre général *Transformateurs de puissance*, se trouve sur le site web de l'IEC.

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TRANSFORMATEURS DE PUISSANCE –

Partie 11: Transformateurs de type sec

1 Domaine d'application

La présente partie de l'IEC 60076 s'applique aux transformateurs de type sec (y compris les autotransformateurs) dont les valeurs de tension la plus élevée pour le matériel sont inférieures ou égales à 72,5 kV avec au moins un enroulement fonctionnant à plus de 1,1 kV.

Le présent document ne s'applique pas aux:

- transformateurs de type sec avec un diélectrique gazeux autre que l'air;
- transformateurs monophasés de moins de 5 kVA;
- transformateurs polyphasés de moins de 15 kVA;
- transformateurs de mesure;
- transformateurs de démarrage;
- transformateurs d'essai;
- transformateurs de traction montés sur matériel roulant;
- transformateurs antidéflagrants et de mines;
- transformateurs de soudure;
- transformateurs de réglage de tension;
- petits transformateurs de puissance pour lesquels la sécurité est spécialement à prendre en compte.

Lorsqu'il n'existe pas de norme IEC pour les transformateurs mentionnés ci-dessus ou pour d'autres transformateurs spéciaux, le présent document peut être appliquée en tout ou en partie.

2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60068-3-3, *Essais d'environnement – Partie 3-3: Guide – Méthodes d'essais sismiques applicables aux matériels*

IEC 60071-1, *Coordination de l'isolement – Partie 1: Définitions, principes et règles*

IEC 60071-2, *Coordination de l'isolement – Partie 2: Lignes directrices en matière d'application*

IEC 60076-1:2011, *Transformateurs de puissance – Partie 1: Généralités*

IEC 60076-2, *Transformateurs de puissance – Partie 2: Echauffement des transformateurs immergés dans le liquide*

IEC 60076-3:2013, *Transformateurs de puissance – Partie 3: Niveaux d'isolement, essais diélectriques et distances d'isolement dans l'air*

IEC 60076-5, *Transformateurs de puissance – Partie 5: Tenue au court-circuit*

IEC 60076-10, *Transformateurs de puissance – Partie 10: Détermination des niveaux de bruit*

IEC 60076-12:2008, *Transformateurs de puissance – Partie 12: Guide de charge pour transformateurs de puissance de type sec*

IEC 60085, *Isolation électrique – Evaluation et désignation thermiques*

IEC 60270, *Techniques des essais à haute tension – Mesures des décharges partielles*

IEC 60332-3-10, *Essais des câbles électriques soumis au feu – Partie 3-10: Essai de propagation verticale de la flamme des fils ou câbles en nappes en position verticale – Appareillage*

IEC 60529, *Degrés de protection procurés par les enveloppes (Code IP)*

IEC 60721-3-4, *Classification des conditions d'environnement – Partie 3: Classification des groupements des agents d'environnement et de leurs sévérités – Section 4: Utilisation à poste fixe, non protégé contre les intempéries*

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

IEC 61378-1, *Transformateurs de conversion – Partie 1: Transformateurs pour applications industrielles*

IEC 62271-202, *Appareillage à haute tension – Partie 202: Postes préfabriqués haute tension/basse tension*

ISO 12944-6, *Peintures et vernis – Anticorrosion des structures en acier par systèmes de peinture – Partie 6: Essais de performance en laboratoire*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse <http://www.electropedia.org/>
- ISO Online browsing platform: disponible à l'adresse <http://www.iso.org/obp>

3.1

transformateur de type sec

transformateur dont le circuit magnétique et les enroulements ne sont pas immergés dans un diélectrique liquide

3.2

transformateur de type sec sous enveloppe entièrement hermétique

transformateur installé dans une enveloppe hermétique non pressurisée, refroidi par circulation intérieure de l'air, sans aucun échange intentionnel avec l'air extérieur

3.3

transformateur de type sec sous enveloppe non hermétique

transformateur installé dans une enveloppe ventilée, refroidi par circulation de l'air extérieur

3.4

transformateur de type sec sans enveloppe

transformateur sans habillage de protection refroidi par ventilation naturelle ou forcée

4 Conditions de service

4.1 Généralités

Les exigences de l'IEC 60076-1 ne s'appliquent aux transformateurs de type sec que si elles font l'objet d'une référence dans le présent document.

4.2 Conditions normales de service

a) Altitude:

Voir l'IEC 60076-1.

b) Température de l'air et de l'eau de refroidissement:

Voir l'IEC 60076-1.

Pour les transformateurs refroidis à l'eau, la spécification de l'eau (température, débit d'eau, etc.) doit être définie par accord entre le constructeur et l'acheteur si la température de l'eau diffère de la valeur spécifiée dans l'IEC 60076-1 et l'IEC 60076-2.

NOTE Des liquides autres que l'eau sont susceptibles d'être utilisés en tant que fluide de refroidissement; dans ce cas, toutes les données techniques du fluide doivent être définies par accord entre le constructeur et l'acheteur.

c) Forme d'onde de la tension d'alimentation:

Une tension d'alimentation sinusoïdale dont le taux d'harmonique total ne dépasse pas 5 % et dont le taux d'harmoniques pairs ne dépasse pas 1 %.

L'acheteur doit spécifier l'amplitude et la fréquence de toutes les tensions harmoniques présentes dans l'alimentation qui dépassent ces limites.

Il convient que le constructeur prenne en compte ces harmoniques pour déterminer les pertes supplémentaires du circuit magnétique et qu'il considère également la saturation du circuit magnétique.

d) Taux d'harmoniques du courant de charge:

Au stade de l'appel d'offres, l'acheteur doit spécifier l'amplitude et la fréquence de chaque composante de courant harmonique générée par la charge.

Le constructeur doit prendre en considération les pertes supplémentaires occasionnées par les courants harmoniques dans le calcul de l'échauffement des enroulements et les effets sur les autres parties métalliques du transformateur.

Le constructeur doit calculer les pertes supplémentaires en utilisant la méthode spécifiée dans l'IEC 61378-1 ou, par accord entre le constructeur et l'acheteur, à l'aide d'une méthode telle que le calcul par éléments finis.

Si le total des harmoniques du courant de charge dépasse 5 %, les pertes supplémentaires dues aux courants harmoniques doivent alors être prises en considération en augmentant le courant d'essai pour l'essai d'échauffement.

L'échauffement avec ces pertes ne doit pas dépasser la limite correspondante spécifiée dans le Tableau 2, lorsque l'essai est réalisé conformément au 14.3.2.

e) Symétrie des tensions d'alimentation triphasées:

Voir l'IEC 60076-1.

f) Environnement d'installation:

La présente norme définit des classes spécifiques d'environnement en fonction des paramètres suivants:

- 1) conditions climatiques;
- 2) humidité et pollution;
- 3) comportement au feu;
- 4) perturbations sismiques;
- 5) conditions environnementales conformes aux définitions suivantes de l'IEC 60721-3-4:
 - i) conditions biologiques 4B1;
 - ii) substances chimiquement actives 4C2;
 - iii) substances mécaniquement actives 4S3;
 - iv) conditions mécaniques 4M4.

g) Pour les transformateurs destinés à être installés à l'intérieur, certaines de ces conditions environnementales sont susceptibles de ne pas être applicables.

h) Courant d'enclenchement:

Les limites du courant d'enclenchement du système, le cas échéant, (valeur maximale, durée) doivent être indiquées au stade de l'appel d'offres par l'acheteur.

i) Fréquence d'enclenchement:

Si la fréquence des enclenchements est supérieure à 24 fois par an, l'acheteur doit alors indiquer le nombre annuel d'enclenchements au stade de l'appel d'offres.

j) Protection contre l'eau et les liquides:

Le transformateur doit être protégé contre le ruissellement d'eau ou la submersion par l'eau et d'autres liquides.

k) Conditions électriques et environnementales spécifiques autour du transformateur:

L'IEC 60076-3 recommande des distances minimales générales d'isolement dans l'air entre les parties sous tension du transformateur et les parties conductrices de l'installation.

Toute partie de l'installation constituée d'un matériau isolant devient conductrice une fois humidifiée avec de l'eau de pluie, de l'eau salée ou d'autres liquides conducteurs. Des décharges partielles à proximité du transformateur peuvent réduire la rigidité diélectrique de l'air.

Par conséquent, les distances dans l'air entre ces parties de l'installation et les parties sous tension du transformateur doivent respecter les valeurs recommandées dans l'IEC 60076-3.

NOTE Un accord entre l'acheteur et le constructeur est nécessaire pour réduire les distances dans l'air entre les parties actives du transformateur et les parties conductrices de l'installation.

l) Niveau de vibration:

Les vibrations de la structure dans laquelle le transformateur est destiné à être installé doivent être prises en considération lors de la conception du transformateur et une attention particulière doit être accordée à la contrainte transmise aux bornes de raccordement.

L'acheteur doit spécifier un spectre de vibration au stade de l'appel d'offres. Il convient que la procédure d'essai de vibration, le cas échéant, fasse l'objet d'un accord entre l'acheteur et le constructeur au stade de l'appel d'offres.

m) Protection contre la corrosion:

En fonction du type d'installation, il convient que l'acheteur choisisse une classe de protection définie dans l'ISO 12944 ou une classe ayant fait l'objet d'un accord entre l'acheteur et le constructeur.

n) Maintenance

L'utilisateur doit suivre les instructions du constructeur pour la maintenance et assurer un nettoyage régulier pour éviter, en particulier, l'accumulation de poussière ou de pollution sur le transformateur.

4.3 Compatibilité électromagnétique (CEM)

Les transformateurs doivent être considérés comme des éléments passifs par rapport à l'émission des perturbations électromagnétiques et l'immunité à ces perturbations.

5 Caractéristiques assignées et exigences générales

5.1 Généralités

Le constructeur doit indiquer les caractéristiques assignées de chaque transformateur, qui doivent être marquées sur la plaque signalétique (voir Article 9). Ces caractéristiques doivent être définies de façon que le transformateur puisse délivrer son courant assigné en service continu, sans que soient dépassées les limites d'échauffement spécifiées à l'Article 10, en supposant que la tension primaire appliquée soit égale à la tension assignée et à la fréquence assignée.

5.2 Puissance assignée

5.2.1 Généralités

La puissance assignée fait référence à une charge en continu. C'est la valeur de référence pour les garanties et les essais concernant les pertes dues à la charge, les échauffements et l'impédance de court-circuit.

NOTE Un transformateur à deux enroulements a seulement une valeur de puissance assignée, identique pour les deux enroulements. Quand le transformateur a une tension assignée appliquée à l'enroulement primaire, et que le courant assigné parcourt cet enroulement, le transformateur reçoit la puissance assignée adéquate pour les deux enroulements.

La puissance assignée correspond au régime continu; cependant, les transformateurs de type sec conformes à cette norme peuvent être surchargés et les principes de surcharge sont donnés dans l'IEC 60076-12.

5.2.2 Définition de la puissance assignée avec refroidissement par ventilateur ou échangeurs de chaleur

Le transformateur doit avoir une puissance assignée pour chaque enroulement, qui doit être indiquée sur la plaque signalétique. La puissance assignée fait référence à une charge en continu. C'est la valeur de référence pour les garanties et les essais concernant les pertes dues à la charge et les échauffements.

Si des valeurs différentes de puissance apparente sont attribuées en fonction de circonstances différentes, par exemple pour des méthodes de refroidissement différentes, la plus élevée de ces valeurs est la puissance assignée.

Quand un refroidissement complémentaire par ventilateurs est fourni, la puissance assignée sans ventilateur doit faire l'objet d'un accord entre le client et le constructeur.

5.2.3 Transformateur IP00 (sans enveloppe)

Le transformateur doit avoir une puissance assignée pour chaque enroulement, qui doit être indiquée sur la plaque signalétique.

5.2.4 Transformateur avec enveloppe

Le présent paragraphe définit la puissance assignée et la distance entre les enveloppes et les parties sous tension lorsque le transformateur est équipé d'une enveloppe.

Deux cas sont définis:

- a) Le transformateur sous enveloppe est fabriqué, soumis à essai dans l'enveloppe, puis livré sur site:
 - Les distances dans l'air entre les parties sous tension et l'enveloppe doivent être définies par le constructeur. Les essais diélectriques doivent être réalisés avec l'enveloppe en tant qu'essai individuel de série.
 - Si la distance dans l'air entre les parties sous tension et l'enveloppe satisfait à l'exigence de l'IEC 60076-3, l'essai diélectrique individuel de série doit être réalisé avec ou sans l'enveloppe.
 - Il est permis de démonter l'enveloppe pour des raisons de transport. Dans ce cas, les distances dans l'air entre les parties sous tension et l'enveloppe lorsque l'enveloppe est démontée doivent satisfaire aux exigences de l'IEC 60076-3.
 - Il ne doit se produire aucune réduction (déclassement) de la puissance assignée.
- b) Le transformateur et l'enveloppe sont livrés sur site séparément, ou ultérieurement:
 - Il existe deux méthodes pour déterminer les performances thermiques de l'enveloppe:
 - Le déclassement de la puissance assignée est déterminé par l'IEC 62271-202. Ensuite, la classe thermique de l'enveloppe doit être déclarée par le fabricant de l'enveloppe (vendeur de l'ensemble).
 - Le calcul pour l'enveloppe est effectué à l'aide de l'Annexe C du présent document.
 - La distance dans l'air entre la partie sous tension et l'enveloppe doit satisfaire à l'exigence de l'IEC 60076-3.
 - L'enveloppe doit être munie d'une plaque signalétique et il incombe au fabricant de l'enveloppe ou au vendeur de l'ensemble la responsabilité de déterminer la puissance assignée du transformateur avec l'enveloppe.

5.2.5 Valeurs préférentielles de puissance assignée

Les valeurs préférentielles doivent être conformes à l'IEC 60076-1 à partir de 50 kVA.

5.2.6 Charge au-delà de la puissance assignée

Les guides de charge pour transformateurs de type sec de l'IEC 60076-12 ainsi que les exigences de l'IEC 60076-1 doivent s'appliquer.

5.3 Dispositions pour conditions de service exceptionnelles

L'acheteur doit préciser, dans son appel d'offres, toutes les conditions de service non prévues dans les conditions de service normales de 4.2. Les exemples de telles conditions sont:

- température ambiante élevée ou basse en dehors des limites prévues en 4.2;
- ventilation insuffisante;
- altitude élevée en dehors des limites prévues en 4.2;
- fumées et vapeurs préjudiciables;

- vapeur;
- humidité en dehors des limites prescrites en 4.2;
- ruissellement d'eau;
- ambiance saline;
- pollution conductrice;
- poussières abrasives excessives;
- taux d'harmoniques élevé du courant de charge prescrit en 4.2;
- distorsion de la forme d'onde de la tension d'alimentation prescrite en 4.2;
- surtensions transitoires rapides en dehors des limites prescrites en 11.1;
- association de compensateur de puissance réactive et système d'enclenchement de condensateurs afin de limiter le courant d'enclenchement;
- courant continu superposé;
- contraintes sismiques qui nécessiteraient par ailleurs des considérations spéciales de conception;
- vibrations et chocs mécaniques importants;
- conditions de transport et de stockage non couvertes par les conditions normales citées en 5.7;
- rayonnement solaire;
- mises sous tension ordinaires fréquentes dépassant 24 fois par an;
- courts-circuits ordinaires fréquents;
- V/Hz dépassant les limites de l'IEC 60076-1;
- si un transformateur élévateur est destiné à être utilisé en mode réinjection lorsqu'il n'est pas raccordé au générateur sans protection sur le côté basse tension;
- protection contre la corrosion, selon le type d'installation;
- environnement (voir 4.2), il est recommandé que l'acheteur choisisse des classes de protection définies dans l'ISO 12944 ou ayant fait l'objet d'un accord entre l'acheteur et le constructeur;
- conditions de rejet de charge pour les transformateurs rotatifs plus sévères que celles décrites dans l'IEC 60076-1.

La spécification du transformateur pour des opérations dans de telles conditions anormales doit faire l'objet d'un accord entre le fournisseur et l'acheteur.

Les exigences supplémentaires dans les limites définies, pour la définition des caractéristiques assignées et les essais des transformateurs dans des conditions de service autres que celles citées en 4.2, telles que température élevée de l'air de refroidissement ou altitude supérieure à 1 000 m, sont données en 10.2 et 10.3.

5.4 Transport et stockage

5.4.1 Limitations de transport

Si des limitations de taille ou de poids de transport s'appliquent, elles doivent être indiquées dans l'appel d'offres.

Si d'autres conditions spéciales s'appliquent durant le transport, elles doivent être indiquées dans l'appel d'offres.

5.4.2 Accélération durant le transport

Le transformateur doit être conçu et fabriqué pour résister à une accélération constante d'au moins 10 m/s^2 dans toutes les directions (en plus de l'accélération due à la gravité dans la direction verticale) sans subir de dommage. (voir 4.2.f 5)

Si la responsabilité du transport n'incombe pas au constructeur et qu'une accélération supérieure à 10 m/s^2 est attendue durant le transport, les accélérations et fréquences doivent être définies au stade de l'appel d'offres. Si des accélérations supérieures sont spécifiées par l'acheteur, il convient que le constructeur les prenne en considération lors de la conception et qu'il fournisse des recommandations de transport et de conditionnement.

Si le transformateur est destiné à être utilisé en tant que transformateur mobile, l'appel d'offres doit le mentionner.

NOTE Des enregistreurs d'impacts ou de chocs sont couramment utilisés durant le transport des transformateurs de grande taille.

5.4.3 Conditions de température et d'environnement pour le transport et le stockage

Tous les transformateurs doivent être adaptés au transport et au stockage à des températures ambiantes allant jusqu'à -25 °C .

Pour le stockage et le transport à d'autres températures ambiantes, se reporter au 12.1.

Durant le transport et le stockage, les transformateurs doivent être protégés de la contamination, de l'eau, etc.

5.5 Tension assignée et fréquence assignée

5.5.1 Tension assignée

Les exigences de l'IEC 60076-1 s'appliquent.

5.5.2 Fréquence assignée

Les exigences de l'IEC 60076-1 s'appliquent.

5.6 Fonctionnement avec tension supérieure à la tension assignée

Les exigences de l'IEC 60076-1 s'appliquent.

NOTE 1 Cette exigence n'est pas censée être utilisée systématiquement en fonctionnement normal. L'augmentation consécutive des pertes à vide dans ces conditions pourrait avoir des effets néfastes sauf si une telle opération est de durée limitée. Cette condition est réservée aux cas relativement rares de service à durée limitée dans le temps, par exemple, en cas de service d'urgence ou de pointe de charge.

NOTE 2 Une sous-induction ne provoquera pas d'augmentation du courant assigné.

5.7 Tension la plus élevée pour le matériel U_m et niveaux des essais diélectriques

Pour les bornes de ligne, sauf spécification contraire de l'acheteur, U_m (tension la plus élevée pour le matériel) doit être la valeur la plus faible dépassant la tension assignée de chaque enroulement, telle qu'indiquée dans le Tableau 3.

Sauf spécification contraire par l'acheteur, les niveaux des essais diélectriques doivent être fixés selon la valeur applicable la plus élevée correspondant à U_m , comme indiqué dans le Tableau 3.

L'acheteur peut choisir, pour respecter la coordination de l'isolement, l'une des valeurs du Tableau 3 ou sélectionner une valeur plus élevée répertoriée dans l'IEC 60076-3.

5.8 Désignation suivant le mode de refroidissement

5.8.1 Généralités

L'acheteur doit spécifier le fluide de refroidissement (air ou eau).

Si l'acheteur a des exigences particulières concernant la ou les méthodes de refroidissement ou le matériel de refroidissement, il doit l'indiquer dans l'appel d'offres.

5.8.2 Symboles de désignation

Les transformateurs doivent être désignés d'après le mode de refroidissement utilisé. Les symboles littéraux correspondant à chaque mode de refroidissement sont mentionnés au Tableau 1.

Tableau 1 – Symboles littéraux

		Symbole
Type de fluide de refroidissement	Air	A
	Eau	W
Type de circulation	Naturelle	N
	Forcée	F

5.8.3 Disposition des symboles

Les transformateurs doivent être identifiés par deux symboles pour chaque mode de refroidissement pour lequel un régime est assigné par le constructeur, généralement de la façon suivante:

- Un transformateur conçu pour une ventilation naturelle par air est désigné par AN.
- Un transformateur conçu pour une ventilation naturelle par air jusqu'à une puissance assignée donnée et avec un refroidissement forcé pour une puissance assignée plus importante est désigné par AN/AF.
- Un transformateur conçu pour un refroidissement forcé avec un échangeur de chaleur à eau est désigné AFWF.
- Un transformateur conçu pour un refroidissement forcé par eau à l'intérieur de la bobine est désigné WF.

5.9 Échauffement garanti en conditions assignées

La conception du transformateur doit s'adapter aux conditions de fonctionnement (taux d'harmoniques, température ambiante, etc.) indiquées par l'acheteur au stade de l'appel d'offres.

L'échauffement garanti doit prendre en compte les pertes supplémentaires dues aux harmoniques, s'ils sont spécifiés, ce qui augmente les pertes par courant de Foucault et les pertes parasites dans les enroulements et les parties de la structure/et tôles maîtresses.

Si les harmoniques ne sont pas spécifiés au stade de la conception mais que le courant de charge réel en service contient des harmoniques, il peut être nécessaire de réduire la charge sur le transformateur ou d'améliorer le refroidissement pour éviter que l'échauffement du transformateur dépasse les limites garanties.

5.10 Informations supplémentaires demandées à l'appel d'offres

Le type de transformateur, par exemple, transformateur à enroulement séparé, autotransformateur ou transformateur série, doit être spécifié par l'acheteur.

5.11 Niveau de bruit

Voir l'IEC 60076-1.

5.12 Composants et matériaux

Tous les composants et matériaux utilisés dans la construction du transformateur doivent satisfaire aux exigences des normes IEC correspondantes lorsqu'elles existent, sauf accord ou spécification contraire.

6 Prises

Les exigences de l'IEC 60076-1 s'appliquent pour les changeurs de prises hors tension (DETC) et pour les changeurs de prises en charge (OLTC).

L'étendue préférentielle de prises pour les DETC est soit:

±5 % par palier de 2,5 % (5 positions de prises);

soit

±5 % (3 positions de prises).

La sélection de prise doit être faite hors tension au moyen de connexions boulonnées ou de DETC.

7 Connexions

Sauf spécifications contraires de l'acheteur, les connexions au transformateur doivent être Dyn11 ou Dyn5 conformément à l'IEC 60076-1. La connexion du neutre doit être capable de faire transiter le courant total assigné des phases.

8 Tenue au court-circuit

Les transformateurs doivent satisfaire aux exigences de l'IEC 60076-5. Si l'acheteur exige un essai pour prouver la tenue au court-circuit, ceci doit être spécifié dans le contrat.

9 Plaque signalétique

9.1 Plaque signalétique fixée sur le transformateur

Chaque transformateur doit être muni d'une plaque signalétique résistant aux intempéries, fixée à un emplacement visible et donnant les informations énumérées ci-dessous. Les inscriptions sur la plaque doivent être indélébiles (par exemple gravées chimiquement, mécaniquement, poinçonnées ou réalisées par processus photochimique):

- a) transformateur de type sec;
- b) numéro et année de cette partie de l'IEC 60076;
- c) nom du constructeur, pays et ville où le transformateur a été assemblé;
- d) numéro de série du constructeur;
- e) année de fabrication;

- f) classe thermique du système d'isolation pour chaque enroulement (soit par température, lettre, ou les deux – voir l'IEC 60085). La première classe thermique doit faire référence à l'enroulement haute tension, la seconde classe thermique doit faire référence à l'enroulement basse tension. Lorsqu'il y a plus de deux enroulements, les classes thermiques doivent être placées dans l'ordre des enroulements de la plus haute à la plus basse tension;
- g) nombre de phases;
- h) puissance assignée;
- i) puissance apparente pour chaque système de refroidissement;
- j) fréquence assignée;
- k) tensions assignées et, le cas échéant, tensions des prises de réglage;
- l) courants assignés pour chaque mode de refroidissement;
- m) symbole de connexion;
- n) impédance de court-circuit au courant assigné, et à température de référence appropriée;
- o) type de refroidissement;
- p) masse totale;
- q) niveaux d'isolement pour chaque enroulement conformément à la notation normalisée de l'IEC 60076-3;
- r) degré de protection;
- s) classe d'environnement;
- t) classe climatique;
- u) classe de comportement au feu;
- v) classe sismique ou accélérations au plancher, le cas échéant;
- w) altitude maximale si cette valeur est supérieure à 1 000 m;
- x) échauffement de l'enroulement pour chaque enroulement si les valeurs garanties diffèrent de celles du Tableau 2.

9.2 Plaque signalétique fixée sur l'enveloppe du transformateur

Chaque enveloppe de transformateur doit être munie d'une plaque signalétique résistant aux intempéries, fixée à un emplacement visible et donnant les informations énumérées en 9.1. Les inscriptions sur la plaque doivent être indélébiles (par exemple gravées chimiquement, mécaniquement, poinçonnées ou réalisées par processus photochimique).

10 Limites d'échauffement

10.1 Limites normales d'échauffement

L'échauffement de chaque enroulement du transformateur conçu pour fonctionner dans des conditions de service normales, ne doit pas dépasser la limite correspondante spécifiée dans le Tableau 2 lors d'un essai réalisé conformément au 14.3.2.

L'échauffement moyen de l'enroulement est défini comme la différence entre la température moyenne de l'enroulement et la température de l'air ou de l'eau de refroidissement au niveau de l'admission du matériel de refroidissement, pour les transformateurs à refroidissement par air ou par eau.

La température maximale relevée sur une quelconque partie du système d'isolation de l'enroulement est appelée température de point chaud. La température de point chaud ne doit pas dépasser la valeur assignée de la température d'enroulement de point chaud spécifiée dans le Tableau 2 de l'IEC 60076-12:2008. Cette température pourrait être mesurée, mais pour des raisons pratiques, une valeur approximative peut être calculée, en utilisant

l'équation 9 du 5.8 de l'IEC 60076-12:2008 avec les valeurs pour Z et q données en l'équation 9 de l'IEC 60076-12:2008.

Les composants utilisés comme matériaux isolants peuvent être utilisés séparément ou combinés, à condition que leur température ne dépasse pas les valeurs données pour la température du système d'isolation correspondant, en conformité avec les exigences prescrites dans la colonne de gauche du Tableau 2.

La température du circuit magnétique, des parties métalliques et des matériaux adjacents ne doit pas atteindre une valeur susceptible d'endommager une partie quelconque du transformateur.

Tableau 2 – Limites d'échauffement d'enroulement

Classe thermique du système d'isolation (voir Note 1) °C	Moyenne des limites d'échauffement d'enroulement à courant assigné (voir 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 (voir Note 3)	175

NOTE 1 Les lettres renvoient aux classifications de température données dans l'IEC 60085.

NOTE 2 Échauffement mesuré conformément au 14.3.2.

NOTE 3 Les désignations des classes thermiques au-dessus de 250 doivent augmenter par paliers de 25 et être indiquées en conséquence.

NOTE 4 Les valeurs figurant dans ce tableau sont définies pour une température ambiante normale: Voir l'IEC 60076-1.

On suppose ici que les températures de service des différentes parties d'un transformateur peuvent chacune être décrites comme la somme de la température du fluide de refroidissement externe (air de refroidissement ou eau de refroidissement) et de l'échauffement de la partie du transformateur.

10.2 Réduction des échauffements dans le cas de transformateurs prévus pour une température élevée du fluide de refroidissement ou pour des conditions spéciales du fluide de refroidissement

Lorsque le transformateur est conçu pour un fonctionnement avec une température du fluide de refroidissement dépassant l'une des valeurs maximales indiquées en 4.2, les limites d'échauffement doivent être réduites dans la même proportion. Les valeurs doivent être arrondies au degré K entier le plus proche.

Il convient que l'acheteur indique toute condition du lieu d'installation susceptible soit d'imposer des restrictions sur le fluide de refroidissement, soit de produire des températures ambiantes élevées du fluide.

10.3 Correction d'échauffement prévue pour des altitudes élevées

Sauf accord contraire entre le constructeur et l'acheteur, pour les transformateurs conçus pour fonctionner à des altitudes supérieures à 1 000 m, mais soumis à essai à des altitudes normales, les limites d'échauffement données dans le Tableau 2 doivent être réduites des quantités suivantes pour chaque tranche de 100 m au-dessus de 1 000 m:

- transformateurs à refroidissement naturel par air: 0,5 %;
- transformateurs à refroidissement forcé par air: 1 %.

Un correctif inverse correspondant peut être appliqué dans les cas où l'altitude de la salle d'essai est supérieure à 1 000 m et où l'altitude du site d'installation est inférieure à 1 000 m.

Toute correction de l'altitude doit être arrondie au nombre de K entier le plus proche.

11 Niveaux d'isolement

11.1 Généralités

Les niveaux de tension d'essai (niveaux d'isolement) doivent être ceux donnés dans le Tableau 3, liste 1 ou liste 2.

Tableau 3 – Niveaux de tension d'essai

Tension la plus élevée pour le matériel U_m (valeur efficace) kV	Tension appliquée AV (efficace) kV	Choc de foudre pleine onde (valeur crête) kV	
		List 1	List 2
≤ 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

Il est recommandé de considérer le degré d'exposition à la foudre et aux surtensions de manœuvre, le type de connexions à la terre et, quand cela est applicable, le type d'appareil de protection contre les surtensions pour faire le choix entre la liste 1 et la liste 2. Voir l'IEC 60071-1 et l'IEC 60071-2.

Dans certains pays, des valeurs différentes de U_m sont utilisées. Ces valeurs sont normalement proches de celles indiquées dans le Tableau 3 de la présente norme, par exemple 25 kV, etc. Dans ce cas, les niveaux d'isolement correspondant à la tension U_m la plus proche du Tableau 3 de la présente norme doivent être utilisés si la tension assignée est inférieure à la valeur U_m choisie.

NOTE Il peut arriver que certaines tensions de prise soient choisies légèrement supérieures à une valeur normalisée de U_m , mais le système auquel l'enroulement sera connecté ait une tension la plus élevée qui reste dans les limites de la valeur normalisée. Les exigences d'isolation doivent être coordonnées avec les conditions

réelles et, par conséquent, cette valeur normalisée peut être acceptée comme U_m pour le transformateur, et non la valeur supérieure la plus proche.

Exemple:

$U_r = 23,8$ kV +/- 5 %, il convient alors d'appliquer les niveaux d'isolement de U_m 24 kV

$U_r = 11,8$ kV +/- 5 %, il convient alors d'appliquer les niveaux d'isolement de U_m 12 kV

11.2 Transformateurs pour utilisation à des altitudes élevées

La rigidité diélectrique de l'air diminue avec l'altitude. Lorsque le transformateur est spécifié pour fonctionner à des altitudes supérieures à 1 000 m au-dessus du niveau de la mer, la conception doit prendre en considération la réduction de la rigidité diélectrique de l'air.

Quand les transformateurs sont conçus pour fonctionner à des altitudes comprises entre 1 000 m et 4 500 m au-dessus du niveau de la mer, mais qu'ils sont soumis aux essais à une autre altitude, une correction doit être appliquée aux tensions d'essai conformément au Tableau 4. Cette correction doit s'appliquer uniquement à l'essai de tension appliquée et non aux autres essais diélectriques.

Lors de la réalisation de l'essai de tension appliquée, la valeur de la tension d'essai doit être multipliée par le coefficient Tcf:

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

Tableau 4 – Facteur de correction du niveau de tension appliquée

Altitude en m	Facteur de correction de l'altitude d'installation	Facteur de correction de l'altitude d'essai
<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

Au-dessus de 4 500 m, le niveau d'isolement doit être défini par accord entre le fournisseur et l'acheteur.

Pour une altitude non répertoriée dans le Tableau 4, le facteur de correction peut être défini en interpolant les données du tableau.

12 Classes climatiques, d'environnement et de comportement au feu

12.1 Classes climatiques

Plusieurs classes climatiques sont définies:

- Classe C1: Le transformateur est apte au fonctionnement à température ambiante égale ou supérieure à -5 °C mais peut-être exposé durant le transport et le stockage à des températures ambiantes pouvant descendre jusqu'à -25 °C .
- Classe C2: Le transformateur est apte au fonctionnement, au transport et au stockage à des températures ambiantes pouvant descendre jusqu'à -25 °C .
- Classe C3: Le transformateur est apte au transport et au stockage à -40 °C et au fonctionnement à -25 °C .
- Classe C4: Le transformateur est apte au transport et au stockage à -50 °C et au fonctionnement à -40 °C .
- Classe C5: Le transformateur est apte au transport et au stockage à -60 °C et au fonctionnement à -50 °C .
- Classe Cxy: Le transformateur est apte au transport et au stockage à $-X\text{ °C}$ et au fonctionnement à $-Y\text{ °C}$.

La Classe C_{xy} doit être définie par accord entre l'acheteur et le constructeur qui indiquent la température pour le transport et le stockage (X) et la température pour le fonctionnement (Y).

Des essais spéciaux comme indiqué en 14.4.4 doivent confirmer la conformité des classes de transformateurs.

Si un transformateur satisfait aux critères d'une classe climatique, il doit également être considéré comme satisfaisant aux critères des classes moins sévères.

12.2 Classes d'environnement

12.2.1 Transformateurs pour application de type intérieur avec ou sans enveloppe et pour application de type extérieur avec enveloppe

Les conditions d'environnement pour les transformateurs de type sec sont identifiées en fonction de l'humidité, de la condensation, de la pollution et de la température ambiante. Le ruissellement d'eau ou d'autres substances conductrices sur la surface des bobines et des parties actives doit être évité durant le stockage et le fonctionnement.

En ce qui concerne l'humidité, la condensation et la pollution, cinq différentes classes d'environnement sont définies pour les transformateurs sans mesures de protection extérieure spéciales:

- Classe E0: Il ne se produit pas de condensation sur les transformateurs et la pollution est négligeable. Ceci est généralement obtenu avec une installation intérieure propre et sèche.
- Classe E1: Une condensation peut se produire occasionnellement sur le transformateur (par exemple quand le transformateur est hors tension). Une pollution limitée est possible.
- Classe E2: Condensation fréquente ou pollution légère ou combinaison des deux.

NOTE 1 Exemples: Les transformateurs sont en accès direct à l'environnement:

- zone sans industries et à faible densité d'habitations équipées de chaudières;
- zone à faible densité d'industries ou d'habitations mais soumise à des vents et/ou des chutes de pluie fréquents;
- zone agricole;
- zone montagneuse.

Toutes ces zones sont situées à au moins 15 km de la mer et ne sont pas exposées aux vents venant directement de la mer.

Classe E3: Condensation fréquente ou pollution moyenne ou combinaison des deux

NOTE 2 Exemples: Les transformateurs sont en accès direct à l'environnement:

- zone incluant des industries ne produisant pas particulièrement de fumée polluante et/ou à densité moyenne d'habitations équipées de chaudières
- zone à forte densité d'habitations et/ou d'industries mais soumise à des vents et/ou des chutes de pluie fréquents
- zone exposée au vent de la mer mais pas trop proche de la côte (au moins quelques kilomètres de distance)

Classe E4: Condensation fréquente ou pollution moyenne ou combinaison des deux

NOTE 3 Exemples: Les transformateurs sont en accès direct à l'environnement:

- zone à forte densité d'industries et banlieues de grandes villes à forte densité de chaudières produisant de la pollution
- zone proche de la mer ou en tout cas exposée à un vent relativement fort en provenance de la mer

Des essais spéciaux selon la procédure du 14.4.4 doivent confirmer la conformité des transformateurs de classe E1, E2, E3 ou E4.

Si un transformateur satisfait aux critères d'une classe d'environnement, il doit également être considéré comme satisfaisant aux critères des classes moins sévères.

Pour un niveau supérieur de condensation ainsi que pour un niveau supérieur de pollution, un accord entre le constructeur et l'acheteur est nécessaire pour fournir une enveloppe de protection adaptée.

NOTE 4 Exemples: Les transformateurs sont en accès direct à l'environnement:

- zone proche d'une industrie, exposée à des poussières conductrices et à une fumée industrielle produisant un dépôt conducteur particulièrement épais
- zone proche de la côte et exposée à un brouillard salin ou à des vents très forts et polluants en provenance de la mer
- zones désertiques, caractérisées par une absence de pluie pendant des périodes prolongées, exposées à des vents forts chargés de sable et de sel, et exposées à une condensation régulière.

12.2.2 Transformateurs de type sec sans enveloppe pour application de type extérieur

Les conditions d'environnement pour ces transformateurs de type sec sont identifiées en fonction de l'humidité, de la condensation, de la pollution, de la température ambiante et du rayonnement ultraviolet solaire (UV).

Le transformateur doit être installé à l'extérieur sans enveloppe (IP00) et peut être exposé à la pluie, à la neige ou à la grêle.

Classe E-O-1: zone rurale ou zone à faible pollution.

Classe E-O-2: zone urbaine, région industrielle ou zone à niveau de pollution modéré.

Classe E-O-3: zone côtière ou zone à forte pollution.

Des essais spéciaux selon la procédure de l'Annexe B doivent confirmer la conformité des transformateurs de Classe E-O-1, de Classe E-O-2, de Classe E-O-3.

Si un transformateur satisfait aux critères d'une classe d'environnement, il doit également être considéré comme satisfaisant aux critères des classes moins sévères.

12.3 Classes de comportement au feu

Deux classes de comportement au feu sont définies:

Classe F0: Il n'y a pas de risque spécial de feu à envisager. Excepté pour les caractéristiques inhérentes à la conception du transformateur, il n'y a pas de mesures spéciales à prendre pour limiter l'inflammabilité. Cependant, les émissions de substances toxiques et de fumée opaque doivent être réduites le plus possible.

Classe F1: Transformateurs soumis au risque de feu. Une inflammabilité restreinte est exigée. Les émissions de substances toxiques et de fumée opaque doivent être réduites le plus possible.

Des essais spéciaux selon la procédure du 14.4.6 doivent confirmer la conformité des transformateurs de classe F1.

12.4 Critères d'essai pour les classes climatiques, d'environnement et de comportement au feu

Lorsqu'un transformateur est déclaré approprié pour une combinaison de classes d'environnement, climatique et de comportement au feu, ces essais qui prouvent la conformité à ces classes, sont à effectuer sur un seul transformateur dans l'ordre donné au Tableau 5. Ce transformateur ou des parties de celui-ci, en fonction des descriptions d'essai individuel, doivent être utilisés pour réaliser les essais climatiques, d'environnement et de comportement au feu.

Pour l'essai au feu, en raison des valeurs des critères (limites de température, fumée, etc.) liées aux limites d'énergie calorifique et de laboratoire, la puissance maximale assignée est de 1 000 kVA avec une isolation de 12 kV ou 24 kV.

Les transformateurs déclarés conformes à ces classes doivent être produits avec une conception, des règles, des matières premières et un processus de fabrication identiques à ceux du transformateur soumis aux essais. Le transformateur en essai doit être prélevé dans une série de production standard et doit être apte comme tout autre transformateur à une mise sous tension et à une fourniture d'énergie sur le réseau.

Le constructeur doit être en mesure de présenter aux acheteurs le schéma, la liste des matières premières et l'essai individuel de série réalisé sur le transformateur soumis avec succès à une combinaison d'essais climatiques, d'environnement et de tenue au feu. Les critères d'équivalence sont donnés dans les articles correspondants.

Pour les transformateurs avec une puissance assignée supérieure à 1 000 kVA ou un niveau d'isolation supérieur à 24 kV, les essais climatiques et les essais d'environnement ne sont valables que si le constructeur dispose d'un certificat sur la séquence d'essais complète décrite dans le Tableau 5 pour un transformateur d'une puissance assignée de 1 000 kVA et d'un niveau d'isolation de 24 kV. Voir en 14.4.4.4 et 14.4.5.3.

Tableau 5 – Séquence des essais

Classes		Climatique	D'environnement		De comportement au feu		
Essais	Paragraphe		C1, C2, C3, C4, C5, Cxy	E0	E1, E2, E3, E4, E-O-1, E-O-2, E-O-3	F0	F1
1	Essai climatique	14.4.4	Oui	-	-	-	-
2	Essai environnemental	14.4.5 Annexe B	-	Non	Oui	-	-
3	Essai de comportement au feu	14.4.6	-	-	-	Non	Oui

Le transformateur soumis à la séquence d'essais doit être transporté dans la salle d'essai climatique pour y subir l'essai climatique; ce transformateur doit être ensuite transporté dans la salle d'essai d'environnement pour y subir l'essai d'environnement et les parties concernées de ce transformateur doivent être démontées et transportées dans la salle d'essai au feu pour y subir l'essai de tenue au feu. Il incombe au laboratoire qui délivre le certificat d'assurer la réalisation correcte des essais mentionnés ci-dessus sur le transformateur.

13 Classe sismique

13.1 Généralités

Un transformateur placé dans un environnement exposé à des perturbations sismiques exige une attention particulière.

Si le niveau d'accélération au sol (AG) est supérieur ou égal à 2 m/s^2 ou approximativement à $0,2 \text{ g}$, la conception du transformateur exige une attention particulière; l'acheteur doit alors fournir aux constructeurs des informations sur la zone d'installation et les conditions sismiques.

Le transformateur doit faire l'objet d'une qualification sismique soit par le biais d'essais, soit au moyen de calculs effectués sur la base d'un ou plusieurs transformateurs de référence soumis à essai.

Les niveaux généraux de performance sismique indiqués dans la présente norme démontrent la capacité de résistance du transformateur aux événements sismiques.

Pour permettre l'évaluation de la capacité sismique d'un transformateur, un spectre représentatif d'accélération au sol doit être défini.

Pour définir le choix du spectre d'accélération au sol le plus approprié à l'évaluation sismique d'un transformateur, il convient d'inclure les éléments suivants:

- la définition de l'accélération au sol pour la zone géographique correspondante;
- l'ajustement de l'accélération au sol en fonction de certains paramètres spécifiques à l'installation étudiée (type de sol, masse et élasticité du châssis de support, amplification, amortissement, etc.).

En l'absence d'informations détaillées permettant la détermination d'un spectre spécifique d'accélération au sol, l'approche de la classe sismique générale doit être suivie conformément à l'IEC 60068-3-3.

Si des informations détaillées permettant la détermination d'un spectre spécifique d'accélération au sol sont disponibles, l'approche de la classe sismique spécifique doit être suivie conformément à l'IEC 60068-3-3, sur la base d'un accord entre le constructeur et l'acheteur.

13.2 Approche de la classe sismique générale

13.2.1 Généralités

En cas d'approche par la classe sismique générale, deux méthodes sont possibles pour déterminer le spectre d'excitation appliqué:

- 1) Méthode à amplitude normalisée: en l'absence d'informations relatives à l'emplacement du transformateur et aux caractéristiques de la structure de support, voir 13.2.2.
- 2) Méthode à amplitude calculée: si des informations suffisantes sont disponibles, relatives à l'emplacement du transformateur et aux caractéristiques de la structure de support, voir 13.2.3.

13.2.2 Méthode à amplitude normalisée

Cette méthode permet la qualification du transformateur pour les classes sismiques en l'absence d'informations relatives à l'emplacement du transformateur et aux caractéristiques de la structure de support.

L'acheteur du transformateur doit spécifier le niveau de performance sismique adapté à l'application considérée.

Pour ce faire, on doit utiliser une approche simplifiée en 4 étapes associant le niveau de performance à une zone sismique différente ou choisir directement le niveau de performance sismique dans le Tableau 6.

- Étape 1: La zone correspondante d'activité sismique doit être identifiée suivant l'IEC 60721-2-6:1990, Figure 5.
- Étape 2: Un niveau d'accélération approché doit être obtenu à partir du Tableau 1 de l'IEC 60721-2-6:1990 en fonction de la zone sismique correspondante.
- Étape 3: Identifier les niveaux de performance correspondants en fonction du niveau d'accélération approché suivant le Tableau 6.
- Étape 4: Choisir l'accélération au plancher verticale ou horizontale dans le Tableau 6 pour le calcul des essais.

Tableau 6 – Niveau d'accélération approché et niveau de performance

Niveau d'accélération approché [m/s ²]	Classes sismiques (Niveau de performance)	Accélération au plancher <i>A_f</i> m/s ²	
		Horizontale	Verticale
2	S-I	6	3
3	S-II	9	4,5
5	S-III	15	7,5

NOTE Les niveaux d'accélération approchés n'incluent pas les facteurs inconnus tels que l'amplification, la direction, l'amortissement et autres; ils sont donc différents de l'accélération au plancher.

13.2.3 Méthode à amplitude calculée

Cette méthode permet la qualification du transformateur pour les classes sismiques lorsque des informations sont disponibles concernant l'emplacement du transformateur et les caractéristiques de la structure de support. Cette méthode est basée sur la norme IEC 60068-3-3.

Dans ce cas, le niveau de performance correspond à l'accélération au plancher définie comme suit:

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

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

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

Le niveau est calculé en prenant en considération les éléments suivants:

AG niveau d'accélération au sol (Tableau 7)

K facteur d'amplification (Tableau 8)

D facteur de direction (Tableau 9)

A_f représente l'accélération au plancher.

L'essai et le calcul doivent être réalisés en prenant la valeur calculée avec *A_f*.

Il incombe à l'acheteur du transformateur de décider du niveau d'accélération le plus adapté pour l'application considérée.