BS IEC 60076-15:2015

BSI Standards Publication

# Power transformers

## Part 15: Gas-filled power transformers

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## National foreword

This British Standard is the UK implementation of IEC 60076-15:2015.

The UK participation in its preparation was entrusted to Technical Committee PEL/14, Power transformers.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.


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# IEC 60076-15

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# NORME INTERNATIONALE

## Power transformers – Part 15: Gas-filled power transformers

## Transformateurs de puissance – Partie 15: Transformateurs de puissance à isolation gazeuse

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# POWER TRANSFORMERS –

## Part 15: Gas-filled power transformers

## FOREWORD

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International Standard IEC 60076-15 has been prepared by IEC technical committee 14: Power transformers.

This second edition of IEC 60076-15 cancels and replaces the first edition published in 2008 and constitutes a technical revision.

The following main technical changes from the first edition are:

– Modified in accordance with the related revised standards of IEC 60076-1, IEC 60076-2, IEC 60076-3 and related items of $SF_6$ gas in the revised standard of "High-voltage switchgear and controlgear"
– Added the clause "minimum power under alternative cooling modes"
– Added the clause "safety, environmental and other requirements"
– Added the clause "d.c. currents in neutral circuits"
– Added the clause "electromagnetic compatibility (EMC)"
– Added the clause "high frequency switching transients"

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

| FDIS | Report on voting |
|---|---|
| 14/811/FDIS | 14/818/RVD |

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

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

A list of all parts 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 publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

# POWER TRANSFORMERS –

# Part 15: Gas-filled power transformers

## 1 Scope

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

– single-phase transformers with rated power less than 1 kVA and three-phase transformers less than 5 kVA;
– transformers, which have no windings with rated voltage higher than 1 000 V;
– instrument transformers;
– traction transformers mounted on rolling stock;
– starting transformers;
– testing transformers;
– welding transformers.

When IEC standards do not exist for such categories of transformers (in particular transformer having no winding exceeding 1 000 V for industrial applications), this part of IEC 60076 may still be applicable either as a whole or in part. This standard does not address the requirements that would make a transformer suitable for mounting in a position accessible to the general public. For those categories of power transformers and reactors which have their own IEC standards, this part is applicable only to the extent in which it is specifically called up by cross-reference in the other standard. Such standards exist for:

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

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

NOTE This standard can be applicable to the gas parts of a transformer in which an insulating gas is used with an insulating liquid.

## 2 Normative references

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

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

IEC 60076-2:2011, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-3, *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 60137, *Insulated bushings for alternating voltages above 1 000 V*

IEC 60376, *Specification of technical grade sulfur hexafluoride (SF6) for use in electrical equipment*

IEC 60480, *Guidelines for the checking and treatment of sulfur hexafluoride (SF6) taken from electrical equipment and specification for its re-use*

IEC 62271-1, *High-voltage switchgear and controlgear – Part 1: Common specifications*

IEC 62271-4:2002, *High-voltage switchgear and controlgear – Part 4: Handling procedures for sulphur hexafluoride (SF6) and its mixtures*

## 3 Terms and definitions

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

NOTE Other terms use the meanings ascribed to them in IEC 60076-1, 2, 3, 5 and 10, or in the IEC 60050 series.

**3.1**
**gas-filled power transformer**
transformer of which the magnetic circuit and windings are placed in an enclosure filled with an insulating gas

Note 1 to entry: Generally sulfur hexafluoride ($SF_6$) gas is used, and sometimes this transformer is called a gas-insulated transformer.

**3.2**
**rated gas pressure**
gas pressure (gauge pressure) at 20 °C designed for use in a gas-filled power transformer

**3.3**
**guaranteed minimum gas pressure**
minimum gas pressure (gauge pressure) at 20 °C, which is able to guarantee the insulation of a gas-filled power transformer

Note 1 to entry: Transformer of which the magnetic circuit and windings are placed in an enclosure or a vessel filled with an insulating liquid such as perfluorocarbon, natural ester, synthetic ester, silicon oil and vegetable oil should be considered a liquid-immersed type transformer.

**3.4**
**design pressure of tanks**
relative pressure used to determine the design of the tanks

Note 1 to entry: It is at least equal to the maximum pressure in the tank at the highest temperature that the gas can reach under specified maximum service condition.

### 3.5 Terms, definitions, symbols and units relating to gas and vacuum tightness

**3.5.1**
**absolute leakage rate**
$F$
amount of gas escaped by time unit at rated filling pressure (or density), expressed in Pa $m^3/s$

**3.5.2**
**permissible leakage rate**
$F_p$
maximum permissible absolute leakage rate of gas at rated filling pressure (or density) specified by the manufacturer, expressed in Pa $m^3/s$

**3.5.3**
**relative leakage rate**
$F_{rel}$
absolute leakage rate related to the total amount of gas in the transformer at rated filling pressure (or density)

Note 1 to entry: It is expressed in percentage per year or per day.

## 4 Service conditions

Service conditions in IEC 60076-1 apply. As far as cooling conditions are concerned, see IEC 60076-2.

## 5 Rating and general requirements

### 5.1 Rated power

#### 5.1.1 General

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

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

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

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

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

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

The transformer shall be capable of carrying, in continuous service, the rated power (for a multi-winding transformer: the specified combination(s) of winding rated power(s) under conditions listed in Clause 4 of IEC 60076-1:2011 and without exceeding the temperature-rise limitations specified in 5.3.

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

National practices can be different.

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

### 5.1.2 Preferred values of rated power

Preferred values of rated power in IEC 60076-1 apply.

### 5.1.3 Minimum power under alternative cooling modes

Where the user has a particular requirement for a minimum power under a particular cooling mode other than the cooling mode for rated power, this shall be stated and subjected to agreement between the supplier and the purchaser in the tender stage.

The transformer shall be capable of carrying, in continuous service, the specified minimum power (for a multi-winding transformer: the specified combination(s) of winding rated power(s) under conditions listed in Clause 4 of IEC 60076-1:2011, and under the specified cooling mode, without exceeding the temperature-rise limitations specified in 5.3.

NOTE An example of this is where the transformer is required to operate at a particular minimum percentage of rated power with the forced cooling out of service (GNAN) to allow for the loss of auxiliary supply and large GNAN rating will be pushed up the transformer cost. A minimum percentage of rated power is determined with consideration of the cost-effectiveness.

### 5.1.4 Loading beyond rated power

Temporary loading beyond nameplate rating capability is subjected to agreement between the supplier and the purchaser in the tender stage.

NOTE 1 The concept of IEC 60076-7 can be applicable to the consideration of the loading beyond rated power of gas-filled power transformers, but constants and/or factors may not be applicable.

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

NOTE 2 This option is intended to be used in particular to give a basis for design and guarantees concerning temporary emergency loading of power transformers.

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

NOTE 3 The relevant component standards IEC 60137 for bushings and IEC 60214-1 for tap-changers are consulted for the loading capability of those components.

NOTE 4 These requirements do not apply to transformers for special applications, which do not need a loading capability beyond rated power. For these transformers, if such a capability is required, It is specified.

## 5.2 Cooling mode

### 5.2.1 General

The user shall specify the cooling medium (air or water). If the user has particular requirements for the cooling method(s) or cooling equipment, this shall be stated in the enquiry and the contract.

### 5.2.2 Identification symbols

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

First letter: Internal cooling medium:

– G: insulating gas;

Second letter: Circulation mechanism for internal cooling medium:

– N: natural/thermosiphon flow through cooling equipment and in windings;
– F: forced circulation through cooling equipment (e.g., gas blower), thermosiphon flow in windings;
– D: forced circulation through cooling equipment, directed from the cooling equipment into at least the main windings.

Third letter: External cooling medium:

– A: air;
– W: water.

Fourth letter: Circulation mechanism for external cooling medium:

– N: natural convection;
– F: forced circulation (fans, air blowers, water pumps).

### 5.2.3 Transformers with alternative cooling methods

A transformer may be specified with alternative cooling methods. In this case, the specification and the nameplate shall then carry information about the power values at which the transformer fulfils the temperature rise limitations when these alternatives apply.

The power value for the alternative with the highest cooling capacity is the rated power of the transformer (or of an individual winding of a multi-winding transformer). The alternatives are conventionally listed in rising order of cooling capacity.

EXAMPLE

GNAN/GDAF. The transformer has cooling equipment with blowers and fans but is also specified with a reduced power-carrying under natural cooling.

NOTE The percentage of natural cooling capacity to forced cooling capacity of gas-filled transformers is smaller than that of oil-immersed transformers. It is not difficult generally in oil-immersed transformers to achieve ONAN capacity as 50 % of the OFAF or ODAF capacity. But in gas-filled transformers, it is sometimes difficult and not economical to achieve GNAN capacity as 50 % of the GDAF capacity. The purchaser consults with the manufacturer about natural cooling capacity to forced cooling capacity.

## 5.3 Temperature-rise limits

### 5.3.1 Classification and insulation system temperature

Transformers are classified by the insulation systems shown in Table 1.

An approximate value for practical purposes of hot-spot temperature can be calculated by using the concept of Annex B.

The application of insulating materials with different thermal classes leads to unconventional insulation systems (see the examples of unconventional insulation systems as described in Clause 5 of IEC 60076-14:2013).

**Table 1 – Classification and insulation system temperature**

| Letter designation[a] | Thermal class (insulation system temperature °C) |
|---|---|
| A | 105 |
| E | 120 |
| B | 130 |
| F | 155 |
| H | 180 |
| N | 200 |
| R | 220 |
| [a] Temperature classifications are given in IEC 60085. | |

### 5.3.2 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 11.5.

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.

In most of the gases, the temperature-rise limit of gas is higher than the temperature-rise limit of winding, so that the temperature-rise limit of gas is not necessary to be specified. If necessary, it is subjected to agreement between the supplier and the purchaser.

**Table 2 – Winding temperature-rise limits**

| Thermal class (insulation system temperature °C) | Average winding temperature-rise limits K (see note) |
|---|---|
| 105 | 60 |
| 120 | 75 |
| 130 | 80 |
| 155 | 100 |
| 180 | 125 |
| 200 | 135 |
| 220 | 150 |
| NOTE Temperature-rise measured in accordance with 11.5. | |

### 5.3.3 Reduced temperature-rises for transformers designed for high cooling air temperatures or special air cooling conditions

Reduced temperature-rises for transformers designed for high cooling air temperatures or special air cooling conditions in IEC 60076-2 apply.

### 5.3.4 High altitude temperature-rise correction

Unless otherwise agreed 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 m by which the intended working altitude exceeds 1 000 m:

– natural-air-cooled transformers: 2 %;
– forced-air-cooled transformers: 3 %.

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

Any temperature-rise correction in dependence on altitude shall be rounded to the nearest whole number of Kelvin.

The influence of differing ambient temperature or altitude on the air cooling of the tank is disregarded for the water-cooled transformers.

#### 5.3.5 Reduced temperature-rise for transformers designed for high cooling water temperatures

Reduced temperature-rise for transformers designed for high cooling water temperatures in IEC 60076-2 apply.

#### 5.3.6 Temperature rise during specified load cycle

By agreement between manufacturer and purchaser, temperature rise limits can be guaranteed and/or a special test regarding load cycle operation specified (see IEC 60076-7).

### 5.4 Insulation level

Insulation level described in IEC 60076-3 apply.

### 5.5 Load rejection on transformers directly connected to a generator

The requirements for transformer connected directly to generators described in IEC 60076-1 apply.

### 5.6 Rated voltage and rated frequency

Rated voltage and rated frequency in IEC 60076-1 apply.

### 5.7 Provision for unusual service conditions

Any service conditions not covered by the normal service conditions shall be identified by the purchaser as described in IEC 60076-1.

### 5.8 Highest voltage for equipment $U_m$ and dielectric tests levels

Highest voltage for equipment $U_m$ and dielectric tests levels in IEC 60076-1 apply.

### 5.9 Additional information required for enquiry

Additional information required for enquiry that is described in IEC 60076-1 apply.

### 5.10 Components and materials

All components and materials used in the construction of the transformer shall comply with the requirements of the relevant IEC standards where they exist unless otherwise agreed or specified. In particular bushings shall comply with IEC 60137 and tap-changers shall comply with IEC 60214-1. Insulating gas shall comply with IEC 60376 and 60480 for new and used $SF_6$ or as agreed for other gases.

### 5.11 Requirements for gases and gas tightness

#### 5.11.1 Requirements for gases

The manufacturer shall specify the type and the required quantity, quality and density of the gas to be used in a gas-filled power transformer.

The maximum allowable moisture content within gas-filled power transformer filled with gas at rated gas pressure shall be such that the dew-point is not higher than –20 °C for a measurement at 20 °C. Adequate correction shall be made for measurement made at other temperatures.

NOTE 1 A dew point of –5 °C for measurement at 20 °C is acceptable for the gas-filled compartments other than main tank.

NOTE 2 The requirement level for the purity of $SF_6$ before filling transformers is equal and more than 97 %.

NOTE 3 For the measurement and determination of the dew point, see IEC 60376 and IEC 60480.

#### 5.11.2 Gas tightness

IEC 62271-1 gives general rules to the gas tightness of high-voltage switchgears. This rule can be applicable to the gas-filled power transformers.

The tightness characteristic shall be consistent with a minimum maintenance and inspection philosophy. The tightness for gas is specified by the relative leakage rate $F_{rel}$.

For $SF_6$-filled transformers, the relative leakage rate of $SF_6$ shall not exceed 0,5 percent per year. For transformers filled with the mixture, consisting of $SF_6$ and other gases, the relative leakage rate of the mixture shall not exceed 0,5 % per year.

## 6 Requirements for transformers having a tapped winding

Requirements for transformers having a tapped winding in IEC 60076-1 apply.

## 7 Connection phase displacement symbols

Connection phase displacement symbols in IEC 60076-1 apply.

## 8 Rating plates

### 8.1 General

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

### 8.2 Information to be given in all cases

The information listed below shall be included on the rating plate in all cases.

a) Kind of gas-filled power transformer (for example gas-filled power transformer, gas-filled auto-transformer, gas-filled series transformer, etc.).
b) Number of this standard.
c) Manufacturer's name, country and town where the transformer was assembled.
d) Manufacturer's serial number.
e) Year of manufacture.

f) Number of phases.

g) Rated power (in kVA or MVA). (For multi-winding transformers, the rated power of each winding shall be given. The loading combinations shall also be indicated unless the rated power of one of the windings is the sum of the rated powers of the other windings.)

h) Rated frequency (in Hz).

i) Rated voltages (in V or kV) and tapping range.

j) Rated currents (in A or kA).

k) Connection and phase displacement symbol.

l) Short-circuit impedance, measured value in percentage. For multi-winding transformers, several impedances for different two-winding combinations are to be given with the respective reference power values. For transformers having a tapped winding, see also 5.5 and item b) of 8.3 in IEC 60076-1:2011.

m) Type of cooling. (If the transformer has several assigned cooling methods, the respective power values may be expressed as percentages of rated power, for example GNAN/GNAF 30/100 %.)

n) Total mass.

o) Mass and type of insulating gas with reference to the relevant IEC standard.

p) Maximum system short-circuit power or current used to determine the transformer withstand capability if not infinite.

q) Insulation system temperature for each winding (for multi-winding transformers, the insulation system temperature of each winding should be given).

r) Rated gas pressure (in MPa-gauge.)

s) Guaranteed minimum gas pressure (in MPa-gauge).

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

### 8.3 Additional information to be given when applicable

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

a) For transformers having one or more windings with 'highest voltage for equipment' $U_m$ equal to or above 3,6 kV:
   - short notation of insulation levels (withstand voltages) as described in IEC 60076-3.

b) Tapping designations
   - For transformers with highest rated voltage less than or equal to 72,5 kV and with rated power less than or equal to 20 MVA (three phase) or 6,7 MVA (single phase) having a tapping range not exceeding ±5 %, tapping voltages on the tapped winding for all tappings.
   - For all other transformers
     - a table stating tapping voltage and maximum allowable tapping service voltage, tapping current, tapping power, and internal connection for all tappings,
     - a table showing the short-circuit impedance values for the principal tapping and at least the extreme tappings in % with the reference power.

c) Guaranteed maximum temperature rises of top gas and windings (if not normal values). When a transformer is intended for installation at high altitude, the altitude, power rating and temperature rise at that altitude shall be indicated on the nameplate together with one of the following:
   - If the transformer is designed for installation at high altitude, the (reduced) temperature rise for rated power under normal external cooling medium temperature conditions.

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

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

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

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

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

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

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

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

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

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

## 9 Safety, environmental and other requirements

### 9.1 Safety and environmental requirements

#### 9.1.1 Gas leaks

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

– joint design;

– gasket materials;

– welds;

– corrosion prevention.

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

#### 9.1.2 Safety considerations

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

– accessibility to parts with high temperatures;

– accessibility of live parts;

– accessibility of moving parts;

– lifting and handling provisions;
– safety during on site gasses handling;
– access for maintenance, where maintenance is required;
– working at height.

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

NOTE 1 ISO 14122 series is consulted where ladders, platforms and similar means of access are provided with the transformer.

NOTE 2 Safety during on site $SF_6$ handling is described in Annex B of IEC 62271-4:2002. Specially, $SF_6$ is handled by certified personal, only.

### 9.2 Dimensioning of neutral connection

Dimensioning of neutral connection in IEC 60076-1 apply.

### 9.3 Handling procedure for $SF_6$

$SF_6$ should be handled in a closed cycle, to avoid any deliberate release to the environment. Among all the voluntary initiatives, gas recovery and reuse have the highest priority.

For the development, manufacturing, installation, operation, maintenance and end-of-life disposal of electric power equipment utilising $SF_6$, state-of-the-art technologies and procedures are applied to minimize $SF_6$ emissions. Handling procedure for $SF_6$ described in IEC 62271-4 apply.

### 9.4 d.c. currents in neutral circuits

d.c. currents in neutral circuits in IEC 60076-1 apply.

### 9.5 Centre of gravity marking

Centre of gravity marking in IEC 60076-1 apply.

## 10 Tolerances

Tolerances in IEC 60076-1 apply.

## 11 Tests

### 11.1 General requirements for routine, type and special tests

#### 11.1.1 General

Transformers shall be subjected to tests as specified below.

Tests other than temperature rise tests shall be made at an external cooling medium temperature between 10 °C and 40 °C. See 11.5 for temperature rise tests.

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

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

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

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

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

All measuring systems used for the tests shall have certified, traceable accuracy and be subjected to periodic calibration.

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

All measurements and tests requiring power frequency supply shall be performed with the supply frequency within 1 % of the rated frequency of the transformer. The waveshape of the supply voltage shall be such that the total harmonic content does not exceed 5 %. If this condition is not satisfied then the effect of the waveshape on the measured parameter shall be evaluated by the manufacturer and subject to approval by the purchaser. Loss measurements should not be corrected downwards to account for harmonics in the supply voltage except as allowed in 11.5 of IEC 60076-1:2011. Where a three-phase supply is used, the supply voltage shall be symmetrical. The maximum voltage across each phase winding under test shall not differ from the minimum voltage by more than 3 %.

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

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

#### 11.1.2 Routine tests

##### 11.1.2.1 General

Routine tests listed in 11.1.2.2 shall be applied to all transformers, and additional routine tests listed in 11.1.2.3 shall be applied to transformers with $U_m$ > 72,5 kV.

##### 11.1.2.2 Routine test for all transformers

a) Measurement of winding resistance (IEC 60076-1).

b) Measurement of voltage ratio and check of phase displacement (IEC 60076-1).

c) Measurement of short-circuit impedance and load loss (11.2).

d) Measurement of no-load loss and current (IEC 60076-1).

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

f) Tests on on-load tap-changers, where appropriate (IEC 60076-1).

g) Tightness tests for tanks (11.3).

h) Pressure tests for tanks (11.4).

i) Check of the ratio and polarity of built-in current transformers (IEC 60076-1).

j) Check of core and frame insulation for gas-filled power transformers with core or frame insulation (IEC 60076-1).

#### 11.1.2.3 Additional routine tests for transformers with $U_m$ > 72,5 kV

a) Determination of capacitances windings-to-earth and between windings (IEC 60076-1).

b) Measurement of d.c. insulation resistance between each winding to earth and between windings (IEC 60076-1).

c) Measurement of dissipation factor (tan δ) of the insulation system capacitances (IEC 60076-1).

d) Measurement of dissolved gasses in insulating gas from main-transformer compartment except diverter switch compartment, cable head compartment and gas-insulated switchgear (GIS) structure compartment.

e) Measurement of no-load loss and current at 90 % and 110 % of rated voltage (IEC 60076-1).

### 11.1.3 Type tests

a) Temperature-rise type test (11.5).

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

c) Determination of sound level (11.6) for each method of cooling for which a guaranteed sound level is specified (IEC 60076-1).

d) Measurement of the power taken by the fan and gas blower motors.

e) Measurement of no-load loss and current at 90 % and 110 % of rated voltage (IEC 60076-1).

### 11.1.4 Special tests

a) Dielectric special tests (IEC 60076-3).

b) Determination of capacitances windings-to-earth, and between windings (IEC 60076-1).

c) Measurement of dissipation factor (tan $\delta$) of the insulation system capacitances (IEC 60076-1).

d) Determination of transient voltage transfer characteristics (Annex B of IEC 60076-3:2013).

e) Measurement of zero-sequence impedance(s) on three-phase transformers (IEC 60076-1).

f) Short-circuit withstand test (IEC 60076-5).

g) Measurement of d.c. insulation resistance each winding to earth and between windings (IEC 60076-1).

h) Measurement of frequency response (Frequency Response Analysis or FRA). The test procedure shall be agreed between manufacturer and purchaser (IEC 60076-1).

i) Check of external coating (ISO 2178 and ISO 2409 or as specified).

j) Measurement of dissolved gasses in insulating gas from main-transformer compartment except diverter switch compartment, cable head compartment and gas-insulated switchgear (GIS) structure compartment.

k) Mechanical test or assessment of tank for suitability for transport (to customer specification) (IEC 60076-1).

l) Determination of weight with transformer arranged for transport. For transformers up to 1,6 MVA by measurement. For larger transformers by measurement or calculation as agreed between manufacturer and purchaser (IEC 60076-1).

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

NOTE Although “winding hot-spot temperature-rise measurements” is listed in 11.1.4 b) of IEC 60076-1:2011, in this standard, direct measurement (e.g. optical fibre sensors) is not recommended due to concerns about gas leakage. Winding hot-spot temperature-rise will be determined by calculation described in 7.10.2 of IEC 60076-2:2011.

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

### 11.2 Measurement of short-circuit impedance and load loss

The test described in IEC 60076-1 applies.

The reference temperature of the short-circuit impedance and load loss shall be

– 75 °C for an insulation system temperature of 105 °C;
– average winding temperature-rise limits K in Table 2 plus 20 °C for other insulation system temperatures.

NOTE Reference temperature with an insulation system of class 200 or above are subjected to agreement between the supplier and the purchaser.

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.

### 11.3 Leak testing with pressure (tightness test)

IEC 62271-1 gives a general test method of the gas tightness of high-voltage switchgears.

This method can be applicable to the gas-filled power transformers.

The purpose of the tightness tests is to demonstrate that the absolute leakage rate $F$ does not exceed the specified value of the permissible leakage rate $F_{\mathrm{p}}$.

Where possible, the tests should be performed at normal ambient temperature on a complete system filled at rated gas pressure. If this is not practical, the tests may be performed on parts, components or sub-assemblies. In such cases, the leakage rate of the total system shall be determined by summation of the component leakage rates. The possible leakage between sub-assemblies of different pressures shall also be taken into account.

In general, only cumulative leakage measurements allow calculation of leakage rates. Due to comparatively small leakage rates of these systems, pressure drop measurements are not applicable. Other methods such as halogen detectors may be used to measure the leakage rate. If the test object is filled with a test gas different from the gas used in service and/or at a test pressure different from the normal operating pressure, corrective factors agreed between manufacturer and purchaser shall be used for calculations.

The test report should include such information as

– a description of the object under test, including its internal volume and the nature of the filling gas;
– the pressures and temperatures recorded at the beginning and end of the test;
– an indication of the calibration of the meters used to detect leakage rates;
– the results of the measurements;
– if applicable, the test gas and the corrective factor to assess the results.

### 11.4 Pressure tests for tanks

Pressure test shall be made on all tanks. The standard test pressure shall be $k$ times the tank design pressure, where the $k$ factor is

– 1,3 for welded steel and aluminum tanks;
– 2,0 for cast steel and aluminum tanks.

NOTE 1 See IEC 62271-203.

NOTE 2 The $k$ factor is applicable to tanks with both bolted and welded cover.

The test pressure measured by the pressure gauge shall be maintained for at least 1,0 min. No rupture or permanent deformation should occur during the test.

Attention is drawn to the safety issue during the test and water is recommended to be used for the test on the tank with cover.

NOTE 3 If there is local regulation relevant to the pressure vessel, it is to be applied to $k$ factor.

### 11.5 Temperature-rise test

#### 11.5.1 General

The test described in IEC 60076-2 applies with replacing liquid with gas.

#### 11.5.2 Corrections

The gas temperature rises over the external cooling medium temperature at the shutdown (of the test power) shall be multiplied by:

$$\left(\frac{\text{total losses}}{\text{test losses}}\right)^{x}$$

The average winding temperature rise over average gas temperature at the shutdown (of the test power) shall be multiplied by:

$$\left(\frac{\text{rated current}}{\text{test current}}\right)^{y}$$

The exponents to be applied are given in Table 3 in accordance with the transformer type and cooling system.

The corrections made using the exponent of the mentioned table are conservative and intended only for reporting the temperature rise during a test in steady state conditions performed within the limits indicated above.

**Table 3 – Exponents for the corrections of temperature rise test results**

| Type of transformer / Type of exponent | Distribution Transformers | Medium and large power transformers | | |
|---|---|---|---|---|
| | GNAN | GN… | GF… | GD… |
| Top-gas exponent $x$ | 0,8 | 0,9 | 1,0 | 1,0 |
| Average winding exponent $y$ | 1,6 | 1,6 | 1,6 | 2,0 |
| NOTE For the purposes of this table, distribution transformers are transformers with a rated power up to and equal to 2 500 kVA. | | | | |

### 11.6 Measurement of sound level

#### 11.6.1 General

Measurement of sound level except for prescribed contour in IEC 60076-10 is applied.

#### 11.6.2 Prescribed contour

For measurement made with forced air cooling and forced gas cooling auxiliaries (if any, e.g., fan, gas blower) out of service, the prescribed contour shall be spaced 0,3 m away from the principal radiating surface.

For measurement made with forced air cooling or forced gas cooling auxiliaries in service, the prescribed contour shall be spaced 2 m away from the principal radiating surface.

## 12 Electromagnetic compatibility (EMC)

Electromagnetic compatibility (EMC) described in IEC 60076-1 apply.

## 13 High frequency switching transients

High frequency switching transients described in IEC 60076-1 apply.

## 14 Earthing terminal

Transformers shall be fitted with an earthing terminal.

## 15 Information required with enquiry and order

The requirements in Annex A apply.

# Annex A
(informative)

# Check list of information to be provided with enquiry and order

## A.1 Rating and general data

### A.1.1 Normal information

The following information shall be given in all cases:

a) Particulars of the specifications to which the transformer shall comply.

b) Kind of transformer, for example, separate winding transformer, auto-transformer or series transformer.

c) Single or three-phase unit.

d) Number of phases in system.

e) Frequency.

f) Gas-filled, type of gas, whether $SF_6$ or others.

g) Indoor or outdoor type.

h) Type of cooling.

i) Rated power for each winding and, for tapping range exceeding ±5 %, the specified maximum current tapping, if applicable. If the transformer is specified with alternative methods of cooling, the respective lower power values are to be stated together with the rated power (which refers to the most efficient cooling).

j) Rated voltage for each winding.

k) For a transformer with tappings (see 6.4 of IEC 60076-1:2011):

- whether ‘de-energized' or 'on-load' tap-changing is required;
- any requirements for fixing the ratio of turns between two particular windings on a more than two winding transformer;
- whether any tapping or range of tappings can be reduced power tappings;
- the number of tapping steps and the size of the tapping step or the tapping range;

and either:

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

or:

- direction of power flow (can be both directions);
- which voltage shall vary for the purpose of defining rated tapping voltage;
- minimum full load power factor.

l) Highest voltage for equipment ($U_m$) for each winding line and neutral terminals (with respect to insulation, see IEC 60076-3).

m) Method of system earthing (for each winding).

n) Insulation level and dielectric test levels (see IEC 60076-3), for each winding line and neutral terminals.

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

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

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

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

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

t) Guaranteed maximum temperature rise information.

u) Unusual service conditions (see Clause 4 and 5.5 of IEC 60076-1:2011).

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

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

x) Vacuum withstand of the transformer tank.

y) Local regulation relevant to pressure vessel.

### A.1.2 Special information

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

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

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

c) Short-circuit impedance, or impedance range (see Annex C of IEC 60076-1:2011). For multi-winding transformers, any impedances that are specified for particular pairs of windings (together with relevant reference ratings if percentage values are given).

d) Tolerances on voltage ratios and short-circuit impedances as left to agreement in Table 1 of IEC 60076-1:2011, or deviating from values given in the table.

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

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

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

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

i) Loss evaluation information or maximum losses.

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

k) Shipping size and weight limitations. Minimum acceleration withstand values if higher than specified in 5.7.4.2 of IEC 60076-1:2011.

l) Transport and storage conditions not covered by normal conditions described in 5.7.4 and 4.2 of IEC 60076-1:2011.

m) Any particular maintenance requirements or limitations.

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

o) Whether facilities for condition monitoring are required (see Annex C).

p) Any particular environmental considerations regarding the impact of the transformer on the environment that shall be taken into account in the transformer design, see Annex G of IEC 60076-1:2011. Especially, $SF_6$ should be handled in a closed cycle, to avoid any deliberate release to the environment. Among all the voluntary initiatives, gas recovery and reuse have the highest priority, see 9.3.

q) Any particular health and safety considerations that shall be taken into account in the transformer design regarding manufacture, installation, operation, maintenance and disposal, see Annex G of IEC 60076-1:2011.

r) Unusual electrical operating conditions as follows:

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

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

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

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

5) details of intended regular cyclic overloading other than covered by 5.1.4 of IEC 60076-1:2011 (to enable the rating of the transformer auxiliary equipment to be established).

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

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

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

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

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

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

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

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

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

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

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

17) frequent short circuits.

s) Unusual physical environmental conditions

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

2) pecial external cooling medium temperature conditions, outside the normal range (see 4.2 b) of IEC 60076-1:2011), or restrictions to circulation of cooling air.

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

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

5) abnormal vibration, tilting, or shock.

## A.2 Parallel operation

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

a) Rated power.

b) Rated voltage ratio.

c) Voltage ratios corresponding to tappings other than the principal tapping.

d) Load loss at rated current on the principal tapping, corrected to the appropriate reference temperature, see 11.1 of IEC 60076-1:2011.

e) Short-circuit impedance on the principal tapping and on the extreme tappings, if the voltage on the extreme tappings is more than 5 % different to the principal tapping. Impedance on other tappings if available.

f) Diagram of connections, or connection symbol, or both.

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

# Annex B
(informative)

# Transient loading – Mathematical model

## B.1 General

The result from a temperature-rise test to steady state, according to 11.5, may be used for an estimate of steady-state temperature-rise at a different loading, and also for an estimate of transient temperature-rise (if the thermal time-constants of the transformer are known).

For small and medium-size transformers such estimates are performed according to a conventional mathematical model which is described in Clause B.2 below.

The validity of this model for any particular large transformer is, however, not so certain as for transformers of lower rated power. When load ability analysis is to be performed, for example, concerning emergency loading above rated power, it is advisable to obtain relevant data for the actual transformer. One way is to conduct special testing with transient load in excess of rated power. Recommendations for a suitable test procedure and for the associated measurements and observations are presented in IEC 60076-2.

## B.2 Mathematical model for temperature distribution in a winding of a gas-filled power transformer – The hot-spot concept

Cooling gas enters the bottom of the winding and is at 'bottom gas temperature'. It passes upwards through the winding and its temperature is assumed to rise linearly with the height. The winding losses are transferred from the winding to the gas all along the winding. This heat transfer requires a temperature drop between winding and surrounding gas which is assumed to be the same at all levels of height. In the graphic presentation, Figure B.1, the winding temperature and the gas temperature will therefore appear as two parallel lines.

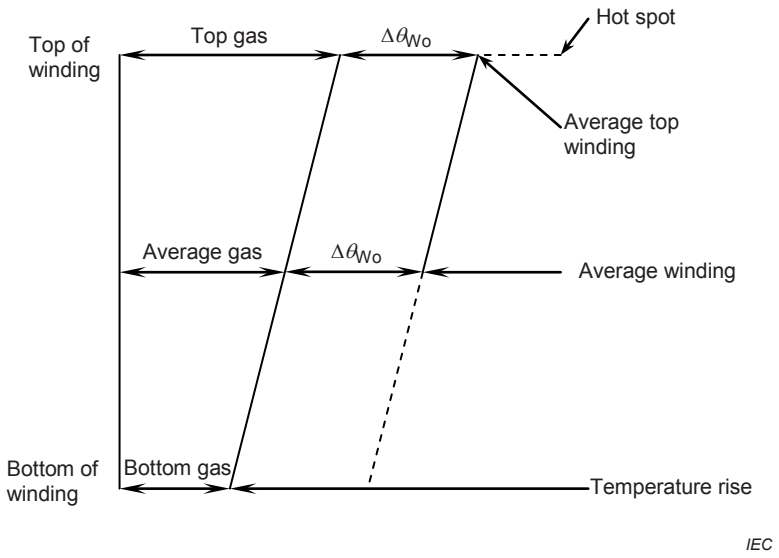


**Figure B.1 – Temperature distribution model**

The maximum temperature occurring in any part of the winding insulation system is called the 'hot-spot temperature'. This parameter is assumed to represent the thermal limitation of loading of the transformer. As a general rule other parts of the transformer, for example, bushings,

current transformers or tap changers, should be selected so as not to represent any narrower restriction of the load ability of the transformer, see 5.1.4 of IEC 60076-1:2011.

Towards the upper end of the winding there is usually a concentration of eddy current losses and the winding may be provided with extra electrical insulation which increases the thermal insulation. The actual local temperature difference between conductor and gas is therefore assumed to be higher by the ‘hot-spot factor’. This factor is assumed to be from 1,1 in distribution transformers to 1,3 in medium size power transformers. In large transformers there is considerable variation depending on design, and the manufacturer should be consulted for information, unless actual measurements are carried out.

The steady-state temperature difference between winding and gas, average along the winding, is taken as the difference between [resistance-measured winding average temperature] and [average gas temperature], see 7.4 and 7.6 in IEC 60076-2:2011 respectively with the translation of liquid to gas.

The steady-state hot-spot temperature-rise above external cooling medium temperature (air or water) is the sum of [top gas temperature-rise above cooling medium temperature] and [hot-spot factor] × [average temperature difference winding-to-gas].

# Annex C
(informative)

## Gauges, indicators and relays for gas-filled power transformers

This annex compares gauges, indicators and relays as shown Table C.1 for gas-filled power transformers to oil-immersed power transformers. The actual gauges, indicators and relays provided shall be agreed between manufacturer and purchaser and will depend on the size and criticality of the gas-filled power transformer.

Further guidance is contained in CIGRE brochure 445 Appendix 2: February 2011.

**Table C.1 – Comparison of gauges, indicators and relays between gas-filled power transformers and oil-immersed power transformers**

<table>
<tr><th></th><th>Gas-filled power transformer</th><th>Oil-immersed power transformer</th></tr>
<tr><td rowspan="4">Recommended components for gas-filled power transformer</td><td>Gas temperature indicator</td><td>Oil temperature indicator</td></tr>
<tr><td>Compound gauge</td><td rowspan="2">Oil level indicator</td></tr>
<tr><td>Gas density relay</td></tr>
<tr><td>Sudden gas pressure relay for OLTC</td><td rowspan="2">Rapid pressure rise relay<br>(Fault gas relay, fault pressure relay, and sudden pressure relay)</td></tr>
<tr><td rowspan="4">Optional components for gas-filled power transformer</td><td>Sudden gas pressure relay for main tank</td></tr>
<tr><td>Winding temperature indicator</td><td>Winding temperature indicator</td></tr>
<tr><td>Pressure relief device (See NOTE 1)</td><td>Pressure relief device</td></tr>
<tr><td>Gas flow indicators</td><td>Oil flow indicators</td></tr>
<tr><td colspan="3">NOTE 1 Pressure relief devices are not recommended to apply on gas-filled transformer tanks because pressure increase in gas-filled power transformer is very small when internal fault occurs.<br><br>NOTE 2 Although buchholz relays are applied on oil-immersed power transformers, there are no relays which has similar functions for gas-filled power transformers.</td></tr>
</table>

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