

INTERNATIONAL STANDARD



Insulated bushings for alternating voltages above 1 000 V

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INTERNATIONAL STANDARD



Insulated bushings for alternating voltages above 1 000 V

INTERNATIONAL
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COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**INSULATED BUSHINGS FOR ALTERNATING
VOLTAGES ABOVE 1 000 V**

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International Standard IEC 60137 has been prepared by sub-committee 36A: Insulated bushings, of IEC technical committee 36: Insulators.

This seventh edition cancels and replaces the sixth edition, published in 2008, and constitutes a technical revision.

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

- Resin-impregnated synthetic (RIS) bushings has been introduced.
- Bushings with $U_m \leq 1,1$ kV, $U_m = 1\ 100$ kV and $U_m = 1\ 200$ kV have been introduced.
- Temperature rise testing has been included for liquid-insulated bushings according to clause to 3.4.
- Introducing dry lightning impulse testing as a routine test for all transformer bushings with $U_m > 72,5$ kV.
- The altitude correction procedure has been revised ($> 1\ 000$ m).
- An explanation about Very Fast Transient (VFT) phenomenon and its impact on bushings has been included.

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

FDIS	Report on voting
36A/187/FDIS	36A/189/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.

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- withdrawn,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 May 2018 have been included in this copy.

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INTRODUCTION

In the preparation of the current edition of this standard further consideration has been given to the test requirements for power transformers as described in IEC 60076-3:2000 2013. ~~Extensions have been made to the requirements for lightning impulse type testing and an additional test – long duration power frequency withstand test – has been included.~~

~~In anticipation of changes in the creepage correction factors defined in IEC 60815 and currently under review by TC 36, details of the correction method have been removed from this standard.~~

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INSULATED BUSHINGS FOR ALTERNATING VOLTAGES ABOVE 1 000 V

1 Scope

This International Standard specifies the characteristics and tests for insulated bushings.

This standard is applicable to bushings, as defined in Clause 3, intended for use in electrical apparatus, machinery, transformers, switchgear and installations for three-phase alternating current systems, having highest voltage for equipment above 1 000 V and power frequencies of 15 Hz up to and including 60 Hz.

Subject to special agreement between purchaser and supplier, this standard may be applied, in part or as a whole, to the following:

- bushings used in other than three-phase systems;
- bushings for high-voltage direct current systems;
- bushings for testing transformers;
- bushings for capacitors.

Special requirements and tests for transformer bushings in this standard apply also to reactor bushings.

This standard is applicable to bushings made and sold separately. Bushings which are a part of an apparatus and which cannot be tested according to this standard should be tested with the apparatus of which they form part.

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 60038:1983, *IEC standard voltages*
Amendment 2 (1997)

IEC 60050-212:1990 2010, *International Electrotechnical Vocabulary – Part 212: Electrical insulating solids, liquids and gases*

IEC 60059, *IEC standard current ratings*

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068-2-17:1994, *Basic environmental testing procedures – Part 2-17: Tests – Test Q: Sealing*

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

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

IEC 60076-7, *Power transformers – Part 7: Loading guide for oil-immersed power transformers*

IEC 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

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

IEC 60296, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

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

IEC 60422, *Mineral insulating oils in electrical equipment – Supervision and maintenance guidance*

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

IEC 60505, *Evaluation and qualification of electrical insulation systems*

~~IEC 60815, *Guide for the selection of insulators in respect of polluted conditions*~~

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 TS 60815-2, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 2: Ceramic and glass insulators for a.c. systems*

IEC TS 60815-3, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 3: Polymer insulators for a.c. systems*

IEC 61099, *Insulating liquids – Specifications for unused synthetic organic esters for electrical purposes*

IEC 61462, *Composite hollow insulators – ~~Hollow~~ Pressurized and unpressurized insulators for use in ~~outdoor and indoor~~ electrical equipment with rated voltage greater than 1 000 V – Definitions, test methods, acceptance criteria and design recommendations*

IEC TS 61463, *Bushings – Seismic qualification*

IEC 62155:2003, *Hollow pressurized and unpressurized ceramic and glass insulators for use in electrical equipment with rated voltages greater than 1 000 V*

IEC 62217, *Polymeric HV insulators for indoor and outdoor use ~~with nominal voltage greater than 1 000 V~~ – General definitions, test methods and acceptance criteria*

~~IEC 62271 (all parts), *High-voltage switchgear and controlgear*~~

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

IEC Guide 109, *Environmental aspects – Inclusion in electrotechnical product standards*

~~IEC Guide 111, Electrical high-voltage equipment in high-voltage substations – Common recommendations for product standards~~

CISPR 16-1 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods*

CISPR 18-2, *Radio interference characteristics of overhead power lines and high-voltage equipment – Parts 2: Methods of measurement and procedure for determining limits*

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

bushing

device that enables one or several conductors to pass through a partition such as a wall or a tank, and insulates the conductors from it; the means of attachment (flange or fixing device) to the partition forms part of the bushing

Note 1 to entry: The conductor may form an integral part of the bushing or be drawn into the central tube of the bushing.

~~NOTE 2 – The bushing may be of the types as described in 3.2 to 3.21.~~

[SOURCE: IEC 60050-471:2007, 471-02-01]

3.2

liquid-filled bushing

bushing in which the space between the inside surface of the insulating envelope and the solid major insulation is filled with mineral oil or other insulating liquid

3.3

compound-filled bushing

bushing in which the space between the inside surface of the insulating envelope and the solid major insulation is filled with an insulating compound

3.4

liquid-insulated bushing

bushing in which the major insulation consists of mineral oil or another insulating liquid, enclosed by an insulating envelope

Note 1 to entry: These bushings are often of an open design which require proper processing after installation in order to avoid trapped air and subsequent partial discharges during testing or in service.

3.5

gas-filled bushing

bushing in which the space between the inside surface of the insulating envelope and the solid major insulation is filled with gas (other than ambient air) at atmospheric pressure or higher

Note 1 to entry: This definition includes bushings which are intended to form an integral part of gas-insulated equipment, the gas of the equipment being in communication with that of the bushing.

3.6

gas-insulated bushing

bushing in which the major insulation consists of gas (other than ambient air) at atmospheric pressure or higher

Note 1 to entry: This definition includes bushings which are intended to form an integral part of gas-insulated equipment, the gas of the equipment being in communication with that of the bushing.

Note 2 to entry: A bushing which contains solid insulating materials other than the envelope containing the gas (e.g. support for conducting layers or insulating cylinder), is a combined insulation bushing (see 3.14).

Note 3 to entry: A bushing in which the desired voltage grading is obtained by an arrangement of conducting or semi-conducting layers incorporated in an insulating material (e.g. plastic film) is referred to as a gas insulated ~~condenser~~ capacitance graded bushing.

3.7

gas-impregnated bushing

bushing in which the major insulation consists of a core wound from paper or plastic film (GIF) and subsequently treated and impregnated with gas (other than ambient air) at atmospheric pressure or higher

Note 1 to entry: the core is contained in an insulating envelope. The space between the core and the insulating envelope being filled with the same gas as used for the impregnation.

3.8

oil-impregnated paper bushing

OIP

bushing in which the major insulation consists of a core wound from paper and subsequently treated and impregnated with an insulating liquid, generally ~~transformer~~ mineral oil

Note 1 to entry: The core is contained in an insulating envelope, the space between the core and the insulating envelope being filled with the same insulating liquid as that used for impregnation.

3.9

resin-bonded paper bushing

RBP

bushing in which the major insulation consists of a core wound from resin-coated paper

Note 1 to entry: During the winding process, each paper layer is bonded to the previous layer by its resin coating and the bonding achieved by curing the resin.

Note 2 to entry: A resin-bonded paper bushing can be provided with an insulating envelope, in which case the intervening space can be filled with an insulating liquid or another insulating medium.

3.10

resin-impregnated paper bushing

RIP

bushing in which the major insulation consists of a core wound from untreated paper and subsequently impregnated with a curable resin

Note 1 to entry: A resin-impregnated paper bushing can be provided with an insulating envelope, in which case the intervening space can be filled with an insulating liquid or another insulating medium.

3.11

resin-impregnated synthetics bushing

RIS

bushing in which the major insulation consists of a core wound from synthetics subsequently impregnated with a curable resin

Note 1 to entry: A resin-impregnated synthetics bushing can be provided with an insulating envelope, in which case the intervening space can be filled with an insulating liquid or another insulating medium.

Note 2 to entry: If not otherwise stated by the manufacturer, bushings in accordance with 3.11 shall be considered as RIP bushings according 3.10.

3.12**ceramic, glass or analogous inorganic material bushing**

bushing in which the major insulation consists of a ceramic, glass or analogous inorganic material

3.13**cast or moulded resin-insulated bushing**

bushing in which the major insulation consists of a cast or moulded organic material with or without an inorganic filler

3.14**combined insulation bushing**

bushing in which the major insulation consists of a combination of at least two different insulating materials

3.15**capacitance graded bushing**

bushing, in which a desired voltage grading is obtained by an arrangement of conducting or semiconducting layers incorporated into the insulating material

[SOURCE: IEC 60050-471:2007, 471-02-03]

3.16**indoor bushing**

bushing, both ends of which are intended to be in ambient air at atmospheric pressure, but not exposed to outdoor atmospheric conditions

[SOURCE: IEC 60050-471:2007, 471-02-05]

3.17**outdoor bushing**

bushing, both ends of which are intended to be in ambient air at atmospheric pressure and exposed to outdoor atmospheric conditions

[SOURCE: IEC 60050-471:2007, 471-02-07]

3.18**outdoor-indoor bushing**

bushing, both ends of which are intended to be in ambient air at atmospheric pressure. One end is intended to be exposed to outdoor atmospheric conditions, and the other end not to be exposed to outdoor atmospheric conditions

[SOURCE: IEC 60050-471:2007, 471-02-09]

3.19**indoor-immersed bushing**

bushing, one end of which is intended to be in ambient air but not exposed to outdoor atmospheric conditions and the other end to be immersed in an insulating medium other than ambient air (e.g. ~~oil~~ liquid or gas)

Note 1 to entry: This definition includes bushings operating in air at temperatures above ambient, such as occur with air-insulated ducting.

[SOURCE: IEC 60050-471:2007, 471-02-06]

3.20

outdoor-immersed bushing

bushing, one end of which is intended to be in ambient air and exposed to outdoor atmospheric conditions and the other end to be immersed in an insulating medium other than ambient air (e.g. $\text{-}\oplus$ liquid or gas)

[SOURCE: IEC 60050-471:2007, 471-02-08]

3.21

completely immersed bushing

bushing, both ends of which are intended to be immersed in an insulating medium other than ambient air (e.g. $\text{-}\oplus$ liquid or gas)

[SOURCE: IEC 60050-471:2007, 421-02-04]

3.22

plug-in type bushing

bushing for separable connector

bushing, one end of which is immersed in an insulating medium and the other end designed to receive a separable insulated cable connector, without which the bushing cannot function

[SOURCE: IEC 60050-471:2007, 471-02-02]

3.23

highest voltage for equipment

U_m

highest r.m.s. value of phase-to-phase voltage for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standard

[SOURCE: IEC 60050-614:2016, 614-03-01]

3.24

rated phase-to-earth voltage

maximum r.m.s. value of the voltage which the bushing withstands continuously between the conductor and the earthed flange or other fixing device, under the operating conditions specified in Clause 5

3.25

rated current

I_r

maximum r.m.s. value of current which the bushing can carry continuously under the operating conditions specified in Clause 5, without exceeding the temperature rise limits of Table 2

3.26

rated thermal short-time current

I_{th}

r.m.s. value of a symmetrical current which the bushing withstands thermally for the rated duration (t_{th}) immediately following continuous operation at rated current with maximum temperatures of ambient air and immersion media in accordance with 5.3

3.27

rated dynamic current

I_d

peak value of a current which the bushing withstands mechanically

3.28**temperature rise**

difference between the measured temperature of the hottest spot of the metal parts of the bushing which are in contact with insulating material and the ambient air temperature (see 4.8)

3.29**rated frequency** f_r

frequency at which the bushing is designed to operate

[SOURCE: IEC 60050-421:1990, 421-04-03, modified ("transformer or reactor" replaced by "bushing")]

3.30**rated filling pressure of gas for insulation**

the pressure in Pascal (Pa) for insulation referred to the standard atmospheric conditions of +20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, to which the bushing is filled before being put into service, or automatically replenished

3.31**maximum internal operating gas pressure**

pressure, when the bushing is in operation, carrying rated current at the highest temperatures in accordance with 5.3

3.32**maximum external operating gas pressure**

maximum pressure of the gaseous insulating medium in which the bushing is partially or completely immersed when in operation

3.33**design pressure** (of the enclosure)

pressure used to determine the thickness of the enclosure

~~(see IEC 62271-203:2003, Definition 3.113, modified)~~

3.34**leak rate** (of gas-filled, gas-insulated, gas-impregnated and gas-immersed bushings)

quantity of dry gas at a given temperature that flows through a leak per unit of time and for a known difference of pressure across the leak

Note 1 to entry: The basic SI unit for leak rate is "Pascal cubic metre per second ($\text{Pa} \times \text{m}^3/\text{s}$)". The derived units " $\text{Pa} \times \text{cm}^3/\text{s}$ " and " $\text{bar} \times \text{cm}^3/\text{s}$ " are used in this standard, as they better conform to the orders of magnitude used in common industrial practice. It should be remembered that: $1 \text{ Pa} \times \text{m}^3/\text{s} = 10^6 \text{ Pa} \times \text{cm}^3/\text{s} = 10 \text{ bar} \times \text{cm}^3/\text{s}$.

[SOURCE: IEC 60068-2-17:1994, 1.1]

3.35**hollow insulator**

insulator which is open from end to end, with or without sheds

Note 1 to entry: An insulating envelope may consist of one insulator unit or two or more permanently assembled insulator units.

[SOURCE: IEC 60050-471:2007, 471-01-8, modified (removal of "including end fittings", modified Note 1 to entry)]

3.36**creepage distance**

shortest distance along the surface of an insulator between two conductive parts

Note 1 to entry: The surface of cement or of any other non-insulating jointing material is not considered as forming part of the creepage distance.

Note 2 to entry: If high-resistance coating is applied to parts of the insulating part of an insulator, such parts are considered to be effective insulating surfaces and the distance over them is included in the creepage distance.

[SOURCE: IEC 60050-471:2007, 471-01-04]

3.37

arcing distance

shortest distance in air external to the insulator between metallic parts which normally have the operating voltage between them

Note 1 to entry: The terms “dry arcing distance” or “taut string distance” are also used.

Note 2 to entry: The arcing distance may be shorter than the values for external clearances in air stated in IEC 60076-3.

[SOURCE: IEC 60050-471:2007, 471-01-01, modified (Notes to entry added)]

3.38

test tap

measuring tap

$\tan \delta$ tap

connection, accessible from outside the bushing, insulated from the flange or other fixing device, made to one of the outer conducting layers of a capacitance graded bushing in order to allow measurements of dissipation factor, capacitance and partial discharge whilst the flange of the bushing is earthed

Note 1 to entry: This connection should be earthed directly when it is not used.

Note 2 to entry: When the test tap is used for condition monitoring, in service, care should be taken to avoid an open circuit.

3.39

voltage tap

potential tap

capacitance tap

connection, accessible from outside the bushing, insulated from the flange or other fixing device, made to one of the outer conducting layers of a capacitance graded bushing in order to provide a voltage source whilst the bushing is in operation

Note 1 to entry: This connection should be earthed directly when it is not used.

Note 2 to entry: This tap can also be used for the measurement of dissipation factor, capacitance and partial discharge.

3.40

rated voltage of the voltage tap

maximum voltage at which the tap is designed to supply the associated equipment, with the rated load connected thereto, when the rated phase-to-earth voltage is applied to the bushing at the rated frequency

3.41

composite bushing

bushing with an insulating envelope consisting of a resin impregnated fibre tube with or without a ~~rubber~~ polymeric compound covering

Note 1 to entry: For bushings defined in 3.9 to 3.13, the ~~rubber~~ polymeric compound may be applied directly on to the bushing major insulation.

3.42

capacitance (of bushing)

3.42.1**main capacitance C_1**

capacitance between the high-voltage conductor and the test tap or the voltage tap of a capacitance-graded bushing

3.42.2**tap capacitance C_2**

capacitance between the test tap or the voltage tap and the mounting flange of a capacitance-graded bushing

3.42.3**capacitance C**

capacitance between the high-voltage conductor and the mounting flange of a bushing without a voltage tap or test tap

4 Ratings**4.1 ~~Standard values of~~ Rated highest voltage for equipment (U_m)**

The values of U_m of a bushing shall be chosen from the ~~standard~~ values of the highest voltage for equipment, defined in IEC 60038 as given below, in kilovolts:

3,6 – 7,2 – 12 – 17,5 – 24 – 36 – 52 – 72,5 – 100 – 123 – 145 – 170 – 245 – 300 – 362 – 420 – 550 – 800 – 1 100 – 1 200 kV.

NOTE ~~The values 525 kV and 765 kV are also used.~~ For standard three phase systems the rated phase-to-earth voltage is $U_m / \sqrt{3}$.

4.2 ~~Standard values of~~ Rated current (I_r)

The values of I_r of a bushing shall be chosen from the ~~standard~~ values as given below, in amperes:

100 – 250 – 315 – 400 – 500 – 630 – 800 – 1 000 – 1 250 – 1 600 – 2 000 – 2 500 – 3 150 – 4 000 – 5 000 – 6 300 – 8 000 – 10 000 – 12 500 – 16 000 – 20 000 – 25 000 – 31 500 – 40 000 A.

The above series of currents are in accordance with the values indicated in IEC 60059.

In the case of transformer bushings with the conductor drawn into the central tube (**draw lead**), the supplier shall indicate the value of the cross-section, **the maximum diameter**, the material of the conductor **and the material and thickness of insulation**, which correspond to I_r in accordance with 4.8.

Bushings for transformers selected with I_r not less than 120 % of rated current of the transformer **and with maximum temperature and maximum daily mean temperature in accordance with Table 4** are considered to be able to withstand the overload conditions according to IEC 60076-7 without further clarification or tests.

4.3 ~~Standard values of~~ Rated thermal short-time current (I_{th})

Unless otherwise specified, the ~~standard~~ value of I_{th} shall be 25 times I_r , t_{th} being 1 s. For bushings with I_r equal to or greater than 4 000 A, I_{th} shall always be 100 kA.

For transformer bushings, t_{th} shall be 2 s, unless otherwise stated, with reference to IEC 60076-5.

For durations of t_{th} greater than 1 s, the relationship between current and time is assumed to be in accordance with

$$I_{th}^2 \times t_{th} = \text{constant}$$

NOTE For transformer bushings, where the conductor is drawn into the central tube, the conductor cross-section corresponding to the operating current may be less than that indicated in 4.2. In such a case, the operating current and cross-section should conform to the requirements of 8.8.

4.4 ~~Standard values of~~ Rated dynamic current (I_d)

The standard value of I_d shall have an amplitude of the first peak of 2,5 times the value of I_{th} in accordance with 4.3.

NOTE In some cases, values greater than 2,5 times the value of I_{th} indicated in 4.3 may be necessary with respect to the transformer characteristics. The transformer manufacturer should stipulate such requirements in the bushing ordering information (see 6.1.4).

4.5 Minimum withstand values of cantilever load

The bushings shall withstand the cantilever load given in Table 1, Level I or II. Level I is normal load and shall be generally applied, unless a purchaser specifies a heavy load of Level II.

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Table 1 – Minimum values of cantilever withstand load (see 4.5 and 8.10)

Highest voltage for equipment U_m kV	Rated current A							
	≤ 800	1 000	2 000	≥3 150	1 600	2 500		
	Cantilever operating load N							
	Bushing installed ≤ 30° from the vertical							
	I	II	I	II	I	II	I	II
≤ 36	500	500	625	625	1 000	1 000	1 575	1 575
52	500	800	625	800	1 000	1 250	1 575	1 575
72,5 to 100	500	1 000	625	1 000	1 000	1 575	2 000	2 000
123 to 145	625	1 575	800	1 575	1 250	2 000	2 000	2 000
170 to 245	625	2 000	800	2 000	1 250	2 500	2 000	2 500
≥ 300	1 250	2 000	1 250	2 000	1 575	2 500	2 500	2 500
	Cantilever test load N							
	I	II	I	II	I	II	I	II
≤ 36	1 000	1 000	1 250	1 250	2 000	2 000	3 150	3 150
52	1 000	1 600	1 250	1 600	2 000	2 500	3 150	3 150
72,5 to 100	1 000	2 000	1 250	2 000	2 000	3 150	4 000	4 000
123 to 145	1 250	3 150	1 600	3 150	2 500	4 000	4 000	4 000
170 to 245	1 250	4 000	1 600	4 000	2 500	5 000	4 000	5 000
≥ 300	2 500	4 000	2 500	4 000	3 150	5 000	5 000	5 000

NOTE 1 Cantilever operating loads include terminal load and wind pressure (70 Pa), reference IEC TS 61463.

NOTE 2 For bushings operating at an angle >30° to the vertical, the effect of bushing self-load should be considered when selecting test load and procedure. The values given above correspond to vertical bushings that are to be tested in a vertical position. If a tilted or horizontal bushing is to be tested vertically, then an equivalent force should be added to achieve the bending moment at the flange, caused by the weight of the bushing in its operating position. If a vertical bushing is to be tested horizontally, then the test load can be reduced in the same manner.

NOTE 3 Level I = normal load, Level II = heavy load.

NOTE 4 For bushings where upper and lower insulating envelopes are assembled by clamping force on the central fixing conductor, it is recommended to choose the cantilever test load, taking into account the thermal expansion of the conductor due to the rated current flow.

4.6 Angle of mounting

All bushings shall be designed for mounting at any angle of inclination not exceeding 30° from the vertical. Any other angle of mounting shall be subject to agreement between purchaser and supplier.

NOTE A bushing operating at an angle up to and including 30° from the vertical is considered a vertical bushing. A bushing operating at an angle equal to or greater than 70° from the vertical is considered a horizontal bushing. A bushing operating at any other angle is considered a tilted bushing (see 6.1.5).

4.7 Minimum nominal creepage distance

Unless otherwise agreed between purchaser and supplier, or demonstrated by a test, the creepage distance for ~~ceramic~~ insulating envelopes shall be in accordance with IEC TS 60815-2 or IEC TS 60815-3.

If artificial pollution tests are required, they shall be performed in accordance with IEC 60507.

NOTE 1 The actual value of creepage distance can ~~differ from the nominal one by the manufacturing tolerances~~ be substantially longer, but not shorter, than what is stated in IEC 62155.

NOTE 2 ~~Requirements for composite insulators are under consideration by TC 36: Insulators.~~ IEC TS 60815-1 defines the Unified Specific Creepage Distance as the total creepage distance divided by the highest operating line-to-ground voltage according to 3.24. Previously the line-to-line voltage was used for calculating the specific creepage distance. This means there is a ratio of $\sqrt{3}$ between the two.

4.8 Temperature limits and temperature rise

The temperature limits of metal parts in contact with insulating material under normal operating conditions are as follows:

- 105 °C for oil-impregnated paper: Class A;
- 120 °C for resin-bonded and resin-impregnated paper, ~~as well as resin-impregnated synthetics~~: Class E;
- 130 °C for gas-insulated: Class B.

The temperature rise above maximum daily mean ambient air temperature in accordance with 5.3 (30 °C) of the hottest spot shall not exceed the values given in Table 2. In the case of other insulating materials, the temperature limits shall be stated by the supplier. Reference shall be made to IEC 60216-2 and IEC 60505.

For bushing terminals and connections, the temperature rises are also given in Table 2.

Bushings used as an integral part of apparatus, such as switchgear or transformers, shall meet the thermal requirements for the relevant apparatus. For transformer bushings, reference shall be made to 4.2.

Temperature of ambient air and immersion media are defined in Table 4.

For bushings operating in liquid-immersed power transformers using high-temperature insulation materials according to IEC 60076-14, the temperature limits for bushings shall be agreed between parties.

NOTE For gaskets in contact with metallic parts, special attention should be paid to the ability of the material to withstand the temperature rise.

4.9 ~~Standard~~ Insulation levels

The ~~standard~~ values of insulation level shall be chosen from Table 3.

The specified ~~standard~~ values of insulation level are in accordance with IEC 60038 and IEC 60071-1.

Table 2 – Maximum values of temperature and temperature rise above ambient air (see 4.8)

Description of component		Maximum temperature rise K	Maximum temperature °C	Comments ^a
Spring contacts	Copper and copper alloys, uncoated:			d
	– in air	45	75	
	– in SF ₆	60 65	90 95	b
	– in oil	50	80	
	Tinned in air, SF ₆ or oil ^f	60	90	
Screwed contacts	Silver/nickel-plated:			
	– in air or SF ₆	75	105	b
	– in oil	60 65	90 95	
	Copper, aluminium and their alloys, uncoated:			
	– in air	60	90	
– in SF ₆	75	105	b	
– in oil	70	100		
Terminals to be connected to exterior conductors by screws or bolts	Tinned: ^f			
	– in air or SF ₆	75	105	b
	– in oil	70	100	
	Silver/nickel-plated:			
	– in air or SF ₆	85	115	b
– in oil	70	100		
Current carrying and non-current carrying metallic parts in contact with	Copper, aluminium and their alloys:			
	– uncoated	60	90	c
	– tinned ^f	75	105	
	– silver or nickel-plated	75	105	
	Insulation class:			
– A (OIP)	75	105		
– E (RBP, RIP, RIS)	90	120		
– (GIF)		^e		
– SF ₆	100	130		
– Oil	85	^e 115	b, g	
	110	140	h	
<p>^a The temperature rise values are based on IEC 60943 with a maximum daily mean temperature of 30 °C. For further information reference should be made to IEC 60943, Table 6.</p> <p>^b Oil in the table above refers to mineral oil. For synthetic other insulating liquids, e. g. silicone, natural or synthetic ester, higher values may be agreed between purchaser and supplier.</p> <p>^c If heavy oxidation is to be expected, the temperature rise shall be limited to 50 K.</p> <p>^d A spring contact is a connection maintained by spring pressure for example a plug-in connection.</p> <p>^e The temperature limits shall be stated by the supplier.</p> <p>^f Tinned contacts must not exceed the given max temperature of 105 °C, if so very rapid or immediate destruction will occur.</p> <p>^g Applicable to liquid-insulated bushings according to 3.4.</p> <p>^h Applicable to transformer bushings with a conductor (solid or flexible) drawn into the central tube.</p> <p>NOTE A and E refers to thermal class according to IEC 60085.</p>				

Table 3 – Insulation levels for highest voltage for equipment (U_m)
(see 4.9, 8.2, 8.4, 8.5, 9.3 and 9.4)

Highest voltage for equipment U_m	Rated lightning impulse withstand voltage (BIL)	Rated switching impulse withstand voltage (SIL)	Power-frequency withstand voltage ^f			
			Transformer bushings ^a (dry)	GIS bushings ^b (dry)	Other bushings ^c (dry)	All bushings ^d (wet)
kV (r.m.s. value)	kV (peak value)	kV (peak value)	kV (r.m.s. value)			
$\leq 1,1$	20		10		10	10
3,6	40		11		10	10
7,2	60		22		20	20
12	75		30		28	28
17,5	95		42		38	38
24	125		55		50	50
36	170		77		70	70
52	250		105		95	95
72,5	325		155		140	140
100	380		165		150	150
	450		205		185	185
123	450		205		185	185
	550		255		230	230
145	450	650	205		185	185
	550	750	255	435	230	230
	650	850	305	435	275	275
170	550	850	255		230	230
	650	850	305		275	275
	750	850	355	325	325	325
245	950	750	435	435	395	395
	1 050	850	505	460	460	460
	1 050	850	505	460	460	-
300	1 050	850	505	460	460	-
362	1 050	850	505	460	460	-
	1 175	950	560	520	510	-
420	1 300	1 050	625	595	570	-
	1 425	1 050	695	650	630	-
	1 550	1 175	750	-	680	-
550 ^e	1 425	1 050	695	650	630	-
		1 175				
	1 550	1 175	750	710	680	-
	1 675	1 175	750	-	680	-
	1 800	1 300	870	-	790	-

Highest voltage for equipment U_m	Rated lightning impulse withstand voltage (BIL)	Rated switching impulse withstand voltage (SIL)	Power-frequency withstand voltage ^f			
kV (r.m.s. value)	kV (peak value)	kV (peak value)	kV (r.m.s. value)			
			Transformer bushings ^a (dry)	GIS bushings ^b (dry)	Other bushings ^c (dry)	All bushings ^d (wet)
800 ^e	1 800	1 300	870	830	790	-
		1 425				-
		1 550				-
	1 950	1 550	915	960	830	-
	2 100	1 425	970	960	880	-
	2 400	1 550	1 075	960	975	-
1 100	2 250	1 800	1 200 ^g	1 100	-	-
	2 400	1 950				
1 200	2 250	1 800	1 320 ^g	1 200	-	-
	2 550	1 950				

^a Values in accordance with IEC 60071-1 and IEC60076-3 enhanced by 10 % in accordance with 9.4.

^b Values in accordance with IEC 62271-1.

^c Values in accordance with IEC 60071-1 and IEC 62271-1.

^d Values in accordance with IEC 60071-1.

^e The values of highest voltage for equipment are in accordance with IEC 60038, Amendment 2 (1997).
~~The values 525 kV and 765 kV are also used.~~

^f The power-frequency withstand voltages quoted are the minimum required based on the BIL of the system or equipment to which the bushing is applied. For transformer applications when a bushing is selected with a higher BIL-class, the bushing may be tested in accordance with column 6, provided the requirement of 10 % higher power-frequency withstand test voltage than its transformer is met.

^g ~~For bushings U_m equal to or greater than 245 kV, a dry switching impulse withstand test is required for transformer bushings only.~~
The test duration shall be 300 s in accordance with IEC 60076-3.

4.10 Test tap on transformer bushings

A test tap according to 3.38 shall be provided on all capacitance graded transformer bushings of U_m equal to or greater than 72,5 kV according to 3.15. In view of its use for partial discharge measurements on transformers, the values for the test tap shall not exceed:

- a capacitance to earth of 10 000 pF;
- a dielectric dissipation factor ($\tan \delta$) of 0,05 measured at power-frequency.

Other values of test tap capacitance to earth may be agreed between purchaser and supplier.

The bushing shall not incorporate substantial capacitances to earth which may divert the partial discharge current and so give rise to incorrect or misleading partial discharge measurements on the transformer.

5 Operating conditions

5.1 Temporary overvoltages

The maximum phase-to-earth voltage of the system may exceed U_m divided by $\sqrt{3}$. For periods not exceeding 8 h in any 24 h, and of which the total period does not exceed 125 h per year, bushings shall be able to operate phase-to-earth at a voltage of

- U_m for bushings of which U_m is equal to or less than 170 kV;
- $0,8 U_m$ for bushings of which U_m is greater than 170 kV.

For systems in which overvoltages in excess of this may occur, it is advisable to choose a bushing with a higher U_m .

5.2 Altitude

Although the insulation level refers to sea level, bushings corresponding to this standard are declared suitable for operation at any altitude not exceeding 1 000 m. In order to ensure that the external withstand voltages of the bushing are sufficient at altitudes exceeding 1 000 m, the arcing distance normally required shall be increased by a suitable amount. It is not necessary to adjust the radial thickness of insulation or the clearance of the immersed end. The puncture strength and the flashover voltage in the immersion medium of a bushing are not affected by altitude.

For installations at an altitude higher than 1 000 m, the arcing distance under the standard reference atmospheric conditions shall be determined in order to withstand the voltages obtained by multiplying the withstand voltages required at the service location by a factor k_a in accordance with Figure 1.

$$k_a = e^{m \frac{(H-1000)}{8150}}$$

where

H is the altitude (in meters), not exceeding 4000 meters.

$m = 1$ for lightning impulse withstand voltage

$m = 1$ for power-frequency withstand voltage where $U_m \leq 245$ kV. For higher U_m altitude correction is not applicable because bushings are tested with switching impulse already corrected for altitude.

m according to Figure 1 for switching impulse withstand voltage.

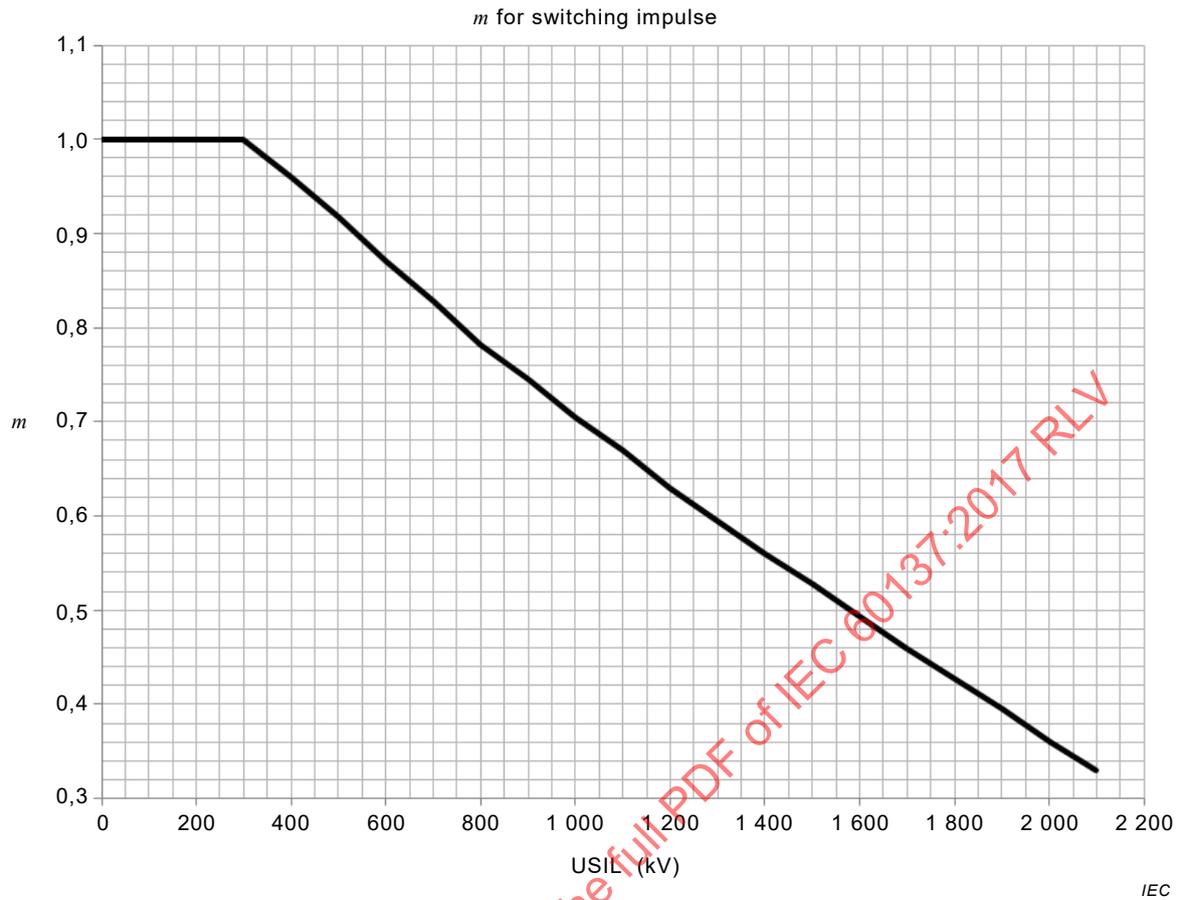


Figure 1 – Factor *m* on the co-ordination switching impulse withstand voltage

If the increased arcing distance is based on a verified arcing distance it can be considered valid without further testing.

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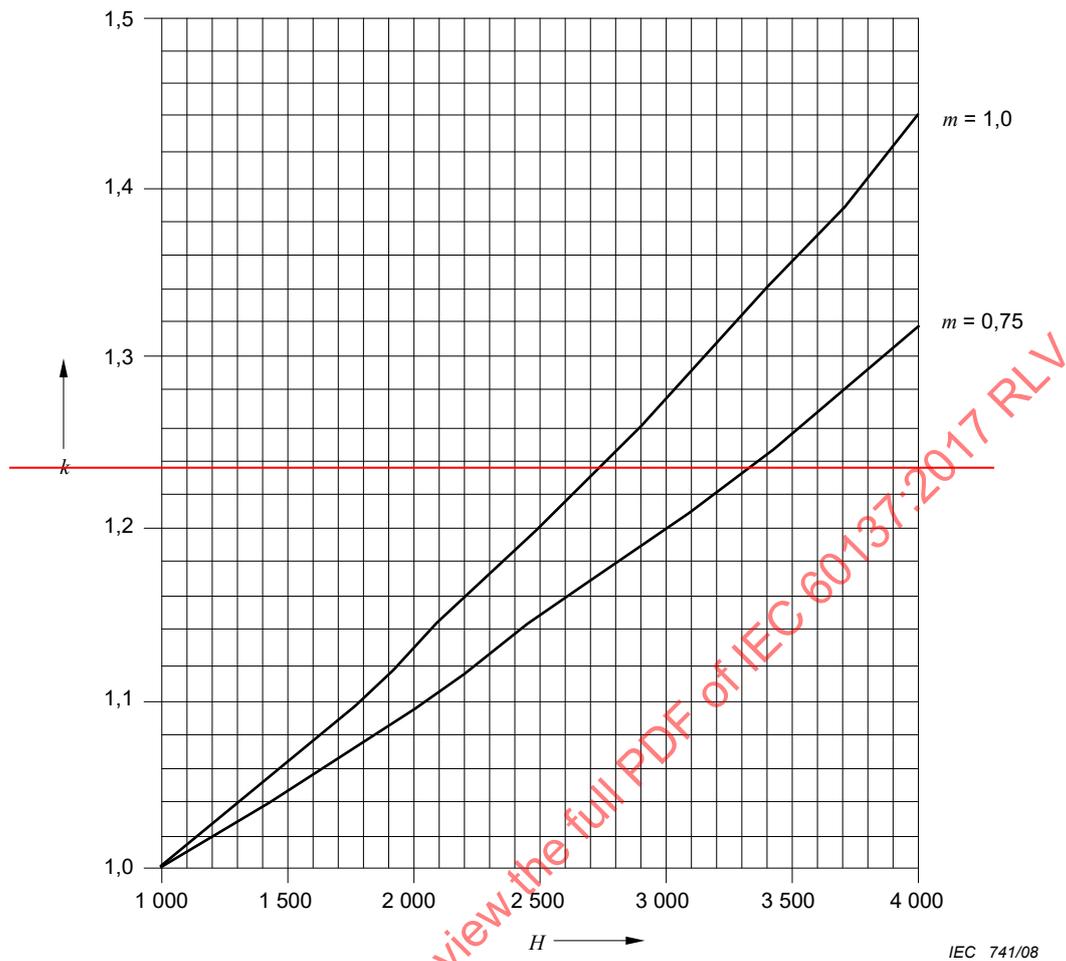


Figure 1 — Altitude correction factor

These factors are calculated with the following equation:

$$k = e^{m(H-1000)/8150}$$

where

H is the altitude, in metres;

$m = 1$ for power frequency and lightning impulse voltage;

$m = 0,75$ for switching impulse voltage.

Owing to the limitations of puncture strength and flashover voltage in the immersion medium, it may not always be possible to check the adequacy of the increased arcing distance by actual tests at any altitude lower than that of operation. In such a case the supplier shall demonstrate that arcing distance of the bushing is adequate.

5.3 Temperature of ambient air and immersion media

Bushings shall be designed for operation at temperatures not exceeding the limits given in Table 4. Considerations should be given to the operating conditions of outside the limits in Table 4 and its effect of the current rating; some example are completely immersed bushings and, bushings operating in high temperature ambient air conditions, or air-insulated ducting.

Moisture condensation on the surface of the indoor part of the bushing is to be prevented, if necessary by ventilation or heating.

Table 4 – Temperature of ambient air and immersion media ~~(see 5.3)~~

Subject	Temperature °C
Ambient air: – maximum – maximum daily mean (open air) – maximum daily mean (air-insulated ducting) – maximum annual mean – minimum <ul style="list-style-type: none"> • Indoors ^a • Outdoors ^a 	40 30 70 20 -5 -15 -25 -10 -25 -40
Mineral oil in transformers: – maximum <ul style="list-style-type: none"> • for normal loading ^b • for short- and long-term emergency duty loading ^b – maximum daily mean	100 115 90
Other media: (gaseous and non-gaseous)	c
^a Unless otherwise specified the minimum ambient air temperature is –5 °C for indoors and –25 °C for outdoors bushings.	
^b The values in transformers are in accordance with IEC 60076-1 and IEC 60076-2 and related to mineral oil. For other insulating liquids, e. g. silicone, natural or synthetic ester, higher values may be agreed between purchaser and supplier. The value for short- and long-term emergency duty loading are in accordance with IEC 60076-7.	
^c In the absence of other information, reference should be made in principle to the corresponding IEC apparatus standard for which the bushing is intended, whereby particular attention should be paid to bushings one end of which is to be immersed in gas.	
NOTE 1 The daily mean temperature of the immersion medium should be calculated by averaging 24 consecutive hourly readings.	
NOTE 2 By agreement between purchaser and supplier, other temperature ranges may be adopted.	

5.4 Seismic conditions

When seismic qualification is required, reference should be made to IEC TS 61463.

5.5 Very fast transients (VFT)

In the case of unusual transient stresses to capacitance graded bushings connected to gas-insulated switchgears, special investigations may be agreed upon between purchaser and supplier to cover the behaviour of the bushings.

Tests are only meaningful as long as all parties understand the limitations of how closely the test arrangements simulates the service conditions.

It is not the steep front of the very fast voltage step generated at a VFT test that is dangerous to the bushing. It is the resonant ringing voltage occurring over the bushing that may feed

internal resonance circuits inside the bushing to high overvoltages. A VFT test will therefore only test the bushing for the ringing frequencies determined by the setup.

5.6 Transformer insulating liquid

Transformer bushings according to this standard are normally intended for use in transformers filled with mineral oil complying with the requirements of IEC 60296 and 60422.

Where other insulating liquids are used details shall be given by the transformer manufacturer.

6 Ordering information and markings

6.1 Enumeration of characteristics

6.1.1 General

When ordering, the purchaser shall furnish as much of the following information as necessary, as well as any additional information needed to determine clearly the required characteristics.

The minimum distance to earthed parts of the end of the bushing which is intended to be immersed in insulation liquid shall be provided by the supplier. In case distances are below the values for the standard arrangements indicated in suppliers documentation, the purchaser may also provide the necessary geometry to evaluate the particular set-up.

6.1.2 Application

Application, including type of apparatus for which the bushing is intended, and the corresponding IEC apparatus standard shall be given.

Attention shall be drawn to any features (including tests) of the completed apparatus which may affect the design of the bushing (see 7.3).

6.1.3 Classification of bushings

Classification according to 3.2 to 3.22.

6.1.4 Ratings

The ratings shall be as follows:

- highest voltage for equipment (U_m) (see 3.23);
- rated phase-to-earth voltage (see 3.24);
- standard insulation level (see 4.9) and the induced and/or applied test voltage level of the transformer (if applicable) (see 9.4);
- rated current (I_r) (see 3.25);
- rated thermal short-time current (I_{th}) and rated duration (t_{th}), if deviating from the values given in 4.3;
- rated dynamic current (I_d), if deviating from the value given in 4.4;
- rated frequency (see 3.29);
- minimum withstand values of cantilever load in accordance with 4.5;
- maximum value of test tap capacitance, if lower value is required, in accordance with 4.10.

6.1.5 Operating conditions

The operating conditions shall be as follows:

- temporary overvoltages, if applicable (see 5.1);
- altitude, if exceeding 1 000 m (see 5.2) (relevant only to indoor and outdoor bushings according to 3.16 to 3.20);
- ambient air and immersion media temperature if deviating from normal values (see 5.3 and Table 4) (relevant to bushings according to 3.16 to 3.22);
- type of immersion medium (relevant only to partly or completely immersed bushings according to 3.19 to 3.22);
- minimum level of immersion medium (relevant only to partly or completely immersed bushings according to 3.19 to 3.22);
- maximum operating pressure of immersion media (relevant only to partly or completely immersed bushings according to 3.19 to 3.22);
- type of insulating gas (relevant only to gas-filled, gas-insulated and gas-impregnated bushings according to 3.5 to 3.7 when the gas of the equipment is in communication with that of the bushing);
- rated filling pressure of gas for insulation (see 3.30) (relevant only to gas-filled, gas-insulated and gas-impregnated bushings according to 3.5 to 3.7 when the gas of the equipment is in communication with that of the bushing);
- maximum internal operating gas pressure (see 3.31) (relevant only to gas-filled, gas-insulated and gas-impregnated bushings according to 3.5 to 3.7 when the gas of the equipment is in communication with that of the bushing);
- maximum external operating gas pressure (see 3.32) (relevant only to partly or completely gas-immersed bushings according to 3.19 to 3.21);
- angle of mounting if exceeding the standard values (see 4.6);
- minimum nominal specific creepage distance (see 4.7) (relevant only to the outdoor part of bushings according to 3.17, 3.18 and 3.20);
- unusual climatic conditions (extreme high and low temperatures, tropical humidity, severe contamination, high wind);
- seismic conditions, if qualification is required (see 5.4).

6.1.6 Design

The ~~design shall cover~~ purchaser should provide requirements about the following, where applicable:

- for bushings supplied without a conductor: diameter, type (cable, solid or hollow stem), material and position of the conductor with which the bushing will be fitted in operation;
- particular dimensional requirements, if any;
- test tap or voltage tap if required (see 3.38 and 3.39);
- the length of earthed sleeve located next to the flange or other fixing device, if any;
- general information concerning the position of the bushing in relation to the earthed parts of the apparatus for which the bushing is foreseen (see 7.1);
- whether protective gaps are to be fitted or not;
- special requirements for corrosion protection of metallic parts;
- bushings for transformers shall be designed to withstand a typical transformer test sequence (works, acceptance and possible repeat tests);
- ~~oil~~ liquid level in central tube of a transformer bushing with the conductor drawn into the central tube, if lower than one-third of the height of the external part (see 8.8);
- provision of an ~~oil~~ liquid sample valve.

Bushings using liquid or gas for insulation should refer to the relevant ~~horizontal~~ standards:

- IEC 60376 for ~~new SF₆ or IEC 60480 for used~~ technical grade SF₆.
- IEC 60480 for re-use of SF₆
- IEC 60296 for mineral insulating oil, or
- IEC 60836 for silicone insulating liquids ~~or~~
- IEC 60867 for synthetic ~~fluid~~ aromatic hydrocarbons
- IEC 61099 for synthetic organic esters

6.2 Markings

~~Each bushing of U_m equal to or greater than 123 kV shall carry the following markings. For bushings of U_m equal to or less than 100 kV, markings indicated ■ are sufficient. Markings for bushings according to Clause 10 are specified in 10.3.~~

This sub-clause applies to capacitance-graded bushings of all voltages, and to other bushings having U_m 72,5 kV and above. For other bushings having U_m 100 kV and below, markings indicated ■ are sufficient:

- supplier's name or trade mark;
- year of manufacture and serial number;
- supplier's type designation;
- country and location of manufacturer shall be directly identifiable;
- highest voltage for equipment (U_m) (see 3.23) or rated phase-to-earth voltage (see 3.24) and rated frequency (see 3.29);
- rated current (I_r) (see 3.25). If the bushing is supplied without conductor, the conductor section shall be specified by the supplier (see 4.2);
- mass if above 100 kg;
- lightning impulse (BIL) and switching impulse (SIL) and power-frequency withstand test voltages (AC) (see 4.9);
- bushing capacitance (see 3.42) and dielectric dissipation factor as measured by factory routine tests;
- type of insulating gas and rated filling pressure (see 3.30), if applicable;
- ~~• mass if above 100 kg;~~
- minimum gas operating pressure at 20 °C, if applicable;
- maximum angle of mounting if exceeding 30° from vertical (see 4.6).

For examples of marking plates, see Figures 2 to 4.

NOTE 1 Capacitance and dielectric dissipation factor measurements made on site may differ from factory values given on the nameplate. ~~It is recommended to make reference measurements at installation.~~

NOTE 2 Non capacitance-graded bushings of highest voltages for equipment equal to or less than 52 kV are addressed in Clause 10.

MANUFACTURER		Country and location
Year	Type designation:.....	No.
U_mkV	I_r A	f_r Hz
BIL kV	SIL kV	AC kV
Mass kg	Max. angle to vertical degree	
Capacitance pF	Dissipation factor%	

In addition, for gas-filled, gas-insulated, gas-immersed and gas-impregnated bushings:

Type of gas	
Rated gas filling pressure at 20 °C	bar gauge kPa absolute
Minimum gas pressure at 20 °C	bar gauge kPa absolute

IEC

Figure 2 – Marking plate for bushings for **rated highest voltage for equipment (U_m) greater than 100 kV**

MANUFACTURER		Country and location
Year	Type designation:.....	No.
U_m kV	I_r A	f_r Hz

IEC

Figure 3 – Marking plate for bushings for **rated highest voltage for equipment (U_m) equal to or less than 100 kV, except for bushings for which Figure 4 is applicable**

MANUFACTURER		Country and location
Year	U_m kV	I_rA

IEC

Figure 4 – Marking plate for bushings for **rated highest voltage for equipment (U_m) equal to or less than 52 kV made of ceramic, glass or inorganic materials, resin or combined insulation (see 10.3)**

7 Test requirements

7.1 General requirements

All tests shall be carried out in accordance with the relevant IEC publication referred to in the particular clause. Tests on insulating envelopes of ceramic material shall be carried out in accordance with IEC 62155. Tests on insulators of composite material shall be carried out in accordance with IEC 61462 and IEC 62217. All high-voltage tests, in accordance with 8.2 to 8.5, 9.3 and 9.4 shall be carried out in accordance with IEC 60060-1.

The supplier shall provide a detailed type test certificate at the request of the purchaser. ~~The tests shall have been carried out on bushings of a design that does not differ from that offered to the purchaser in any way that may improve the features to be checked by a type test.~~ Type tests shall be performed on the supplied bushing design unless evidence of previous type tests is available. In case of different designs the supplier shall provide a statement of comparison between the tested and supplied designs. All electrical, mechanical and thermal stresses of the supplied design shall be covered by the evidence of test. Repetition of a type test is only mandatory when specified in a particular contract.

At the request of the purchaser, the supplier shall furnish any information concerning the minimum clearances to earthed parts in the operating arrangement.

The values of the applicable withstand test voltages for newly manufactured bushings are indicated in Table 3. For bushings, which have been in operation, the routine withstand test voltages shall be reduced to 85 % of the values indicated in the table.

The bushings shall tolerate and not be damaged by ~~the tolerated~~ flashover in air when tested in accordance with 8.2, 8.4, 8.5, 9.3 and 9.4, but slight marks remaining on the surface of the ~~porcelain~~ insulating parts are acceptable.

A definition of the terms “flashover” and “puncture” is given in IEC 60050-212: ~~1990~~ 2010, definition 212-11-47 and 212-11-49, respectively.

7.2 Test classification

7.2.1 General

Tables 5, 6, 10 and 11 show the applicability of the tests to the various types of bushings.

For bushings of highest voltages for equipment equal to or less than 52 kV, made of ceramic, glass or inorganic materials, resin or composite insulation, see Clause 10. For other bushings, tests to check dielectric, thermal and mechanical properties of bushings comprise the following tests.

7.2.2 Type tests

- dry or wet power-frequency voltage withstand test (see 8.2);
- long duration power-frequency voltage withstand test ~~(ACLD)~~ (see 8.3);
- dry lightning impulse voltage withstand test (see 8.4);
- dry or wet switching impulse voltage withstand test (see 8.5);
- thermal stability test (see 8.6);
- electromagnetic compatibility test (see 8.7);
- temperature rise test (see 8.8);
- verification of thermal short-time current withstand (see 8.9);
- cantilever load withstand test (see 8.10);

- tightness test on liquid-filled, compound-filled and liquid-insulated bushings (see 8.11);
- internal pressure test on gas-filled, gas-insulated and gas-impregnated bushings (see 8.12);
- external pressure test on partly or completely gas-immersed bushings (see 8.13);
- verification of dimensions (see 8.14).

Table 5 – Applicability of type tests (see 7.2.2, excluding bushings according to Clause 10)

Subclause	Short title	Applicable to bushing type	Bushing defined in subclause
8.2	AC dry	All indoor, indoor immersed and completely immersed <300 kV , $U_m \leq 245 \text{ kV}$	3.16, 3.19, 3.21
8.2	AC wet	All outdoor <300 kV , $U_m \leq 245 \text{ kV}$	3.17, 3.18, 3.20
8.3	ACLD	All transformer bushings, $U_m \geq 170 \text{ kV}$	3.19, 3.20, 3.21
8.4	Lightning	All	
8.5	Switching	All, $U_m \geq 300 \text{ kV}$	
	– dry	– indoor, indoor immersed and completely immersed and all transformer bushings, $U_m \geq 245 \text{ kV}$	3.16, 3.19, 3.21
	– wet	– outdoor	3.17, 3.18, 3.20
8.6	Thermal stability	All partly or completely immersed, immersion medium $\geq 60 \text{ }^\circ\text{C}$ and $U_m > 300 \text{ kV}$ for OIP and RIP $U_m \geq 145 \text{ kV}$ for others	3.19, 3.20, 3.21
8.8	Temperature rise	All, except liquid insulated as in 3.4	
8.9	Thermal short-time	All, if calculated temperature is too high	
8.10	Cantilever	All	
8.11	Tightness	All liquid-filled and insulated, except with highly viscous filling	3.2, 3.4
8.12	Pressure	All containing gas of $\geq 1 \text{ l}$ and $> 0,5 \text{ bar}$ gauge	3.5, 3.6, 3.7
8.13	External pressure	All partly or completely immersed in gas, gas pressure $> 0,5 \text{ bar}$ gauge	3.19, 3.20, 3.21
8.14	Dimensions	All	

7.2.3 Routine tests

- measurement of dielectric dissipation factor ($\tan \delta$) and capacitance at ambient temperature (see 9.2);
- dry lightning impulse voltage withstand test (see 9.3);
- dry power-frequency voltage withstand test (see 9.4);
- measurement of partial discharge quantity (see 9.5);
- tests of tap insulation (see 9.6);
- internal pressure test of gas-filled, gas-insulated and gas-impregnated bushings (see 9.7);
- tightness test on liquid-filled, compound-filled and liquid-insulated bushings (see 9.8);
- tightness test on gas-filled, gas-insulated and gas-impregnated bushings (see 9.9);
- tightness test at the flange or other fixing device (see 9.10);
- visual inspection and dimensional check (see 9.11).

Table 6 – Applicability of routine tests (see 7.2.3, excluding bushings according to Clause 10)

Subclause	Short title	Applicable to bushing type	Bushing defined in subclause
9.2	$\tan \delta$ / capacity	All capacitance graded	3.15
9.3	Lightning	All transformer bushings, BIL \geq 245 kV $U_m > 72,5$ kV	
9.4	AC dry	All	
9.5	Partial discharges	All	
9.6	Tap	All with a tap	
9.7	Internal pressure	All gas-containing	3.5, 3.6, 3.7
9.8	Tightness for liquid	All liquid-containing, except with highly viscous filling	3.2, 3.4
9.9	Tightness for gas	All gas-containing with some exceptions	3.5, 3.6, 3.7 3.19, 3.20, 3.21
9.10	Tightness at flange	All partly or completely immersed in oil liquid or gas with some exceptions	3.19, 3.20, 3.21
9.11	Visual and dimensions	All	

7.2.4 Special tests

Special tests are only performed when contractually agreed upon between purchaser and supplier. **Examples of such special tests are:**

- seismic test (reference to IEC TS 61463);
- **switching impulse test for voltage classes not included as routine- or type test**
- artificial pollution test for porcelain insulators (reference to IEC 60507).

NOTE If the insulator is designed to IEC TS 60815-1, and IEC TS 60815-2 or IEC TS 60815-3 whichever is applicable, no artificial pollution test is required.

7.3 Condition of bushings during dielectric and thermal tests

During all tests, the temperature of the ambient air and immersion media, if any, shall be between 10 °C and 40 °C. Dielectric and thermal tests shall be carried out only on bushings complete with their fixing flanges or other fixing devices, and all accessories with which they will be fitted when in use, but without protective arcing gaps, if any. Test taps and voltage taps shall be either earthed or held near earth potential.

~~Liquid filled and~~ Liquid-insulated bushings, according to 3.4, shall be filled to the normal level with the insulating liquid of the quality specified by the supplier.

Gas-filled, gas-insulated and gas-impregnated bushings, according to 3.5, 3.6 and 3.7, shall be filled with the type of insulating gas specified by the supplier and raised to the minimum pressure according to 3.30, at the reference temperature of 20 °C. If, at the beginning of the test, the temperature differs from 20 °C, the pressure shall be adjusted accordingly.

Partly or completely immersed bushings, according to 3.19, 3.20 and 3.21, shall normally be immersed in an immersion medium which is as similar as possible to that used in normal operation. Other media shall be agreed between purchaser and supplier. In the case of bushings for direct connection between GIS and transformers it is permitted to increase the pressure in the gas enclosure during routine dielectric tests to compensate for differences in withstand requirements for GIS and transformers bushings (see Table 3).

The purchaser may request a simulation test as a special test to prove the adequacy of the bushing in a specific operating arrangement. In particular, in the case of bushings intended for use on gas-insulated switchgear and transformers, tests may be required with simulation of adjacent metal parts on the GIS or transformer side. Such tests shall be the subject of previous agreement between purchaser and supplier.

NOTE For transformer bushings special consideration should be given to the clearances under ~~oil~~ liquid, for example with a larger diameter than the intended transformer turret, to satisfy the requirements of 9.4 without any contingent breakdown in ~~oil~~ liquid.

As the dielectric routine tests (see 7.2.3) are intended to check the internal insulation only, it is permissible practice to screen the external metal parts of the bushing during these tests.

A bushing is normally tested in an arrangement having sufficient clearance to surrounding earthed parts to avoid direct flashover to them through the ambient air or the immersion medium.

Normally, GIS and transformer bushings are tested in the vertical position, with the flange earthed or held near to earth potential.

The angle of mounting of the bushing for the wet power-frequency voltage withstand test and wet switching impulse voltage withstand test may be the subject of special agreement between purchaser and supplier.

Before commencing dielectric tests, the insulator shall be clean and dry and in thermal equilibrium with the ambient air.

If the actual atmospheric conditions deviate from the values given in IEC 60060-1, correction shall be made as given in Table 7.

Table 7 – Correction of test voltages (see 7.3)

Clause	Test	Correction ^{a, b, c}
8.2	Dry power-frequency voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.2	Wet power-frequency voltage withstand test	Multiply by k_1
8.3	Long duration power-frequency withstand test	None
8.4	Dry lightning impulse voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.5	Dry switching impulse voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.5	Wet switching impulse voltage withstand test	Multiply by k_1 in the conditions indicated below
8.6	Thermal stability test	None
8.7	Electromagnetic compatibility tests	None
9.2	Measurement of dielectric dissipation factor and capacitance	None
9.4	Dry power-frequency voltage withstand test	None
9.5	Measurement of partial discharge quantity	None
9.6	Tests of tap insulation	None
^a k_1 and k_2 shall be determined according to IEC 60060-1.		
^b In the case of impulse tests when the correction leads to a test voltage value lower than that specified, such correction shall be made on the polarity for which the external withstand voltage is the most critical one, whereas the opposite polarity shall be applied with at least the full voltage value.		
^c When the correction factor is higher than 1, the correction applies to both polarities, but if the correction factor is higher than 1,05 the purchaser and supplier shall agree as to whether the test shall or shall not be performed.		

8 Type tests

8.1 General

The order or possible combination of the tests is at the discretion of the supplier, except the impulse voltage withstand tests which shall be made before the dry power-frequency voltage withstand test (see 9.4). Before and after the series of type tests, measurements of dielectric dissipation factor and capacitance (see 9.2) and of partial discharge quantity (see 9.5) shall be carried out in order to check whether damage has occurred.

8.2 Dry or wet power-frequency voltage withstand test

8.2.1 Applicability

The dry test is applicable to all bushings according to 3.16, 3.19 and 3.21, which are not subjected to a routine test (see 9.4).

The wet test is applicable to all outdoor bushings according to 3.17, 3.18 and 3.20, and for which U_m ~~is less than or equal to~~ 245 kV and below.

8.2.2 Test method and requirements

The magnitude of the test voltage is given in Table 3. The test duration shall be 60 s, independent of test frequency, ~~except for transformer bushings with U_m equal to or above 1100 kV where the test duration is 300 s.~~

8.2.3 Acceptance

The bushing shall be considered to have passed the test if no flashover or puncture occurs. If there is a puncture, the bushing shall be considered to have failed the test. For capacitance graded bushings it is assumed that a puncture has occurred if the capacitance measured after the test raises above the capacitance previously measured by about the amount attributable to the capacitance of one layer. If a flashover occurs, the test shall be repeated once only. If during the repetition of the test no flashover or puncture occurs, the bushing shall be considered to have passed the test.

8.3 Long duration power-frequency voltage withstand test (ACLD)

8.3.1 Applicability

The test is applicable to all transformer bushings ~~rated~~ with U_m 170 kV and above.

8.3.2 Test method and requirements

The voltage shall be following the profile given in Figure 5;

- raise to $1,1 U_m / \sqrt{3}$ and held for a duration of 5 min. **Measure partial discharge;**
- raised to $U_2 = 1,5 U_m / \sqrt{3}$ and held for a duration of 5 min. **Measure partial discharge;**
- raised to $U_1 = U_m$ and held for a duration of 1 min;
- immediately after the test time, reduced without interruption to U_2 and held for a duration of at least 60 min ~~when $U_m \geq 300$ kV or 30 min for $U_m < 300$ kV to measure partial discharges.~~ The duration of the test shall be independent of the test frequency. Partial discharge shall be monitored during the whole application of test voltage and shall be recorded at 5 min intervals;
- reduced to $1,1 U_m / \sqrt{3}$ and held for a duration of 5 min. **Measure partial discharge;**
- reduced to 0 V.

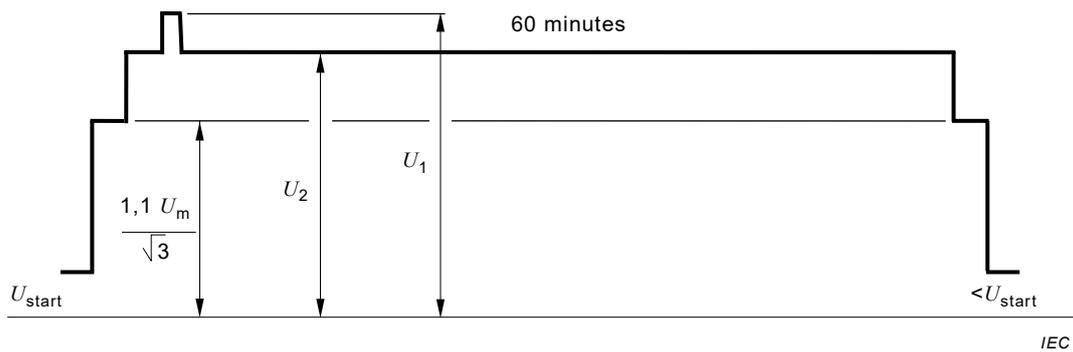


Figure 5 – Voltage profile for long duration test ~~ACLD~~

where U_{start} is the switch-in voltage for test equipment.

8.3.3 Acceptance

The bushing shall be considered to have passed the test if no flashover or puncture occurs. For capacitance graded bushings it is assumed that a puncture has occurred if the capacitance measured after the test raises above the capacitance previously measured by about the amount attributable to the capacitance of one layer.

The maximum acceptable values of partial discharge quantity, according to the type of bushing, at any stage in the test shall be as given in Table 9.

8.4 Dry lightning impulse voltage withstand test ~~(BIL)~~

8.4.1 Applicability

The test is applicable to all types of bushings.

8.4.2 Test method and requirements

The magnitude of the test voltage is given in Table 3. The bushing shall be subjected to

- 15 full lightning impulses of positive polarity, followed by
- 15 full lightning impulses of negative polarity

of the standard lightning impulse 1,2/50 μ s.

Bushings for transformers of U_m greater than 72,5 kV shall be subjected to

- 15 full lightning impulses of positive polarity, followed by
- 1 full lightning impulse of negative polarity at 110 % of the rated ~~BIL~~ withstand voltage, followed by
- 5 chopped lightning impulses of negative polarity at 121 % of the rated ~~BIL~~ withstand voltage, and by
- 14 full lightning impulses of negative polarity at 110 % of the rated ~~BIL~~ withstand voltage.

The time to sparkover on the chopping device shall be between 2 μ s and 6 μ s.

~~For transformer bushings of U_m greater than 72,5 kV and less than 245 kV rating not subject to routine impulse tests (see 9.2) the test shall be performed on three bushings of the same design and same production batch.~~

It is permissible, after changing polarity, to apply some impulses of minor amplitude before the application of the test impulses. The time intervals between consecutive applications of

the voltage shall be sufficient to avoid effects from the previous applications of voltage. Voltage records shall be made for each impulse.

~~In the case of bushings for gas-insulated switchgear, special test requirements for chopped lightning test may be agreed upon between purchaser and supplier to cover the behaviour of the bushing concerning very fast transient voltage.~~

8.4.3 Acceptance

The bushings shall be considered to have passed the test, if

- no puncture occurs at either polarity, and
- the number of flashovers in air does not exceed two for each series of 15 impulses;

except for transformer bushings for which

- no ~~oil-end~~ flashover on liquid immersed parts,
- not more than two flashovers in air at positive polarity, and
- no flashover in air at negative polarity

are permitted.

For gas-insulated bushings

- the number of disruptive discharges shall not exceed two for each series of 15 impulses;
- no disruptive discharges on non-self-restoring insulation shall occur.

This is verified by at least five impulses without disruptive discharge following that impulse out of the series of 15 impulses of each polarity, which caused the last disruptive discharge. If this impulse is one of the last five out of the series of 15 impulses of each polarity, additional impulses shall be applied.

If disruptive discharges occur and for any reason evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, after the completion of the dielectric tests the bushing shall be dismantled and inspected. If punctures of non-self-restoring insulation are observed, the bushing has failed the test.

8.5 Dry or wet switching impulse voltage withstand test ~~(SIL)~~

8.5.1 Applicability

The test is applicable to all bushings of U_m equal to or greater than 300 kV.

A dry test is applicable to indoor, indoor-immersed and completely immersed bushings, according to 3.16, 3.19 and 3.21.

The wet test is applicable to outdoor bushings, according to 3.17, 3.18 and 3.20.

In addition a dry test is applicable to all transformer bushings of U_m equal to or greater than 245 kV.

8.5.2 Test method and requirements

For these tests, IEC 60060-1 may be used. To simulate service conditions, the bushing shall be mounted on an earthed plane, radially extended from the axis of the bushing at least $0,4 L$ in every direction, L being the dry arcing distance of the bushing. The high-voltage connection shall extend in line with the axis of the bushing to a point at least $0,4 L$ above the top of the bushing. In the case of bushings where one end is immersed, the details of immersion shall

be subject to agreement. For bushings for gas insulated switchgear a smaller earth plane may be used subject to agreement.

The magnitude of the test voltage is given in Table 3.

The bushing shall be subjected to

- 15 impulses of positive polarity, followed by
- 15 impulses of negative polarity

of the standard switching impulse 250/2 500 μ s.

For transformer bushings ~~the dry, negative polarity test shall be at 110 % of the rated SIL U_m~~ equal to or greater than 245 kV the additional dry test shall be 15 impulses of negative polarity at 110 % of the rated withstand voltage.

It is permissible, after changing polarity, to apply some impulses of minor amplitude before the application of the test impulses. The time intervals between consecutive applications of the voltage shall be sufficient to avoid effects from the previous application of voltage.

Voltage records shall be made of each impulse.

8.5.3 Acceptance

The bushing shall be considered to have passed the test if

- no puncture occurs at either polarity, and if
- the number of flashovers in air at either polarity does not exceed two in the series of 15 impulses;

except for transformer bushings for which

- no ~~oil-end~~ flashover on liquid immersed parts, and
- not more than two flashovers in air at positive polarity, and
- no flashover in air at negative polarity

are permitted.

For gas-insulated bushings

- the number of disruptive discharges shall not exceed two for each series of 15 impulses;
- no disruptive discharges on non-self-restoring insulation shall occur.

This is verified by at least five impulses without disruptive discharge following that impulse out of the series of 15 impulses of each polarity, which caused the last disruptive discharge. If this impulse is one of the last five out of the series of 15 impulses of each polarity, additional impulses shall be applied.

If disruptive discharges occur and for any reason evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, after the completion of the dielectric tests the bushing shall be dismantled and inspected. If punctures of non-self-restoring insulation are observed, the bushing has failed the test.

8.6 Thermal stability test

8.6.1 Applicability

The test is applicable to all partly or completely immersed bushings, according to 3.19, 3.20 and 3.21. The major insulation of these bushings consists of an organic material, intended for apparatus filled with an insulating medium, the operating temperature of which is equal to or above 60 °C and where U_m is greater than 300 kV for oil-, resin-impregnated paper bushings and resin-impregnated ~~paper~~ synthetics bushings, and equal to or greater than 145 kV for other types of bushings.

The test may, however, be omitted if it can be demonstrated, based on the results of comparative tests or calculations, that the thermal stability of the bushing is assured.

8.6.2 Test method and requirements

The ends of the bushings, which are intended for immersion in mineral oil, or another liquid-insulating medium, shall be immersed in ~~oil~~ liquid. The temperature of the ~~oil~~ liquid shall be maintained at the operating temperature of the apparatus ± 2 K, except for transformer bushings ~~where the intended for use in mineral~~ oil the temperature shall be $90\text{ °C} \pm 2\text{ °C}$. This temperature shall be measured by means of thermometers, immersed in ~~oil~~ liquid about 3 cm below the surface, and about 30 cm from the bushing.

The ends of the bushings, which are intended for immersion in a gaseous insulating medium other than air at atmospheric pressure, shall be appropriately immersed in insulating gas at minimum pressure as defined in 3.30. The gas shall be maintained at a temperature agreed upon between purchaser and supplier.

The conductor losses corresponding to I_r shall be simulated by appropriate means. One method is to wrap a resistive insulated wire around a conductor dummy and to feed it by a suitable supply. The resistance of the wire and the current shall be adjusted in such a way as to produce the same losses as the final conductor.

The test voltage shall be

- U_m for bushings of U_m equal to or less than 170 kV,
- $0,8 U_m$ for bushings of U_m greater than 170 kV.

The test shall not be started until thermal equilibrium between the ~~oil~~ liquid and the bushing has been reached.

During the test, the dielectric dissipation factor shall be measured frequently and the ambient air temperature shall be recorded at each measurement.

The bushing has reached thermal stability when its dielectric dissipation factor ~~shows no appreciable rising tendency, with respect to the ambient temperature, for~~ rises no more than 0,0002 over a period of 5 h.

8.6.3 Acceptance

The bushing shall be considered to have passed the test if it reaches thermal stability and subsequently withstands dielectric routine tests without significant change from previous results.

8.7 Electromagnetic compatibility tests (EMC)

8.7.1 Emission test

8.7.1.1 Applicability

This test is applicable for all indoor and outdoor bushings having highest voltage for equipment (U_m) equal to and above 123 kV.

8.7.1.2 Test method and requirements

The bushing shall be installed as stated in 7.3.

The flange and other normally earthed parts shall be connected to earth. Care should be taken to avoid influencing the measurements by earthed or unearthed objects near to the bushing and to the test and measuring circuits.

The bushing shall be dry and clean and at approximately the same temperature as the room in which the test is made. It should not be subjected to other dielectric tests within 2 h prior to the present test.

The test connections and their ends shall not be a source of radio interference voltage of higher values than those indicated below. The high-voltage connections shall extend in line with the bushing axis to a point at least $0,2 L$ above the top of the bushing, where L is the arcing distance of the bushing. The maximum diameter of this connection shall be half the diameter of the bushing head.

The measuring circuit shall comply with CISPR 18-2. The measuring circuit shall preferably be tuned to a frequency within 10 % of 0,5 MHz, but other frequencies in the range 0,5 MHz to 2 MHz may be used, the measuring frequency being recorded. The results shall be expressed in microvolts.

If measuring impedances different from those specified in CISPR publications are used, they shall be not more than 600 Ω nor less than 30 Ω , in any case the phase angle shall not exceed 20°. The equivalent radio interference voltage referred to 300 Ω can be calculated, assuming the measured voltage to be directly proportional to the resistance, except for bushings of large capacitance, for which a correction made on this basis may be inaccurate. Therefore, a 300 Ω resistance is recommended for bushings with earthed flanges.

The filter F shall have a high impedance at the measuring frequency, so that the impedance between the high-voltage conductor and earth is not appreciably shunted as seen from the bushing under test. This filter also reduces circulating radio-frequency currents in the test circuit, generated by the high-voltage transformer or picked up from extraneous sources. A suitable value for its impedance has been found to be 10 000 Ω to 20 000 Ω at the measuring frequency.

It shall be ensured by suitable means that the radio interference background level (radio interference level caused by external field and by the high-voltage transformer when magnetised at the full test voltage) is at least 6 dB and preferably 10 dB below the specified radio interference level of the bushing to be tested. Calibration methods for the measuring instrument and for the measuring circuits are given in CISPR 16-1 and CISPR 18-2 respectively.

As the radio interference level may be affected by fibres or dust settling on the insulators, it is permitted to wipe the insulators with a clean cloth before taking a measurement. The atmospheric conditions during the test shall be recorded. It is not known what correction factors apply to radio interference testing but it is known that tests may be sensitive to high relative humidity and the results of the test may be open to doubt if the relative humidity exceeds 80 %.

The following test procedure shall be followed:

A voltage of $1,1 U_m / \sqrt{3}$ shall be applied to the bushing and maintained for at least 5 min, U_m being the highest voltage for equipment. The voltage shall then be decreased by steps down to $0,3 U_m / \sqrt{3}$, raised again by steps to the initial value and finally decreased by steps to $0,3 U_m / \sqrt{3}$. At each step radio interference measurement shall be taken and the radio interference level, as recorded during the last series of voltage reductions, shall be plotted versus the applied voltage; the curve so obtained is the radio interference characteristic of the bushing. The amplitude of voltage steps shall be approximately $0,1 U_m / \sqrt{3}$.

8.7.1.3 Acceptance

The bushing shall be considered to have passed the test if the radio interference level at $1,1 U_m / \sqrt{3}$ does not exceed 2 500 μV .

If it can be shown that the bushing, without external shielding, is partial discharge free, i.e. there is no discharge above the background noise level specified in 9.5.2, it can be considered to pass the emission test.

8.7.2 Immunity test

No test is required.

8.8 Temperature rise test

8.8.1 Applicability

The test is applicable to all types of bushings, ~~excluding liquid-insulated bushings according to 3.4~~, unless it can be demonstrated by a calculation based on comparative tests that specified temperature limits are met.

8.8.2 Test method and requirements

Bushings, one or both ends of which are intended to be immersed in mineral oil or another liquid-insulating medium, shall be appropriately immersed in ~~oil~~ liquid at ambient temperature, except for transformer bushings intended for use in mineral oil, where the oil shall be maintained at a temperature of $60 \text{ K} \pm 2 \text{ K}$ above the ambient air. ~~If the transformer is filled with another liquid-insulation medium, the temperature shall be subject to agreement.~~

~~NOTE 4~~ In some applications using mineral oil (e.g. generator transformer), the transformer top-oil temperature is often restricted to values below the normal IEC limits. Subject to agreement between manufacturer and purchaser, the standard oil temperature rise of 60 K may be reduced to reflect the real transformer top oil temperature.

Bushings with a conductor drawn into the central tube shall be assembled with an appropriate conductor, the cross-section of which shall conform to I_r . When the transformer ~~oil~~ liquid is in communication with the bushing central tube, the ~~oil~~ liquid level shall not exceed one-third of the height of the external part.

The end of bushings, which are intended for immersion in a gaseous insulating medium other than air at atmospheric pressure, shall normally be appropriately immersed in an enclosure insulated with gas at minimum pressure, according to 3.30, the gas being at ambient temperature at the beginning of the test.

Gas-insulated bushings shall be at ambient temperature at the beginning of the test.

For transformer bushings operating in air-insulated ducting, the air side shall be enclosed in an appropriate chamber. During the test, the air in the chamber shall be heated to $40 \text{ K} \pm 2 \text{ K}$ above ambient air, either by self-heating or indirectly.

An appropriate number of thermocouples or other measuring devices shall, as far as possible, be placed along the bushing conductor, central tube and other current-carrying parts, as well as possibly on the flange or other fixing device, so as to determine the ~~hottest spot of the bushing metal parts in contact with insulating material~~ temperature rise of the bushing components in relation to the values given in table 2 with reasonable accuracy.

The ambient air temperature shall be measured with lagged thermometers placed around the bushing at mid-height and at a distance of 1 m to 2 m from it.

NOTE-2 A satisfactory degree of lagging is obtained by placing the thermometers in ~~oil~~ liquid-filled containers with a volume of approximately 0,5 l.

The temperature of the ~~oil~~ liquid or gas shall be measured by means of thermometers placed at a distance of 30 cm from the bushing and, in the case of ~~oil~~ liquid, 3 cm below the surface of the ~~oil~~ liquid.

The test shall be carried out at $I_r \pm 2 \%$ at rated frequency, all parts of the bushing being substantially at earth potential. If the frequency at the test differs from the rated frequency, the current may be adjusted to achieve equivalent losses.

Temporary external connections used for this test shall be of such dimensions that they do not contribute unduly to the cooling of the bushing under test. These conditions are assumed to be fulfilled if the temperature decrease from the bushing termination to a point at 1 m distance along the connection does not exceed 5 K, or the thermal gradient along the external conductor is 5 K per metre for short connections.

The test shall be continued until the temperature rise is sensibly constant. This is considered to be the case if the temperature does not vary more than $\pm 1 \text{ K}$ during 1 h.

In order to provide data for thermal modelling of bushings, e.g. GIS-outdoor bushings, operating under different current loading and ambient temperature conditions, it is recommended by agreement to carry out overload tests and to record time functions of all temperature readings.

To avoid destruction of the insulation in the case of bushings with the conductor embedded in the insulating material, the temperature of the hottest spot may, by agreement between purchaser and supplier, be determined by suitably validated finite element calculations. (See also Annex A for an approximate method.)

8.8.3 Acceptance

The bushing shall be considered to have passed the test if the permissible temperature limits in accordance with 4.8 are met, and if there is no visible evidence of damage.

8.9 Verification of thermal short-time current withstand

8.9.1 Applicability

The verification is applicable to all types of bushings.

8.9.2 Verification method and requirements

The ability of the bushings to withstand the standard value of I_{th} shall be demonstrated by the following calculation:

$$\theta_f = \theta_o + \alpha \frac{I_{th}^2}{S_t \times S_e} \times t_{th} \quad (1)$$

where

- θ_f is the final temperature of the conductor, in degrees Celsius;
- θ_o is the temperature of the conductor in degrees Celsius, under continuous operation with I_r at an ambient temperature of 40 °C;
- α is 0,8 (K/s)/(kA/cm²)² for copper, 1,8 (K/s)/(kA/cm²)² for aluminium;
- t_{th} is the rated duration as specified, in seconds;
- I_{th} is the standard value as specified above, in kiloamperes;
- S_e is the equivalent cross-section, in square centimetres, taking account of skin effect;
- S_t is the total cross-section, in square centimetres corresponding to I_r .

For other materials the value of α used may be derived from the formula given below:

$$\alpha = \frac{\rho}{c \times \delta} \quad (2)$$

where

- ρ is the resistivity of conductor, in $\mu\Omega \cdot \text{cm}$
- c is the specific heat of conductor, in J/(g·K)
- δ is the density of the conductor, in g/cm³.

Values of ρ , c and δ used in Equation (2) should be correct at an average temperature of 160 °C.

In circular conductors of diameter D (cm), the equivalent cross-section shall take skin effect into account. The skin effect may be determined by considering a depth of penetration d of current derived from the formula given below:

$$d = \frac{1}{2\pi} \times \sqrt{\frac{\rho \times 10^3}{f}} \text{ cm} \quad (3)$$

where f is the rated frequency, in hertz.

Therefore:

$$S_e = \pi d(D - d) \quad (4)$$

8.9.3 Acceptance

The bushing shall be considered to be able to withstand the standard value of I_{th} if θ_f does not exceed 180 °C.

If the calculated temperature exceeds this limit, the ability of the bushing to withstand the standard value of I_{th} shall be demonstrated by a test. The test shall be carried out as follows:

- the bushing can be installed in any position;
- a current of at least the standard value of I_{th} and of duration t_{th} , in accordance with 4.3, shall be passed through the conductor, the cross-section of which shall conform to the rated current I_r .

Before the test, the bushing shall carry a current that produces the same stable conductor temperature as the rated current at maximum ambient temperature.

The bushing shall be considered to have passed the test if there is no visual evidence of damage and if it has withstood a repetition of all routine tests without significant change from the previous results.

8.10 Cantilever load withstand test

8.10.1 Applicability

The test is applicable to the air side of bushings.

8.10.2 Test method and requirements

The test values shall be in accordance with Table 1. For bushings according to 3.22, cantilever withstand load test values shall be restricted to:

$$300 \text{ N for } I_r \leq 800 \text{ A}$$

$$1\,000 \text{ N for } I_r > 800 \text{ A}$$

The bushing shall be completely assembled and, if applicable, filled with the insulating medium specified. Unless otherwise stated, the bushing shall be installed vertically and its flange rigidly fixed to a suitable device.

A pressure equal to 1 bar \pm 0,1 bar above the maximum operating pressure shall be applied inside the bushing, and also inside the central tube in the case of a bushing with a hollow stem with a gasket joint at the terminal to be tested.

For bushings with internal bellows, the pressure shall be stated by the supplier.

For bushings according to 3.5, 3.6 and 3.7 the test shall be performed with an internal gas pressure equal to the rated filling pressure.

For safety reasons on bushings with porcelain envelope the test may be performed without internal gas pressure and the relevant mechanical stress shall be replaced by an equivalent additional moment calculated in accordance with IEC 62155:2003, Annex D.

The load shall be applied perpendicular to the axis of the bushing at the mid-point of the terminal for 60 s. The load shall be in the direction which will cause the highest stress at the critical parts of the bushing in normal operation.

For bushings with more than one air side terminal, it is generally sufficient to apply the load to one terminal only.

For wall bushings the test load shall be applied to each end of the bushing separately.

Bushing types as defined in 3.5, 3.6 and 3.7 shall pass the leakage test according to 9.8 after the cantilever test.

8.10.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of damage (deformation, rupture or leakage) and if it has withstood a repetition of all routine tests without significant change from previous results.

8.11 Tightness test on liquid-filled, compound-filled and liquid-insulated bushings

8.11.1 Applicability

The test is applicable to all liquid-filled or compound-filled and liquid-insulated bushings, according to 3.2 and 3.4, except those bushings where the liquid filling has a viscosity equal to or greater than $5 \times 10^{-4} \text{ m}^2/\text{s}$ at 20 °C.

8.11.2 Test method and requirements

The bushing shall be assembled as for normal operation, filled with the liquid specified and placed in a suitably heated enclosure, maintained at a temperature of 75 °C for 12 h. For bushings where this is not possible, alternative methods may be agreed between purchaser and supplier.

A minimum pressure of 1 bar \pm 0,1 bar above the maximum internal operating pressure according to 3.31, shall be maintained inside the bushing during the test.

For bushing with internal bellows, the pressure shall be stated by the supplier.

8.11.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of leakage. The method of detection shall be the one described in IEC 60068-2-17:1994, Clause C.2.

8.12 Internal pressure test on gas-filled, gas-insulated and gas-impregnated bushings

8.12.1 Applicability

The test is applicable to all gas-filled, gas-insulated and gas-impregnated bushings, according to 3.5, 3.6 and 3.7, where the insulating envelope is of ceramic or composite material and intended for use with a permanent gas pressure higher than 0,5 bar gauge, having an internal volume equal to or greater than 1 l (1 000 cm³).

8.12.2 Test method and requirements

The test is performed on the insulating envelope in accordance with IEC 61462 and IEC 62217 or IEC 62155 where appropriate.

The insulating envelope shall be equipped with its fixing devices and fittings, preferably as in the intended application, and with additional plates with valve and pressure gauge for the test.

The insulator shall be completely filled with an appropriate medium. The pressure shall be increased steadily without producing any shock.

Other components should be tested to their appropriate standards.

8.12.3 Acceptance

The insulator shall be considered to have passed the test if there is no evidence of cracks, neither in the ceramic nor composite nor in the fittings. Where there is no evidence of the above, the test is considered satisfactory even though the fittings may have been stressed beyond their yield point.

8.13 External pressure test on partly or completely gas-immersed bushings

8.13.1 Applicability

The test is applicable to all gas-immersed bushings, according to 3.19 to 3.21, intended for use at a permanent gas pressure higher than 0,5 bar gauge.

8.13.2 Test method and requirements

The test shall be carried out before the tightness test according to 9.10. The bushing shall be assembled as far as necessary for the test, but there shall not be any internal gas pressure. The end for immersion shall be mounted in a tank as for normal operation at ambient temperature. The tank shall be completely filled with an appropriate liquid. A pressure of three times the external maximum operating pressure (see 3.32) shall be applied for 1 min.

8.13.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of mechanical damage (e.g. deformation, rupture).

8.14 Verification of dimensions

8.14.1 Applicability

This verification is applicable to all types of bushings.

8.14.2 Acceptance

The dimensions of the bushing under test shall be in accordance with the relevant drawings, particularly with regard to any dimensions to which special tolerances apply and to details affecting interchangeability.

9 Routine tests

9.1 General

The order or possible combination of the tests is at the discretion of the supplier, except if the tests include impulse voltage withstand tests, which shall be made before the dry power-frequency voltage withstand test (see 9.4). Before and after the dielectric routine tests, measurements of dielectric dissipation factor ($\tan \delta$) and capacitance (see 9.2) shall be carried out in order to check whether damage has occurred. The measurement of partial discharge quantity (see 9.5) shall be made before the last measurement of $\tan \delta$.

9.2 Measurement of dielectric dissipation factor ($\tan \delta$) and capacitance at ambient temperature

9.2.1 Applicability

The measurement is only applicable to capacitance-graded bushings according to 3.15.

9.2.2 Test method and requirements

During this test, the bushing conductor shall not carry current. The measurement shall be made at an ambient temperature of between 10 °C and 40 °C by means of a Schering bridge, or other similar equipment, at least at:

- $1,05 U_m / \sqrt{3}$ for bushings of $U_m \leq 36$ kV;
- $1,05 U_m / \sqrt{3}$ and U_m for bushings of $U_m \geq 52$ kV.

The measurement shall not be made at a voltage exceeding the dry power-frequency withstand voltage.

A measurement of $\tan \delta$ and capacitance at a voltage between 2 kV and 20 kV shall be carried out as a reference value for measurements carried out later when the bushing is in operation.

9.2.3 Acceptance

The maximum permissible values of $\tan \delta$ and for the increase of $\tan \delta$ with voltage are given in Table 8. If the values are not acceptable, it is permitted to wait for 1 h before repeating the test.

The actual temperature during the measurement shall be stated in the test report.

Table 8 – Maximum values of $\tan \delta$ and $\tan \delta$ increase (see 9.2)

Type of bushing insulation	Maximum value of $\tan \delta^a$	
	Value at $1,05 U_m / \sqrt{3}$	Increase between $1,05 U_m / \sqrt{3}$ and U_m^{*b}
Oil-impregnated paper	0,007	0,001
Resin-impregnated paper	0,007	0,001
Resin-impregnated synthetics	0,007	0,001
Resin-bonded paper	0,015	0,004
Gas impregnated film	0,005	0,001
Gas	0,005	0,001
Cast or moulded resin	0,015	0,004
Combined		^{b c}
Other		^{b c}

^a Bushings require full thermal stability at all service conditions while considering both the ohmic losses as well as the dielectric losses. For a properly designed bushing a lower dissipation factors does not necessarily contribute to the service life.

^b Not applicable to bushings where $U_m \leq 36$ kV.

^{b c} The supplier shall indicate the values.

9.3 Dry lightning impulse voltage withstand test ~~(BIL)~~

9.3.1 Applicability

The test as a routine test is applicable only for transformer bushings with U_m ~~equal to or greater than 245~~ > 72,5 kV.

9.3.2 Test method and requirements

The test values shall be as follows:

- five full lightning impulses of negative polarity at 105 % of the rated withstand voltage shall be applied.

Or ~~alternatively~~ by contractual agreement:

- one full lightning impulses of negative polarity at 105 % of the rated withstand voltage followed by:
- two chopped lightning impulses of negative polarity at ~~110~~ 115 % of the ~~full wave value~~ rated withstand voltage, followed by:
- two full lightning impulses of negative polarity at 105 % of the rated withstand voltage shall be applied.

For test conditions, 8.4 shall be followed.

9.3.3 Acceptance

For criteria, 8.4 shall be followed.

9.4 Dry power-frequency voltage withstand test

9.4.1 Applicability

The test is applicable to all types of bushings. For gas-insulated bushings according to 3.6, which are intended to be used as an integral part of a gas-insulated apparatus, of which the gas filling is common to that of the bushing, this test shall be a type test only, provided the insulating envelope of the bushing has been subjected to an adequate electrical test (e.g. wall test of the porcelain) before assembly.

9.4.2 Test method and requirements

The test shall be made or repeated after any impulse voltage withstand test, if required in a series of tests.

The magnitude of the test voltage is given in Table 3. Bushings for transformers shall be tested at least at 110 % of the induced and/or applied test voltage level of the transformer. If the transformer test level is not stated the bushing may be tested at the other bushings level given in Table 3.

The test duration shall be 60 s, independent of frequency, except for transformer bushings with U_m equal to or above 1100 kV where the test duration is 300 s.

9.4.3 Acceptance

The bushing shall be considered to have passed the test if no flashover or puncture occurs. If there is a puncture, the bushing shall be considered to have failed the test. For capacitance graded bushings it is assumed that a puncture has occurred if the capacitance measured after the test rises above the capacitance previously measured by about the amount attributable to the capacitance of one layer. If a flashover occurs the test shall be repeated once only. If, during the repetition of the test, no flashover or puncture occurs, the bushing shall be considered to have passed the test.

9.5 Measurement of partial discharge quantity

9.5.1 Applicability

The measurement shall be carried out on all types of bushings, except for bushings according to 3.6 and 3.13, for which this test shall be a type test only, provided the insulating envelope of the bushing has been subjected to an adequate electrical test (e.g. wall test of the porcelain) before assembly.

9.5.2 Test method and requirements

The test shall be made in accordance with IEC 60270.

When, as a substitute for the measurement of partial discharge quantity, the radio interference voltage, expressed in microvolts, is measured by means of a radio interference meter, the method of calibration to be used is that described in IEC 60270.

Unless otherwise stated, the elements of the test circuit shall be such that background noise and sensitivity at the measuring circuit enable a partial discharge quantity of 5 pC or 20 % of the specific value to be detected, whichever value is higher.

The measurement shall be made after the dry power-frequency withstand voltage test (see 9.4) at the values given in Table 3 during the decrease of the voltage from the dry

power-frequency withstand test level; ~~depending on test facilities, the voltage level could be reduced to $2 U_m / \sqrt{3}$ by agreement between the manufacturer and purchaser.~~

NOTE The system for detecting partial discharge quantity does not have to be continuously connected at voltage above U_m during this test.

9.5.3 Acceptance

The maximum acceptable values of partial discharge quantity, according to the type of bushing after the last dielectric test, shall be as given in Table 9.

When the measured values at $1,5 U_m / \sqrt{3}$ are greater than those indicated in Table 9, the supplier may extend the test for a period of up to 1 h to check if the values return to the allowed limits. If the partial discharge at the end of the period is within limits, then the bushing shall be accepted.

Partial discharge measurements before dielectric tests may be requested for information purpose only, and are not subject to guarantee.

Table 9 – Maximum values of partial discharge quantity (see 8.3 and 9.5)

Type of bushing insulation	Maximum discharge quantity pC measured at		
	U_m ^a	$1,5 U_m / \sqrt{3}$ ^b	$1,05 U_m / \sqrt{3}$ and $1,1 U_m / \sqrt{3}$ ^e
Oil-impregnated paper	10	10	5
Resin-impregnated paper	10	10	5
Resin-impregnated synthetics	10	10	5
Resin-bonded paper ^c	–	250	100
– with metal layers	d	d	300 ^c
Gas-impregnated film	10	10	5
Gas	–	10	5
Cast and moulded resin	–	10	5
Combined		d	
Other		d	

^a Only applicable to transformer bushings.

^b For switchgear bushings, the discharge quantities may be measured at a lower voltage, based on agreement between purchaser and supplier.

^c For resin-bonded paper bushings for use on power transformers, lower discharge quantities may be agreed between purchaser and supplier.

^d The maximum permissible values of discharge quantity shall be agreed between purchaser and supplier.

^e The value at $1,1 U_m / \sqrt{3}$ refers to 8.3 only.

NOTE The values for partial discharges are under consideration by the IEC and may be changed in coming revisions.

9.6 Tests of tap insulation

9.6.1 Applicability and test requirements

The following power-frequency voltage withstand test with respect to earth shall be applied to all taps:

- test tap (see 3.38): at least 2 kV;
- voltage tap (see 3.39): twice the rated voltage of the voltage tap but at least 2 kV.

The test duration is 60 s, independent of frequency.

After the test $\tan \delta$ and capacitance with respect to earth shall be measured at least at 1 kV.

9.6.2 Acceptance

The tap shall be considered to have passed the test if no flashover or puncture occurs.

For test taps the values of $\tan \delta$ and capacitance shall be in accordance with 4.10.

9.7 Internal pressure test on gas-filled, gas-insulated and gas-impregnated bushings

9.7.1 Applicability

The test is applicable to all gas-filled, gas-insulated and gas-impregnated bushings according to 3.5, 3.6 and 3.7.

9.7.2 Test method and requirements

The bushing, complete as for normal operation, shall be filled with gas at the choice of the supplier. A pressure of $(1,5 \times \text{maximum operating pressure}) \text{ bar} \pm 0,1 \text{ bar}$ shall be produced inside the bushing and maintained for 15 min at ambient temperature.

In the case of bushings where the insulating envelope is made of ceramic or composite material and intended to be operated under pressure, the unassembled insulating envelope shall be previously tested in accordance with IEC 62155 or IEC 61462 and IEC 62217, where appropriate. Other components should be tested to their appropriate standards.

NOTE It is allowed to remove the pressure relief devices during the test.

9.7.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of mechanical damage (e.g. deformation, rupture).

9.8 Tightness test on liquid-filled, compound-filled and liquid-insulated bushings

9.8.1 Applicability

The test is applicable to all liquid-filled or compound-filled and liquid-insulated bushings according to 3.2 and 3.4, except those bushings where the liquid filling has a viscosity equal to or greater than $5 \times 10^{-4} \text{ m}^2/\text{s}$ at 20 °C.

9.8.2 Test method and requirements

The bushing shall be assembled as for normal operation, filled with the liquid specified at ambient temperature of not less than 10 °C, except bushings for transformers, which shall be filled with the liquid having a minimum temperature of 60 °C. A pressure of 1 bar \pm 0,1 bar above the maximum operating pressure shall be applied inside the bushing as soon as possible after filling and maintained for at least 12 h.

For bushings with internal bellows, the pressure shall be stated by the supplier.

9.8.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of leakage. The method of detection shall be as described in IEC 60068-2-17:1994, Clause C.2.

It is advisable to carry out a preliminary tightness test on components for which the test is considered useful. Special consideration may be necessary for bushings, one or both ends of which are intended to be immersed in a gaseous medium.

9.9 Tightness test on gas-filled, gas-insulated and gas-impregnated bushings

9.9.1 Applicability

The test is applicable to all gas-filled, gas-insulated and gas-impregnated bushings, according to 3.5 to 3.7 and 3.18 to 3.21.

For gas-insulated bushings, intended to form an integral part of gas-insulated equipment, and of which assembly is intended to be achieved on site, it is permitted to replace the tightness test on the assembled bushing by a tightness test on each component, completed by a tightness test on each sealing assembly. The sealing assembly method shall be agreed upon between purchaser and supplier.

9.9.2 Test method and requirements

The bushings shall be assembled as for normal operation and filled with gas at maximum operating pressure at ambient temperature. The bushing shall be enclosed in an envelope, for example a plastic bag. The concentration of gas in the air inside the envelope shall be measured twice at an interval equal to or greater than 2 h.

Alternative methods of leakage detection may be used by agreement between purchaser and supplier.

It is advisable to carry out a preliminary tightness test on such components as is considered useful.

9.9.3 Acceptance

The bushing shall be considered to have passed the test if the calculated escape of gas is equal to or less than 0,5 % per year of the equivalent amount of gas contained inside the bushing in service.

9.10 Tightness test at the flange or other fixing device

9.10.1 Applicability

The test is applicable to all partly or completely immersed bushings, according to 3.19 to 3.21 intended to be used as an integral part of an apparatus, such as switchgear or transformers, where the bushings contribute to the sealing of the complete apparatus.

The test shall be a type test only in the case of bushings with gaskets of which the final placing is not carried out by the supplier, for example the top cap gasket of draw-through conductor transformer bushings.

The test may be omitted for transformer bushings fitted with a one-piece metal flange, provided the flange has been subjected to a preliminary tightness test, and the bushing has passed the type test in accordance with 8.11 (for example oil-impregnated paper bushings) or

the routine test in accordance with 9.8, or the end to be immersed does not include any gaskets.

9.10.2 Test method and requirements

The bushing shall be assembled at least as far as necessary for the test. The end for immersion shall be mounted on a tank as for normal operation at ambient temperature.

For ~~oil~~ liquid-immersed bushings, the tank shall be filled with air or any suitable gas at a relative pressure of $1,5 \text{ bar} \pm 0,1 \text{ bar}$ and maintained for 15 min, or with ~~oil~~ liquid at a relative pressure of $1 \text{ bar} \pm 0,1 \text{ bar}$ maintained for 12 h.

For gas-immersed bushings, the tank shall be filled with gas at maximum operating pressure at ambient temperature. The external part of the bushing shall be enclosed in an envelope, where necessary. Liquid-containing bushings shall remain empty and shall have an opening for free gas circulation within the envelope. The concentration of gas in the air inside the envelope shall be measured twice at an interval equal to or greater than 2 h.

9.10.3 Acceptance

An ~~oil~~ liquid-immersed bushing shall be considered to have passed the test if there is no evidence of leakage detected by visual inspection (see IEC 60068-2-17:1994, Clause C.2).

Gas-immersed bushings shall be considered to have passed the test, if:

- for all parts of a bushing where the leak gas escapes directly to the environment, the calculated total escape of gas is equal to or less than 0,5 % per year of the amount of gas contained in the adjacent switchgear compartment;
- for all parts of a liquid-containing bushing, especially liquid-insulated and oil-impregnated paper bushings, where the leak gas penetrates into the inside of the bushing, the calculated total leak rate (see 3.33) is equal to or less than $0,05 \text{ Pa} \times \text{cm}^3/\text{s} \times l$ ($5 \times 10^{-7} \text{ bar} \times \text{cm}^3/\text{s} \times l$), "l" being the quantity of liquid inside the bushing in litres;
- for all parts of a bushing, the other end of which is designed for a transformer, where the leak gas penetrates directly into the transformer, the calculated total leak rate (see 3.34) is equal to or less than $10 \text{ Pa} \times \text{cm}^3/\text{s}$ ($10^{-4} \text{ bar} \times \text{cm}^3/\text{s}$).

9.11 Visual inspection and dimensional check

9.11.1 Applicability

The inspections are applicable to all types of bushings and shall be made on the complete bushings before release. The visual inspection shall be made on each bushing.

9.11.2 Acceptance

No surface defects shall be tolerated which could affect the satisfactory performance in service.

Dimensions of parts for assembling and/or interconnection shall be in accordance with the relevant drawings, checked by sampling.

10 Requirements and tests for **non-capacitance graded bushings of rated highest voltages for equipment equal to or less than up to and including 52 kV** ~~made of ceramic, glass or inorganic materials, resin or combined insulation~~

10.1 General

This clause is applicable to all **non-capacitance graded bushings** ~~where the major insulation consists of ceramic, glass or analogous inorganic materials, cast and moulded resin, or combined insulation, as defined in 3.11 to 3.13~~ including 3.4, 3.12 to 3.14.

10.2 Temperature requirements

Bushings that may be required to withstand the drying process of the apparatus on which they are mounted, shall be able to withstand a temperature of 140 °C for 12 h without mechanical or electrical damage, provided that no external forces are applied.

10.3 Level of immersion medium

For transformer bushings, the supplier shall specify the minimum depth of immersion medium.

10.4 Markings

Each bushing shall carry the following marking:

- supplier's name or trade mark;
- year of manufacture;
- type or minimum nominal creepage distance or highest voltage for equipment (U_m);
- rated current (I_r) or maximum current if the bushing is supplied without conductor.

NOTE It may sometimes be difficult to provide all the above markings on small bushings and, in this case, other markings may be agreed between supplier and purchaser.

An example of a marking plate is given in Figure 4.

10.5 Test requirements

10.5.1 General

The test conditions and requirements shall be equivalent to Clauses 7, 8 and 9. Reference is made in parenthesis to the relevant sub-clause.

10.5.2 Type tests

The following tests are applicable to all bushings:

- dry or wet power-frequency voltage withstand test (8.2);
- dry lightning impulse voltage withstand test (8.4);
- temperature rise test (8.8);
- verification of thermal short-time current withstand (8.9);
- cantilever load withstand test (8.10);
- verification of dimensions (8.14).

~~For bushings according to 3.22, cantilever withstand load test values are reduced.~~

For bushings according to 3.22, precautions shall be taken to ensure that the end, which is designed to receive the movable part, will withstand the relevant test voltage, where applicable.

Table 10 – Applicability of type tests for bushings according to Clause 10 (see 10.5.1)

Short title	Applicable to bushing type	Bushing defined in subclause
AC dry	Indoor, outdoor immersed and completely immersed	3.12
AC wet	All outdoors	3.4, 3.12 to 3.14
Lightning	All	3.4, 3.12 to 3.14, 3.22
Temperature rise	All	Ditto 3.4, 3.12 to 3.14, 3.22
Thermal short time	All, if calculated temperature is too high	Ditto 3.4, 3.12 to 3.14, 3.22
Cantilever	All (reduced requirement for type defined in 3.22)	Ditto 3.4, 3.12 to 3.14, 3.22
Dimensions	All	Ditto 3.4, 3.12 to 3.14, 3.22

NOTE For fully dimensionally standardized bushing according to clause 3.4 with proven long service experience, type testing may be excluded.

10.5.3 Routine tests

The following tests are applicable to all bushings except for liquid-insulated bushings (3.4) and ceramic, glass or analogous inorganic material bushings (3.12), where only visual inspection and dimensional checks are applicable:

- dry power-frequency voltage withstand test (9.4);
- measurement of the partial discharge quantity (9.5);
- tests of tap insulation (9.6), if applicable;
- visual inspection and dimensional check (9.11).

Tables 10 and 11 show the applicability of the tests to the various types of bushings.

Table 11 – Applicability of routine tests for bushings according to Clause 10 (see 10.5.3)

Short title	Applicability to bushing type	Bushing defined in subclause
AC dry	All, except except for liquid-insulated bushings (3.4) and ceramic, glass or analogous inorganic material bushings (3.12)	3.13, 3.14, 3.22
Partial discharge	Ditto	Ditto 3.13, 3.14, 3.22
Tap	Ditto, with a tap	Ditto 3.13, 3.14, 3.22
Visual and dimensions	All	3.4, 3.12 to 3.14, 3.22

11 Recommendations for transport, storage, erection, operation and maintenance

11.1 General

It is essential that the transport, storage and installation of bushings, as well as their operation and maintenance in service, be performed in accordance with instructions given by the manufacturer.

Consequently, the manufacturer should provide instructions for the transport, storage, installation, operation and maintenance of bushings. The instructions for the transport and storage should be given at a convenient time before delivery, and the instructions for the installation, operation and maintenance should be given by the time of delivery at the latest.

It is impossible, here, to cover in detail the complete rules for the installation, operation and maintenance of each one of the different types of apparatus manufactured, but the following information is given relative to the most important points to be considered for the instructions provided by the manufacturer.

11.2 Conditions during transport, storage and installation

A special agreement should be made between manufacturer and user if the services conditions defined in the order, cannot be guaranteed during transport and storage. Special precautions may be essential for the protection of insulation during transport, storage and installation, and prior to energising, to prevent moisture absorption due, for instance, to rain, snow or condensation. Vibrations during transport should be considered. Appropriate instructions should be given.

Gas impregnated and gas-insulated bushings should be filled to a pressure sufficient to maintain positive pressure during transportation. A factory filling pressure of $1,3 \times 10^5$ Pa at 20 °C is appropriate for all temperature categories. If sulphur hexafluoride is used for filling the bushing during transportation it should comply with IEC 60376.

11.3 Installation

For each type of bushing the instructions provided by the manufacturer should at least include the items listed below.

11.4 Unpacking and lifting

Required Information for unpacking and lifting safely, including details of any special lifting and positioning devices necessary should be given.

At the arrival on site and before the final filling, the bushing should be checked according to the manufacturer instructions. For gas impregnated and gas insulated bushings, the gas pressure measured at ambient temperature should be above the atmospheric pressure.

11.5 Assembly

11.5.1 General

When the bushing is not fully assembled for transport, all transport units should be clearly marked. Drawings showing assembly of these parts should be provided with the bushing.

11.5.2 Mounting

Instructions for mounting of bushing, these instructions should indicate:

- the total mass of the bushing;
- the mass of the bushing (or heaviest part if to be assembled on site) if exceeding 100 kg;
- the centre of gravity.

The gas impregnated and gas insulated bushings should be filled with the specified gas, for example new sulphur hexafluoride complying with IEC 60376. The pressure of the gas at the end of filling, at the standard atmospheric air conditions (20 °C and 101,3 kPa), should be the rated filling pressure.

11.5.3 Connections

Instructions should include information on:

- connection of conductors, comprising the necessary advice to prevent overheating and unnecessary strain on the bushing and to provide adequate clearance distances;
- connection of any auxiliary circuits;
- connection of liquid or gas systems, if any, including size and arrangement of piping;
- connection for earthing.

11.5.4 Final installation inspection

Instruction should be provided for inspection and tests that should be made after the bushing has been installed and all connections have been completed.

These instructions should include:

- a schedule of recommended site tests to establish correct operation;
- procedures for carrying out any adjustment that may be necessary to obtain correct operation;
- recommendations for any relevant measurements that should be made and recorded to help with future maintenance decisions;
- instructions for final inspection and putting into service.

The results of the tests and inspection should be recorded in a commissioning report.

Gas impregnated and gas insulated bushings should be submitted to the following final checking:

- Measurement of gas pressure – the pressure of the gas measured at the end of filling and standard atmospheric air conditions (20 °C and 101,3 kPa) should be not less than the minimum functional pressure and not greater than the rated filling pressure of gas for insulation.
- Measurement of the dew point – the gas dew point at rated filling pressure should not exceed -5 °C when measured at 20 °C. Adequate corrections should be applied for measurement at the other temperatures.
- Enclosure tightness check – The check should be performed with the probing method for closed pressurised systems as specified for the routine test (see 9.9). The check should be started at least one hour after the filling of the bushing in order to reach a stabilised leakage flow. The check can be limited to gaskets, over pressure device, valves, terminals, manometers, temperature sensors, using a suitable leak detector.

11.6 Operation

The instructions given by the manufacturer should contain the following information:

- a general description of the equipment with particular attention to the technical description of its characteristics and all operation features provided, so that the user has an adequate understanding of the main principles involved;
- a description of the safety features of the equipment and their operation;
- as relevant, a description of the action to be taken to manipulate the equipment for maintenance and testing.

11.7 Maintenance

11.7.1 General

The effectiveness of maintenance depends mainly on the way instructions are prepared by the manufacturer and implemented by the user

11.7.2 Recommendation for the manufacturer

- a) The manufacturer should issue a maintenance manual including the following information:
- 1) schedule maintenance frequency;
 - 2) detailed description of the maintenance work;
 - recommended place for the maintenance work (indoor, outdoor, in factory, on site, etc.);
 - procedures for inspection, diagnostic tests, examination, overhaul, function check out (e.g. limits of values and tolerances);
 - reference to drawings;
 - reference to part numbers (when applicable);
 - use of special equipment or tools (cleaning and degreasing agents);
 - precautions to be observed (e.g.; cleanliness).
 - 3) comprehensive drawings of the details of the bushing important for maintenance, with clear identification (part number and description) of assemblies, sub-assemblies and significant parts;
- ~~NOTE Expanded detail drawing which indicate the relative position of components in assemblies and subassemblies are a recommended illustration method.~~
- 4) list of recommended spare-parts (description, reference number quantities) and advice for storage;
 - 5) estimate of active scheduled maintenance time;
 - 6) how to proceed with the equipment at the end of its operating life, taking into consideration environmental requirements.
- b) The manufacturer should inform the users of a particular type of bushing about corrective actions required by possible systematic defects and failures.
- c) Availability of spares. The manufacturer should be responsible for ensuring the continued availability of recommended spare parts required for maintenance for a period not less than 10 years from the date of the final manufacture of the bushing.

11.7.3 Recommendations for the user

- a) If the user wishes to carry out his own maintenance, he should ensure that his staff has sufficient qualification as well as a detailed knowledge of the bushing.
- b) The user should record the following information:
- the serial number and the type of bushing;
 - the date when the bushing is put in service;
 - the results of all measurements and tests including diagnostic tests carried out during the life of the bushing;
 - dates and extent of the maintenance work carried out;
 - the history of service, records of the bushing measurements during and following a special operating condition (e.g. fault and post fault operating state);
 - references to any failure report.

- c) In case of failure and defects, the user should make a failure report and should inform the manufacturer by stating the special circumstances and measures taken. Depending upon the nature of the failure, an analysis of the failure should be made in collaboration with the manufacturer.
- d) In case of disassembling for reinstallation in the future, the user must record the time and the storage conditions.

11.7.4 Failure report

The purpose of the failure report is to standardise the recording of bushing failures with the following objectives:

- to describe the failure using a common terminology;
- to provide data for the user statistics;
- to provide a meaningful feedback to the manufacturer;

The following gives guidance on how to make a failure report.

A failure report should include the following whenever such data is available:

- a) Identification of the bushing, which failed:
 - substation name;
 - identification of the bushing (manufacturer, type, serial number, ratings);
 - bushing family (oil, resin or SF6 insulation,);
 - location (indoor, outdoor).
- b) History of the Bushing:
 - history of the storage;
 - date of commissioning of the equipment
 - date of failure/defect;
 - date of last maintenance;
 - date of the last visual checking of the ~~oil~~ liquid level indicator
 - details of any changes made to the equipment since manufacture;
 - condition of the bushing when the failure/defect was discovered (in service, maintenance, etc.).
- c) Identification of the sub-assembly/component responsible for the primary failure/defect:
 - high-voltage stressed components;
 - tapping;
 - other components.
- d) Stresses presumed contributing to the failure/defect
 - environmental conditions (temperature, wind, snow, ice, pollution, lightning, etc.);
 - grid conditions (switching operations, failure of other equipment...);
 - others.
- e) Classification of the failure/defect
 - major failure;
 - minor failure;
 - defect.
- f) Origin and cause of the failure/defect
 - origin (mechanical, electrical, tightness etc.);

- cause in the opinion of the person having established the report (design, manufacture, inadequate instructions, incorrect mounting, incorrect maintenance, stresses beyond those specified, etc.).

g) Consequences of the failures or defect

- equipment down-time;
- time consumption for repair;
- labour cost;
- spare parts cost.

A failure report may include the following information:

- drawings, sketches;
- photographs of defective components;
- single-line station diagram;
- records or plots;
- references to maintenance manual.

12 Safety

12.1 General

High-voltage equipment can be safe only when installed in accordance with the relevant installations rules, and used and maintained in accordance with the manufacturer's instructions.

High-voltage equipment is normally only accessible by instructed persons. It should be operated and maintained by skilled persons. When unrestricted access is available to bushings, additional safety features may be required.

The following specifications of this standard provide personal safety measures for equipment against various hazards:

12.2 Electrical aspects

- insulation of the isolating distance
- earthing (indirect contact)
- IP coding (direct contact)

12.3 Mechanical aspects

- pressurised components
- mechanical impact protection

12.4 Thermal aspects

- flammability

13 Environmental aspects

The need to minimise the impact of the natural environment of bushings during all phases of their life is now recognised.

IEC Guide 109 gives guidance in this respect in term of life cycle impacts and recycling and disposal at the end of life.

The manufacturer should specify information regarding the relation between operation during service life, dismantling of the equipment and environmental aspects.

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Annex A (informative)

Determination of the hottest spot in bushings with conductors embedded in the insulation material

The maximum conductor temperature θ_M is deduced by equations (A.1) and (A.2):

$$\theta_M = \frac{\left[3 \left(\frac{R_C}{R_A} \times \frac{1}{\alpha} + \theta_A \right) - \frac{3}{\alpha} - \theta_1 - \theta_2 \right]^2 - [\theta_1 \times \theta_2]}{3 \left[2 \left(\frac{R_C}{R_A} \times \frac{1}{\alpha} + \theta_A \right) - \frac{2}{\alpha} - \theta_1 - \theta_2 \right]} \quad (\text{A.1})$$

$$M = \left[3 \left(\frac{R_C}{R_A} \times \frac{1}{\alpha} + \theta_A \right) - \frac{3}{\alpha} - \theta_1 - \theta_2 \right] - \theta_M \quad (\text{A.2})$$

If the result M of equation (A.2) is positive, the higher temperature of the conductor is θ_M , and it is situated in any point of the conductor between the two extremities. If the result M is negative or zero, the higher temperature of the conductor is θ_2 .

The point of maximum conductor temperature lies at distance L_M from the cooler end.

$$L_M = \frac{L}{1 \pm \sqrt{\frac{\theta_M - \theta_2}{\theta_M - \theta_1}}} \quad (\text{A.3})$$

where

- α is the temperature coefficient of resistance at which conductor resistance R_A is measured;
- θ_1 is the measured temperature at the cooler end of the conductor, in degrees Celsius;
- θ_2 is the measured temperature at the hotter end of the conductor, in degrees Celsius;
- θ_A is the uniform reference temperature of the conductor, in degrees Celsius;
- θ_M is the maximum temperature of conductor, in degrees Celsius;
- L is the length of conductor;
- L_M is the distance from the cooler end of the conductor to the point of highest temperature;
- R_A is the resistance between the ends of the conductor at uniform temperature θ_A ;
- R_C is the resistance of the conductor carrying I_r after stabilisation of temperature.

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Insulated bushings for alternating voltages above 1 000 V

Traversées isolées pour tensions alternatives supérieures à 1 000 V

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**INSULATED BUSHINGS FOR ALTERNATING
VOLTAGES ABOVE 1 000 V**

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International Standard IEC 60137 has been prepared by sub-committee 36A: Insulated bushings, of IEC technical committee 36: Insulators.

This seventh edition cancels and replaces the sixth edition, published in 2008, and constitutes a technical revision.

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

- Resin-impregnated synthetic (RIS) bushings has been introduced.
- Bushings with $U_m \leq 1,1$ kV, $U_m = 1\ 100$ kV and $U_m = 1\ 200$ kV have been introduced.
- Temperature rise testing has been included for liquid-insulated bushings according to clause to 3.4.
- Introducing dry lightning impulse testing as a routine test for all transformer bushings with $U_m > 72,5$ kV.
- The altitude correction procedure has been revised ($> 1\ 000$ m).

- An explanation about Very Fast Transient (VFT) phenomenon and its impact on bushings has been included.

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

FDIS	Report on voting
36A/187/FDIS	36A/189/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.

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 May 2018 have been included in this copy.

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INTRODUCTION

In the preparation of the current edition of this standard further consideration has been given to the test requirements for power transformers as described in IEC 60076-3:2013.

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INSULATED BUSHINGS FOR ALTERNATING VOLTAGES ABOVE 1 000 V

1 Scope

This International Standard specifies the characteristics and tests for insulated bushings.

This standard is applicable to bushings, as defined in Clause 3, intended for use in electrical apparatus, machinery, transformers, switchgear and installations for three-phase alternating current systems, having highest voltage for equipment above 1 000 V and power frequencies of 15 Hz up to and including 60 Hz.

Subject to special agreement between purchaser and supplier, this standard may be applied, in part or as a whole, to the following:

- bushings used in other than three-phase systems;
- bushings for high-voltage direct current systems;
- bushings for testing transformers;
- bushings for capacitors.

Special requirements and tests for transformer bushings in this standard apply also to reactor bushings.

This standard is applicable to bushings made and sold separately. Bushings which are a part of an apparatus and which cannot be tested according to this standard should be tested with the apparatus of which they form part.

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 60038, *IEC standard voltages*

IEC 60050-212:2010, *International Electrotechnical Vocabulary – Part 212: Electrical insulating solids, liquids and gases*

IEC 60059, *IEC standard current ratings*

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068-2-17:1994, *Basic environmental testing procedures – Part 2-17: Tests – Test Q: Sealing*

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

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

IEC 60076-7, *Power transformers – Part 7: Loading guide for oil-immersed power transformers*

IEC 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

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

IEC 60296, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

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

IEC 60422, *Mineral insulating oils in electrical equipment – Supervision and maintenance guidance*

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

IEC 60505, *Evaluation and qualification of electrical insulation systems*

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 TS 60815-2, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 2: Ceramic and glass insulators for a.c. systems*

IEC TS 60815-3, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 3: Polymer insulators for a.c. systems*

IEC 61099, *Insulating liquids – Specifications for unused synthetic organic esters for electrical purposes*

IEC 61462, *Composite hollow insulators – Pressurized and unpressurized insulators for use in electrical equipment with rated voltage greater than 1 000 V – Definitions, test methods, acceptance criteria and design recommendations*

IEC TS 61463, *Bushings – Seismic qualification*

IEC 62155:2003, *Hollow pressurized and unpressurized ceramic and glass insulators for use in electrical equipment with rated voltages greater than 1 000 V*

IEC 62217, *Polymeric HV insulators for indoor and outdoor use – General definitions, test methods and acceptance criteria*

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

IEC Guide 109, *Environmental aspects – Inclusion in electrotechnical product standards*

CISPR 16-1 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods*

CISPR 18-2, *Radio interference characteristics of overhead power lines and high-voltage equipment – Parts 2: Methods of measurement and procedure for determining limits*

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

bushing

device that enables one or several conductors to pass through a partition such as a wall or a tank, and insulates the conductors from it; the means of attachment (flange or fixing device) to the partition forms part of the bushing

Note 1 to entry: The conductor may form an integral part of the bushing or be drawn into the central tube of the bushing.

[SOURCE: IEC 60050-471:2007, 471-02-01]

3.2

liquid-filled bushing

bushing in which the space between the inside surface of the insulating envelope and the solid major insulation is filled with mineral oil or other insulating liquid

3.3

compound-filled bushing

bushing in which the space between the inside surface of the insulating envelope and the solid major insulation is filled with an insulating compound

3.4

liquid-insulated bushing

bushing in which the major insulation consists of mineral oil or another insulating liquid, enclosed by an insulating envelope

Note 1 to entry: These bushings are often of an open design which require proper processing after installation in order to avoid trapped air and subsequent partial discharges during testing or in service.

3.5

gas-filled bushing

bushing in which the space between the inside surface of the insulating envelope and the solid major insulation is filled with gas (other than ambient air) at atmospheric pressure or higher

Note 1 to entry: This definition includes bushings which are intended to form an integral part of gas-insulated equipment, the gas of the equipment being in communication with that of the bushing.

3.6

gas-insulated bushing

bushing in which the major insulation consists of gas (other than ambient air) at atmospheric pressure or higher

Note 1 to entry: This definition includes bushings which are intended to form an integral part of gas-insulated equipment, the gas of the equipment being in communication with that of the bushing.

Note 2 to entry: A bushing which contains solid insulating materials other than the envelope containing the gas (e.g. support for conducting layers or insulating cylinder), is a combined insulation bushing (see 3.14).

Note 3 to entry: A bushing in which the desired voltage grading is obtained by an arrangement of conducting or semi-conducting layers incorporated in an insulating material (e.g. plastic film) is referred to as a gas insulated capacitance graded bushing.

3.7**gas-impregnated bushing**

bushing in which the major insulation consists of a core wound from paper or plastic film (GIF) and subsequently treated and impregnated with gas (other than ambient air) at atmospheric pressure or higher

Note 1 to entry: the core is contained in an insulating envelope. The space between the core and the insulating envelope being filled with the same gas as used for the impregnation.

3.8**oil-impregnated paper bushing****OIP**

bushing in which the major insulation consists of a core wound from paper and subsequently treated and impregnated with an insulating liquid, generally mineral oil

Note 1 to entry: The core is contained in an insulating envelope, the space between the core and the insulating envelope being filled with the same insulating liquid as that used for impregnation.

3.9**resin-bonded paper bushing****RBP**

bushing in which the major insulation consists of a core wound from resin-coated paper

Note 1 to entry: During the winding process, each paper layer is bonded to the previous layer by its resin coating and the bonding achieved by curing the resin.

Note 2 to entry: A resin-bonded paper bushing can be provided with an insulating envelope, in which case the intervening space can be filled with an insulating liquid or another insulating medium.

3.10**resin-impregnated paper bushing****RIP**

bushing in which the major insulation consists of a core wound from untreated paper and subsequently impregnated with a curable resin

Note 1 to entry: A resin-impregnated paper bushing can be provided with an insulating envelope, in which case the intervening space can be filled with an insulating liquid or another insulating medium.

3.11**resin-impregnated synthetics bushing****RIS**

bushing in which the major insulation consists of a core wound from synthetics subsequently impregnated with a curable resin

Note 1 to entry: A resin-impregnated synthetics bushing can be provided with an insulating envelope, in which case the intervening space can be filled with an insulating liquid or another insulating medium.

Note 2 to entry: If not otherwise stated by the manufacturer, bushings in accordance with 3.11 shall be considered as RIP bushings according 3.10.

3.12**ceramic, glass or analogous inorganic material bushing**

bushing in which the major insulation consists of a ceramic, glass or analogous inorganic material

3.13**cast or moulded resin-insulated bushing**

bushing in which the major insulation consists of a cast or moulded organic material with or without an inorganic filler

3.14

combined insulation bushing

bushing in which the major insulation consists of a combination of at least two different insulating materials

3.15

capacitance graded bushing

bushing, in which a desired voltage grading is obtained by an arrangement of conducting or semiconducting layers incorporated into the insulating material

[SOURCE: IEC 60050-471:2007, 471-02-03]

3.16

indoor bushing

bushing, both ends of which are intended to be in ambient air at atmospheric pressure, but not exposed to outdoor atmospheric conditions

[SOURCE: IEC 60050-471:2007, 471-02-05]

3.17

outdoor bushing

bushing, both ends of which are intended to be in ambient air at atmospheric pressure and exposed to outdoor atmospheric conditions

[SOURCE: IEC 60050-471:2007, 471-02-07]

3.18

outdoor-indoor bushing

bushing, both ends of which are intended to be in ambient air at atmospheric pressure. One end is intended to be exposed to outdoor atmospheric conditions, and the other end not to be exposed to outdoor atmospheric conditions

[SOURCE: IEC 60050-471:2007, 471-02-09]

3.19

indoor-immersed bushing

bushing, one end of which is intended to be in ambient air but not exposed to outdoor atmospheric conditions and the other end to be immersed in an insulating medium other than ambient air (e.g. liquid or gas)

Note 1 to entry: This definition includes bushings operating in air at temperatures above ambient, such as occur with air-insulated ducting.

[SOURCE: IEC 60050-471:2007, 471-02-06]

3.20

outdoor-immersed bushing

bushing, one end of which is intended to be in ambient air and exposed to outdoor atmospheric conditions and the other end to be immersed in an insulating medium other than ambient air (e.g. liquid or gas)

[SOURCE: IEC 60050-471:2007, 471-02-08]

3.21

completely immersed bushing

bushing, both ends of which are intended to be immersed in an insulating medium other than ambient air (e.g. liquid or gas)

[SOURCE: IEC 66050-471:2007, 421-02-04]

3.22

plug-in type bushing

bushing for separable connector

bushing, one end of which is immersed in an insulating medium and the other end designed to receive a separable insulated cable connector, without which the bushing cannot function

[SOURCE: IEC 60050-471:2007, 471-02-02]

3.23

highest voltage for equipment

U_m

highest r.m.s. value of phase-to-phase voltage for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standard

[SOURCE: IEC 60050-614:2016, 614-03-01]

3.24

rated phase-to-earth voltage

maximum r.m.s. value of the voltage which the bushing withstands continuously between the conductor and the earthed flange or other fixing device, under the operating conditions specified in Clause 5

3.25

rated current

I_r

maximum r.m.s. value of current which the bushing can carry continuously under the operating conditions specified in Clause 5, without exceeding the temperature rise limits of Table 2

3.26

rated thermal short-time current

I_{th}

r.m.s. value of a symmetrical current which the bushing withstands thermally for the rated duration (t_{th}) immediately following continuous operation at rated current with maximum temperatures of ambient air and immersion media in accordance with 5.3

3.27

rated dynamic current

I_d

peak value of a current which the bushing withstands mechanically

3.28

temperature rise

difference between the measured temperature of the hottest spot of the metal parts of the bushing which are in contact with insulating material and the ambient air temperature (see 4.8)

3.29

rated frequency

f_r

frequency at which the bushing is designed to operate

[SOURCE: IEC 60050-421:1990, 421-04-03, modified ("transformer or reactor" replaced by "bushing")]

3.30**rated filling pressure of gas for insulation**

the pressure in Pascal (Pa) for insulation referred to the standard atmospheric conditions of +20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, to which the bushing is filled before being put into service, or automatically replenished

3.31**maximum internal operating gas pressure**

pressure, when the bushing is in operation, carrying rated current at the highest temperatures in accordance with 5.3

3.32**maximum external operating gas pressure**

maximum pressure of the gaseous insulating medium in which the bushing is partially or completely immersed when in operation

3.33**design pressure** (of the enclosure)

pressure used to determine the thickness of the enclosure

3.34**leak rate** (of gas-filled, gas-insulated, gas-impregnated and gas-immersed bushings)

quantity of dry gas at a given temperature that flows through a leak per unit of time and for a known difference of pressure across the leak

Note 1 to entry: The basic SI unit for leak rate is "Pascal cubic metre per second ($\text{Pa} \times \text{m}^3/\text{s}$)". The derived units " $\text{Pa} \times \text{cm}^3/\text{s}$ " and " $\text{bar} \times \text{cm}^3/\text{s}$ " are used in this standard, as they better conform to the orders of magnitude used in common industrial practice. It should be remembered that: $1 \text{ Pa} \times \text{m}^3/\text{s} = 10^6 \text{ Pa} \times \text{cm}^3/\text{s} = 10 \text{ bar} \times \text{cm}^3/\text{s}$.

[SOURCE: IEC 60068-2-17:1994, 1.1)

3.35**hollow insulator**

insulator which is open from end to end, with or without sheds

Note 1 to entry: An insulating envelope may consist of one insulator unit or two or more permanently assembled insulator units.

[SOURCE: IEC 60050-471:2007, 471-01-8, modified (removal of "including end fittings", modified Note 1 to entry)]

3.36**creepage distance**

shortest distance along the surface of an insulator between two conductive parts

Note 1 to entry: The surface of cement or of any other non-insulating jointing material is not considered as forming part of the creepage distance.

Note 2 to entry: If high-resistance coating is applied to parts of the insulating part of an insulator, such parts are considered to be effective insulating surfaces and the distance over them is included in the creepage distance.

[SOURCE: IEC 60050-471:2007, 471-01-04]

3.37**arcing distance**

shortest distance in air external to the insulator between metallic parts which normally have the operating voltage between them

Note 1 to entry: The terms "dry arcing distance" or "taut string distance" are also used.

Note 2 to entry: The arcing distance may be shorter than the values for external clearances in air stated in IEC 60076-3.

[SOURCE: IEC 60050-471:2007, 471-01-01, modified (Notes to entry added)]

3.38

test tap

measuring tap

$\tan \delta$ tap

connection, accessible from outside the bushing, insulated from the flange or other fixing device, made to one of the outer conducting layers of a capacitance graded bushing in order to allow measurements of dissipation factor, capacitance and partial discharge whilst the flange of the bushing is earthed

Note 1 to entry: This connection should be earthed directly when it is not used.

Note 2 to entry: When the test tap is used for condition monitoring, in service, care should be taken to avoid an open circuit.

3.39

voltage tap

potential tap

capacitance tap

connection, accessible from outside the bushing, insulated from the flange or other fixing device, made to one of the outer conducting layers of a capacitance graded bushing in order to provide a voltage source whilst the bushing is in operation

Note 1 to entry: This connection should be earthed directly when it is not used.

Note 2 to entry: This tap can also be used for the measurement of dissipation factor, capacitance and partial discharge.

3.40

rated voltage of the voltage tap

maximum voltage at which the tap is designed to supply the associated equipment, with the rated load connected thereto, when the rated phase-to-earth voltage is applied to the bushing at the rated frequency

3.41

composite bushing

bushing with an insulating envelope consisting of a resin impregnated fibre tube with or without a polymeric compound covering

Note 1 to entry: For bushings defined in 3.9 to 3.13, the polymeric compound may be applied directly on to the bushing major insulation.

3.42

capacitance (of bushing)

3.42.1

main capacitance C_1

capacitance between the high-voltage conductor and the test tap or the voltage tap of a capacitance-graded bushing

3.42.2

tap capacitance C_2

capacitance between the test tap or the voltage tap and the mounting flange of a capacitance-graded bushing

3.42.3**capacitance C**

capacitance between the high-voltage conductor and the mounting flange of a bushing without a voltage tap or test tap

4 Ratings**4.1 Rated highest voltage for equipment (U_m)**

The values of U_m of a bushing shall be chosen from the values of the highest voltage for equipment, defined in IEC 60038 as given below, in kilovolts:

3,6 – 7,2 – 12 – 17,5 – 24 – 36 – 52 – 72,5 – 100 – 123 – 145 – 170 – 245 – 300 – 362 – 420 – 550 – 800 – 1 100 – 1 200 kV.

NOTE For standard three phase systems the rated phase-to-earth voltage is $U_m / \sqrt{3}$.

4.2 Rated current (I_r)

The values of I_r of a bushing shall be chosen from the values as given below, in amperes:

100 – 250 – 315 – 400 – 500 – 630 – 800 – 1 000 – 1 250 – 1 600 – 2 000 – 2 500 – 3 150 – 4 000 – 5 000 – 6 300 – 8 000 – 10 000 – 12 500 – 16 000 – 20 000 – 25 000 – 31 500 – 40 000 A.

The above series of currents are in accordance with the values indicated in IEC 60059.

In the case of transformer bushings with the conductor drawn into the central tube (draw lead), the supplier shall indicate the value of the cross-section, the maximum diameter, the material of the conductor, and the material and thickness of insulation, which correspond to I_r in accordance with 4.8.

Bushings for transformers selected with I_r not less than 120 % of rated current of the transformer and with maximum temperature and maximum daily mean temperature in accordance with Table 4 are considered to be able to withstand the overload conditions according to IEC 60076-7 without further clarification or tests.

4.3 Rated thermal short-time current (I_{th})

Unless otherwise specified, the value of I_{th} shall be 25 times I_r , t_{th} being 1 s. For bushings with I_r equal to or greater than 4 000 A, I_{th} shall always be 100 kA.

For transformer bushings, t_{th} shall be 2 s, unless otherwise stated, with reference to IEC 60076-5.

For durations of t_{th} greater than 1 s, the relationship between current and time is assumed to be in accordance with

$$I_{th}^2 \times t_{th} = \text{constant}$$

For transformer bushings, where the conductor is drawn into the central tube, the conductor cross-section corresponding to the operating current may be less than that indicated in 4.2. In such a case, the operating current and cross-section should conform to the requirements of 8.8.

4.4 Rated dynamic current (I_d)

The standard value of I_d shall have an amplitude of the first peak of 2,5 times the value of I_{th} in accordance with 4.3.

In some cases, values greater than 2,5 times the value of I_{th} indicated in 4.3 may be necessary with respect to the transformer characteristics. The transformer manufacturer should stipulate such requirements in the bushing ordering information (see 6.1.4).

4.5 Minimum withstand values of cantilever load

The bushings shall withstand the cantilever load given in Table 1, Level I or II. Level I is normal load and shall be generally applied, unless a purchaser specifies a heavy load of Level II.

Table 1 – Minimum values of cantilever withstand load (see 4.5 and 8.10)

Highest voltage for equipment U_m kV	Rated current A							
	≤ 800	1 000 1 600	2 000 2 500	≥ 3 150				
	Cantilever operating load N							
	Bushing installed ≤ 30° from the vertical							
	I	II	I	II	I	II	I	II
≤ 36	500	500	625	625	1 000	1 000	1 575	1 575
52	500	800	625	800	1 000	1 250	1 575	1 575
72,5 to 100	500	1 000	625	1 000	1 000	1 575	2 000	2 000
123 to 145	625	1 575	800	1 575	1 250	2 000	2 000	2 000
170 to 245	625	2 000	800	2 000	1 250	2 500	2 000	2 500
≥ 300	1 250	2 000	1 250	2 000	1 575	2 500	2 500	2 500
	Cantilever test load N							
	I	II	I	II	I	II	I	II
≤ 36	1 000	1 000	1 250	1 250	2 000	2 000	3 150	3 150
52	1 000	1 600	1 250	1 600	2 000	2 500	3 150	3 150
72,5 to 100	1 000	2 000	1 250	2 000	2 000	3 150	4 000	4 000
123 to 145	1 250	3 150	1 600	3 150	2 500	4 000	4 000	4 000
170 to 245	1 250	4 000	1 600	4 000	2 500	5 000	4 000	5 000
≥ 300	2 500	4 000	2 500	4 000	3 150	5 000	5 000	5 000

Cantilever operating loads include terminal load and wind pressure (70 Pa), reference IEC TS 61463.

For bushings operating at an angle >30° to the vertical, the effect of bushing self-load should be considered when selecting test load and procedure. The values given above correspond to vertical bushings that are to be tested in a vertical position. If a tilted or horizontal bushing is to be tested vertically, then an equivalent force should be added to achieve the bending moment at the flange, caused by the weight of the bushing in its operating position. If a vertical bushing is to be tested horizontally, then the test load can be reduced in the same manner.

Level I = normal load, Level II = heavy load.

For bushings where upper and lower insulating envelopes are assembled by clamping force on the central fixing conductor, it is recommended to choose the cantilever test load, taking into account the thermal expansion of the conductor due to the rated current flow.

4.6 Angle of mounting

All bushings shall be designed for mounting at any angle of inclination not exceeding 30° from the vertical. Any other angle of mounting shall be subject to agreement between purchaser and supplier.

NOTE A bushing operating at an angle up to and including 30° from the vertical is considered a vertical bushing. A bushing operating at an angle equal to or greater than 70° from the vertical is considered a horizontal bushing. A bushing operating at any other angle is considered a tilted bushing (see 6.1.5).

4.7 Minimum nominal creepage distance

Unless otherwise agreed between purchaser and supplier, or demonstrated by a test, the creepage distance for insulating envelopes shall be in accordance with IEC TS 60815-2 or IEC TS 60815-3.

If artificial pollution tests are required, they shall be performed in accordance with IEC 60507.

NOTE 1 The actual value of creepage distance can be substantially longer, but not shorter, than what is stated in IEC 62155.

NOTE 2 IEC TS 60815-1 defines the Unified Specific Creepage Distance as the total creepage distance divided by the highest operating line-to-ground voltage according to 3.24. Previously the line-to-line voltage was used for calculating the specific creepage distance. This means there is a ratio of $\sqrt{3}$ between the two.

4.8 Temperature limits and temperature rise

The temperature limits of metal parts in contact with insulating material under normal operating conditions are as follows:

- 105 °C for oil-impregnated paper: Class A;
- 120 °C for resin-bonded and resin-impregnated paper, as well as resin-impregnated synthetics: Class E;
- 130 °C for gas-insulated: Class B.

The temperature rise above maximum daily mean ambient air temperature in accordance with 5.3 (30 °C) of the hottest spot shall not exceed the values given in Table 2. In the case of other insulating materials, the temperature limits shall be stated by the supplier. Reference shall be made to IEC 60216-2 and IEC 60505.

For bushing terminals and connections, the temperature rises are also given in Table 2.

Bushings used as an integral part of apparatus, such as switchgear or transformers, shall meet the thermal requirements for the relevant apparatus. For transformer bushings, reference shall be made to 4.2.

Temperature of ambient air and immersion media are defined in Table 4.

For bushings operating in liquid-immersed power transformers using high-temperature insulation materials according IEC 60076-14, the temperature limits for bushings shall be agreed between parties.

For gaskets in contact with metallic parts, special attention should be paid to the ability of the material to withstand the temperature rise.

4.9 Insulation levels

The values of insulation level shall be chosen from Table 3.

The specified values of insulation level are in accordance with IEC 60038 and IEC 60071-1.

Table 2 – Maximum values of temperature and temperature rise above ambient air (see 4.8)

Description of component		Maximum temperature rise K	Maximum temperature °C	Comments ^a
Spring contacts	Copper and copper alloys, uncoated:			d
	– in air	45	75	
	– in SF ₆	65	95	b
	– in oil	50	80	
	Tinned in air, SF ₆ or oil ^f	60	90	
	Silver/nickel-plated:			
– in air or SF ₆	75	105	b	
– in oil	65	95		
Screwed contacts	Copper, aluminium and their alloys, uncoated:			
	– in air	60	90	
	– in SF ₆	75	105	b
	– in oil	70	100	
	Tinned: ^f			
	– in air or SF ₆	75	105	b
	– in oil	70	100	
	Silver/nickel-plated:			
	– in air or SF ₆	85	115	b
– in oil	70	100		
Terminals to be connected to exterior conductors by screws or bolts	Copper, aluminium and their alloys:			
	– uncoated	60	90	c
	– tinned ^f	75	105	
	– silver or nickel-plated	75	105	
Current carrying and non-current carrying metallic parts in contact with	Insulation class:			
	– A (OIP)	75	105	
	– E (RBP, RIP, RIS)	90	120	
	– (GIF)	^e	^e	
	– SF ₆	100	130	
	– Oil	85	115	b, g
	110	140	h	
<p>^a The temperature rise values are based on IEC 60943 with a maximum daily mean temperature of 30 °C. For further information reference should be made to IEC 60943, Table 6.</p> <p>^b Oil in the table above refers to mineral oil. For other insulating liquids, e. g. silicone, natural or synthetic ester, higher values may be agreed between purchaser and supplier.</p> <p>^c If heavy oxidation is to be expected, the temperature rise shall be limited to 50 K.</p> <p>^d A spring contact is a connection maintained by spring pressure for example a plug-in connection.</p> <p>^e The temperature limits shall be stated by the supplier.</p> <p>^f Tinned contacts must not exceed the given max temperature of 105 °C, if so very rapid or immediate destruction will occur.</p> <p>^g Applicable to liquid-insulated bushings according to 3.4.</p> <p>^h Applicable to transformer bushings with a conductor (solid or flexible) drawn into the central tube.</p> <p>NOTE A and E refers to thermal class according to IEC 60085.</p>				

Table 3 – Insulation levels for highest voltage for equipment (U_m)
(see 4.9, 8.2, 8.4, 8.5, 9.3 and 9.4)

Highest voltage for equipment U_m	Rated lightning impulse withstand voltage (BIL)	Rated switching impulse withstand voltage (SIL)	Power-frequency withstand voltage ^f			
			kV (r.m.s. value)			
			Transformer bushings ^a (dry)	GIS bushings ^b (dry)	Other bushings ^c (dry)	All bushings ^d (wet)
≤ 1,1	20		10		10	10
3,6	40		11		10	10
7,2	60		22		20	20
12	75		30		28	28
17,5	95		42		38	38
24	125		55		50	50
36	170		77		70	70
52	250		105		95	95
72,5	325		155		140	140
100	380		165		150	150
	450		205		185	185
123	450		205		185	185
	550		255		230	230
145	450	650	205		185	185
	550		255		230	230
	650		305		275	275
170	550		255		230	230
	650		305		275	275
	750		355	325	325	325
245		650				
	950	750	435	435	395	395
		850				
	1 050	750	505	460	460	460
	850					
300	1 050	850	505	460	460	-
362	1 050	850	505	460	460	-
		950				
	1 175	950	560	520	510	-
420	1 300	1 050	625	595	570	-
	1 425	1 050	695	650	630	-
	1 550	1 175	750	-	680	-
550 ^e	1 425	1 050	695	650	630	-
		1 175				
	1 550	1 175	750	710	680	-
	1 675	1 175	750	-	680	-
	1 800	1 300	870	-	790	-
800 ^e	1 800	1 300				-
		1 425	870	830	790	-
		1 550				-
	1 950	1 550	915	960	830	-

Highest voltage for equipment U_m	Rated lightning impulse withstand voltage (BIL)	Rated switching impulse withstand voltage (SIL)	Power-frequency withstand voltage ^f			
			Transformer bushings ^a (dry)	GIS bushings ^b (dry)	Other bushings ^c (dry)	All bushings ^d (wet)
kV (r.m.s. value)	kV (peak value)	kV (peak value)	kV (r.m.s. value)			
	2 100	1 425	970	960	880	-
	2 400	1 550	1 075	960	975	-
1 100	2 250	1 800	1 200 ^g	1 100	-	-
	2 400	1 950				
1 200	2 250	1 800	1 320 ^g	1 200	-	-
	2 550	1 950				
^a Values in accordance with IEC 60071-1 and IEC60076-3 enhanced by 10 % in accordance with 9.4. ^b Values in accordance with IEC 62271-1. ^c Values in accordance with IEC 60071-1 and IEC 62271-1. ^d Values in accordance with IEC 60071-1. ^e The values of highest voltage for equipment are in accordance with IEC 60038, Amendment 2 (1997). ^f The power-frequency withstand voltages quoted are the minimum required based on the BIL of the system or equipment to which the bushing is applied. For transformer applications when a bushing is selected with a higher BIL-class, the bushing may be tested in accordance with column 6, provided the requirement of 10 % higher power-frequency withstand test voltage than its transformer is met. ^g The test duration shall be 300 s in accordance with IEC 60076-3.						

4.10 Test tap on transformer bushings

A test tap according to 3.38 shall be provided on all capacitance graded transformer bushings according to 3.15. In view of its use for partial discharge measurements on transformers, the values for the test tap shall not exceed:

- a capacitance to earth of 10 000 pF;
- a dielectric dissipation factor ($\tan \delta$) of 0,05 measured at power-frequency.

Other values of test tap capacitance to earth may be agreed between purchaser and supplier.

The bushing shall not incorporate substantial capacitances to earth which may divert the partial discharge current and so give rise to incorrect or misleading partial discharge measurements on the transformer.

5 Operating conditions

5.1 Temporary overvoltages

The maximum phase-to-earth voltage of the system may exceed U_m divided by $\sqrt{3}$. For periods not exceeding 8 h in any 24 h, and of which the total period does not exceed 125 h per year, bushings shall be able to operate phase-to-earth at a voltage of

- U_m for bushings of which U_m is equal to or less than 170 kV;
- $0,8 U_m$ for bushings of which U_m is greater than 170 kV.

For systems in which overvoltages in excess of this may occur, it is advisable to choose a bushing with a higher U_m .

5.2 Altitude

Although the insulation level refers to sea level, bushings corresponding to this standard are declared suitable for operation at any altitude not exceeding 1 000 m. In order to ensure that the external withstand voltages of the bushing are sufficient at altitudes exceeding 1 000 m, the arcing distance normally required shall be increased by a suitable amount. It is not necessary to adjust the radial thickness of insulation or the clearance of the immersed end. The puncture strength and the flashover voltage in the immersion medium of a bushing are not affected by altitude.

For installations at an altitude higher than 1 000 m, the arcing distance under the standard reference atmospheric conditions shall be determined in order to withstand the voltages obtained by multiplying the withstand voltages required at the service location by a factor k_a .

$$k_a = e^{m \frac{(H-1000)}{8150}}$$

where

H is the altitude (in meters), not exceeding 4000 meters.

$m = 1$ for lightning impulse withstand voltage

$m = 1$ for power-frequency withstand voltage where $U_m \leq 245$ kV. For higher U_m altitude correction is not applicable because bushings are tested with switching impulse already corrected for altitude.

m according to Figure 1 for switching impulse withstand voltage.

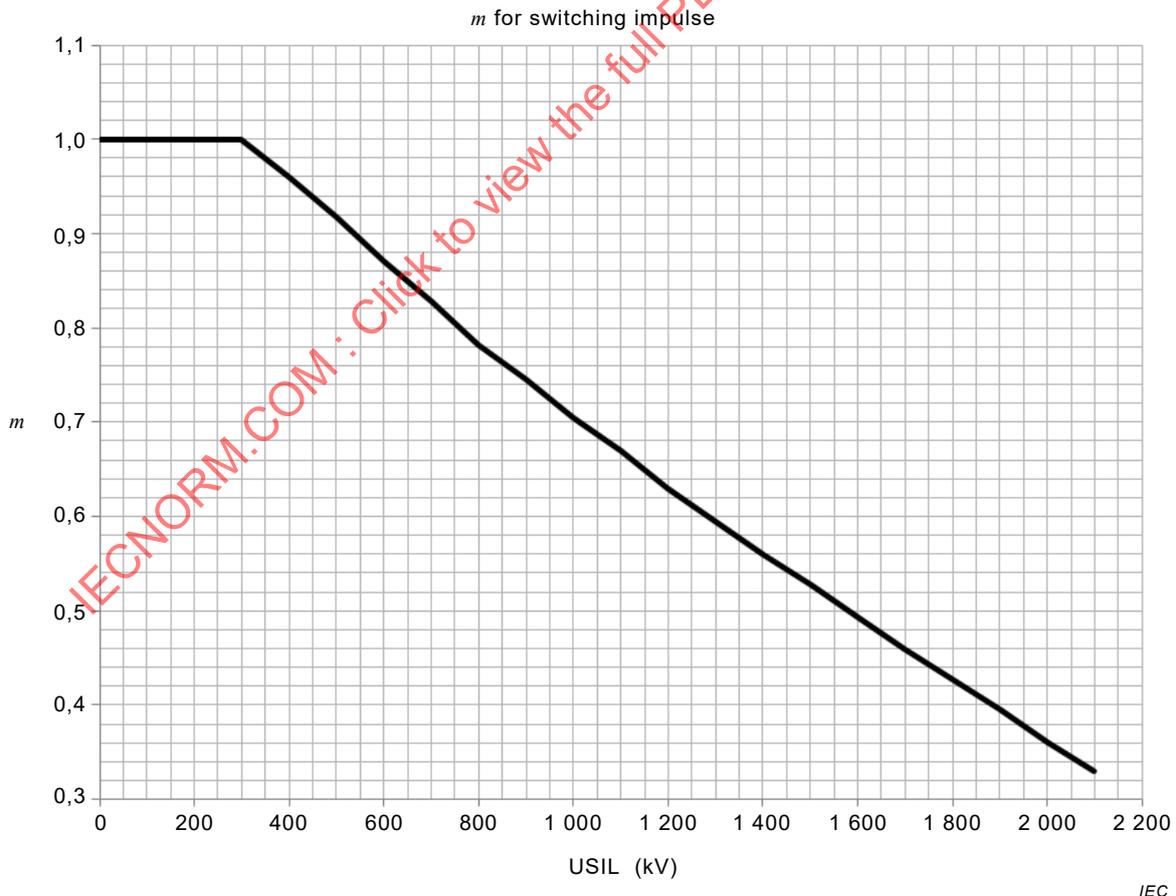


Figure 1 – Factor m on the co-ordination switching impulse withstand voltage

If the increased arcing distance is based on a verified arcing distance it can be considered valid without further testing.

5.3 Temperature of ambient air and immersion media

Bushings shall be designed for operation at temperatures not exceeding the limits given in Table 4. Considerations should be given to the operating conditions outside the limits in Table 4 and its effect of the current rating; some example are completely immersed bushings, bushings operating in high temperature ambient air conditions, or air-insulated ducting.

Moisture condensation on the surface of the indoor part of the bushing is to be prevented, if necessary by ventilation or heating.

Table 4 – Temperature of ambient air and immersion media

Subject	Temperature °C
Ambient air:	
– maximum	40
– maximum daily mean (open air)	30
– maximum daily mean (air-insulated ducting)	70
– maximum annual mean	20
– minimum	
• Indoors ^a	-5
	-15
	-25
• Outdoors ^a	-10
	-25
	-40
Mineral oil in transformers:	
– maximum	
• for normal loading ^b	100
• for short- and long-term emergency loading ^b	115
– maximum daily mean	90
Other media: (gaseous and non-gaseous)	^c
^a Unless otherwise specified the minimum ambient air temperature is –5 °C for indoors and –25 °C for outdoors bushings. ^b The values in transformers are in accordance with IEC 60076-1 and IEC 60076-2 and related to mineral oil. For other insulating liquids, e. g. silicone, natural or synthetic ester, higher values may be agreed between purchaser and supplier. The value for short- and long-term emergency loading are in accordance with IEC 60076-7. ^c In the absence of other information, reference should be made in principle to the corresponding IEC apparatus standard for which the bushing is intended, whereby particular attention should be paid to bushings one end of which is to be immersed in gas.	
NOTE 1 The daily mean temperature of the immersion medium should be calculated by averaging 24 consecutive hourly readings.	
NOTE 2 By agreement between purchaser and supplier, other temperature ranges may be adopted.	

5.4 Seismic conditions

When seismic qualification is required, reference should be made to IEC TS 61463.

5.5 Very fast transients (VFT)

In the case of unusual transient stresses to capacitance graded bushings connected to gas-insulated switchgears, special investigations may be agreed upon between purchaser and supplier to cover the behaviour of the bushings.

Tests are only meaningful as long as all parties understand the limitations of how closely the test arrangements simulates the service conditions.

It is not the steep front of the very fast voltage step generated at a VFT test that is dangerous to the bushing. It is the resonant ringing voltage occurring over the bushing that may feed internal resonance circuits inside the bushing to high overvoltages. A VFT test will therefore only test the bushing for the ringing frequencies determined by the setup.

5.6 Transformer insulating liquid

Transformer bushings according to this standard are normally intended for use in transformers filled with mineral oil complying with the requirements of IEC 60296 and 60422.

Where other insulating liquids are used details shall be given by the transformer manufacturer.

6 Ordering information and markings

6.1 Enumeration of characteristics

6.1.1 General

When ordering, the purchaser shall furnish as much of the following information as necessary, as well as any additional information needed to determine clearly the required characteristics.

The minimum distance to earthed parts of the end of the bushing which is intended to be immersed in insulation liquid shall be provided by the supplier. In case distances are below the values for the standard arrangements indicated in suppliers documentation, the purchaser may also provide the necessary geometry to evaluate the particular set-up.

6.1.2 Application

Application, including type of apparatus for which the bushing is intended, and the corresponding IEC apparatus standard shall be given.

Attention shall be drawn to any features (including tests) of the completed apparatus which may affect the design of the bushing (see 7.3).

6.1.3 Classification of bushings

Classification according to 3.2 to 3.22.

6.1.4 Ratings

The ratings shall be as follows:

- highest voltage for equipment (U_m) (see 3.23);
- rated phase-to-earth voltage (see 3.24);
- standard insulation level (see 4.9) and the induced and/or applied test voltage level of the transformer (if applicable) (see 9.4);
- rated current (I_r) (see 3.25);

- rated thermal short-time current (I_{th}) and rated duration (t_{th}), if deviating from the values given in 4.3;
- rated dynamic current (I_d), if deviating from the value given in 4.4;
- rated frequency (see 3.29);
- minimum withstand values of cantilever load in accordance with 4.5;
- maximum value of test tap capacitance, if lower value is required, in accordance with 4.10.

6.1.5 Operating conditions

The operating conditions shall be as follows:

- temporary overvoltages, if applicable (see 5.1);
- altitude, if exceeding 1 000 m (see 5.2) (relevant only to indoor and outdoor bushings according to 3.16 to 3.20);
- ambient air and immersion media temperature if deviating from normal values (see 5.3 and Table 4) (relevant to bushings according to 3.16 to 3.22);
- type of immersion medium (relevant only to partly or completely immersed bushings according to 3.19 to 3.22);
- minimum level of immersion medium (relevant only to partly or completely immersed bushings according to 3.19 to 3.22);
- maximum operating pressure of immersion media (relevant only to partly or completely immersed bushings according to 3.19 to 3.22);
- type of insulating gas (relevant only to gas-filled, gas-insulated and gas-impregnated bushings according to 3.5 to 3.7 when the gas of the equipment is in communication with that of the bushing);
- rated filling pressure of gas for insulation (see 3.30) (relevant only to gas-filled, gas-insulated and gas-impregnated bushings according to 3.5 to 3.7 when the gas of the equipment is in communication with that of the bushing);
- maximum internal operating gas pressure (see 3.31) (relevant only to gas-filled, gas-insulated and gas-impregnated bushings according to 3.5 to 3.7 when the gas of the equipment is in communication with that of the bushing);
- maximum external operating gas pressure (see 3.32) (relevant only to partly or completely gas-immersed bushings according to 3.19 to 3.21);
- angle of mounting if exceeding the standard values (see 4.6);
- minimum nominal specific creepage distance (see 4.7) (relevant only to the outdoor part of bushings according to 3.17, 3.18 and 3.20);
- unusual climatic conditions (extreme high and low temperatures, tropical humidity, severe contamination, high wind);
- seismic conditions, if qualification is required (see 5.4).

6.1.6 Design

The purchaser should provide requirements about the following, where applicable:

- for bushings supplied without a conductor: diameter, type (cable, solid or hollow stem), material and position of the conductor with which the bushing will be fitted in operation;
- particular dimensional requirements, if any;
- test tap or voltage tap if required (see 3.38 and 3.39);
- the length of earthed sleeve located next to the flange or other fixing device, if any;
- general information concerning the position of the bushing in relation to the earthed parts of the apparatus for which the bushing is foreseen (see 7.1);

- whether protective gaps are to be fitted or not;
- special requirements for corrosion protection of metallic parts;
- bushings for transformers shall be designed to withstand a typical transformer test sequence (works, acceptance and possible repeat tests);
- liquid level in central tube of a transformer bushing with the conductor drawn into the central tube, if lower than one-third of the height of the external part (see 8.8);
- provision of an liquid sample valve.

Bushings using liquid or gas for insulation should refer to the relevant standards:

- IEC 60376 for technical grade SF₆
- IEC 60480 for re-use of SF₆
- IEC 60296 for mineral insulating oil, or
- IEC 60836 for silicone insulating liquids
- IEC 60867 for synthetic aromatic hydrocarbons
- IEC 61099 for synthetic organic esters

6.2 Markings

This sub-clause applies to capacitance-graded bushings of all voltages, and to other bushings having U_m 72,5 kV and above. For other bushings having U_m 100 kV and below, markings indicated ■ are sufficient:

- supplier's name or trade mark;
- year of manufacture and serial number;
- supplier's type designation;
- country and location of manufacturer shall be directly identifiable;
- highest voltage for equipment (U_m) (see 3.23) or rated phase-to-earth voltage (see 3.24) and rated frequency (see 3.29);
- rated current (I_r) (see 3.25). If the bushing is supplied without conductor, the conductor section shall be specified by the supplier (see 4.2);
- mass if above 100 kg;
- lightning impulse (BIL) and switching impulse (SIL) and power-frequency withstand test voltages (AC) (see 4.9);
- bushing capacitance (see 3.42) and dielectric dissipation factor as measured by factory routine tests;
- type of insulating gas and rated filling pressure (see 3.30), if applicable;
- minimum gas operating pressure at 20 °C, if applicable;
- maximum angle of mounting if exceeding 30° from vertical (see 4.6).

For examples of marking plates, see Figures 2 to 4.

NOTE 1 Capacitance and dielectric dissipation factor measurements made on site may differ from factory values given on the nameplate.

NOTE 2 Non capacitance-graded bushings of highest voltages for equipment equal to or less than 52 kV are addressed in Clause 10.

MANUFACTURER		Country and location
Year	Type designation:.....	No.
U_mkV	I_r A	f_r Hz
BIL kV	SIL kV	AC kV
Mass kg	Max. angle to vertical degree	
Capacitance pF	Dissipation factor%	

In addition, for gas-filled, gas-insulated, gas-immersed and gas-impregnated bushings:

Type of gas	
Rated gas filling pressure at 20 °C	kPa absolute
Minimum gas pressure at 20 °C	kPa absolute

IEC

Figure 2 – Marking plate for bushings for rated highest voltage for equipment (U_m) greater than 100 kV

MANUFACTURER		Country and location
Year	Type designation:.....	No.
U_m kV	I_r A	f_r Hz

IEC

Figure 3 – Marking plate for bushings for rated highest voltage for equipment (U_m) equal to or less than 100 kV, except for bushings for which Figure 4 is applicable

MANUFACTURER		Country and location
Year	U_m kV	I_rA

IEC

Figure 4 – Marking plate for bushings for rated highest voltage for equipment (U_m) equal to or less than 52 kV made of ceramic, glass or inorganic materials, resin or combined insulation (see 10.3)

7 Test requirements

7.1 General requirements

All tests shall be carried out in accordance with the relevant IEC publication referred to in the particular clause. Tests on insulating envelopes of ceramic material shall be carried out in accordance with IEC 62155. Tests on insulators of composite material shall be carried out in accordance with IEC 61462 and IEC 62217. All high-voltage tests, in accordance with 8.2 to 8.5, 9.3 and 9.4 shall be carried out in accordance with IEC 60060-1.

The supplier shall provide a detailed type test certificate at the request of the purchaser. Type tests shall be performed on the supplied bushing design unless evidence of previous type tests is available. In case of different designs the supplier shall provide a statement of comparison between the tested and supplied designs. All electrical, mechanical and thermal stresses of the supplied design shall be covered by the evidence of test. Repetition of a type test is only mandatory when specified in a particular contract.

At the request of the purchaser, the supplier shall furnish any information concerning the minimum clearances to earthed parts in the operating arrangement.

The values of the applicable withstand test voltages for newly manufactured bushings are indicated in Table 3. For bushings, which have been in operation, the routine withstand test voltages shall be reduced to 85 % of the values indicated in the table.

The bushings shall tolerate and not be damaged by flashover in air when tested in accordance with 8.2, 8.4, 8.5, 9.3 and 9.4, but slight marks remaining on the surface of the insulating parts are acceptable.

A definition of the terms “flashover” and “puncture” is given in IEC 60050-212:2010, definition 212-11-47 and 212-11-49, respectively.

7.2 Test classification

7.2.1 General

Tables 5, 6, 10 and 11 show the applicability of the tests to the various types of bushings.

For bushings of highest voltages for equipment equal to or less than 52 kV, made of ceramic, glass or inorganic materials, resin or composite insulation, see Clause 10. For other bushings, tests to check dielectric, thermal and mechanical properties of bushings comprise the following tests.

7.2.2 Type tests

- dry or wet power-frequency voltage withstand test (see 8.2);
- long duration power-frequency voltage withstand test (see 8.3);
- dry lightning impulse voltage withstand test (see 8.4);
- dry or wet switching impulse voltage withstand test (see 8.5);
- thermal stability test (see 8.6);
- electromagnetic compatibility test (see 8.7);
- temperature rise test (see 8.8);
- verification of thermal short-time current withstand (see 8.9);
- cantilever load withstand test (see 8.10);
- tightness test on liquid-filled, compound-filled and liquid-insulated bushings (see 8.11);
- internal pressure test on gas-filled, gas-insulated and gas-impregnated bushings (see 8.12);
- external pressure test on partly or completely gas-immersed bushings (see 8.13);
- verification of dimensions (see 8.14).

Table 5 – Applicability of type tests (see 7.2.2, excluding bushings according to Clause 10)

Subclause	Short title	Applicable to bushing type	Bushing defined in subclause
8.2	AC dry	All indoor, indoor immersed and completely immersed, $U_m \leq 245$ kV	3.16, 3.19, 3.21
8.2	AC wet	All outdoor, $U_m \leq 245$ kV	3.17, 3.18, 3.20
8.3	ACLD	All transformer bushings, $U_m \geq 170$ kV	3.19, 3.20, 3.21
8.4	Lightning	All	
8.5	Switching	All, $U_m \geq 300$ kV	
	– dry	– indoor, indoor immersed and completely immersed and all transformer bushings, $U_m \geq 245$ kV	3.16, 3.19, 3.21
	– wet	– outdoor	3.17, 3.18, 3.20
8.6	Thermal stability	All partly or completely immersed, immersion medium ≥ 60 °C and $U_m > 300$ kV for OIP and RIP $U_m \geq 145$ kV for others	3.19, 3.20, 3.21
8.8	Temperature rise	All	
8.9	Thermal short-time	All, if calculated temperature is too high	
8.10	Cantilever	All	
8.11	Tightness	All liquid-filled and insulated, except with highly viscous filling	3.2, 3.4
8.12	Pressure	All containing gas of ≥ 1 l and $>0,5$ bar gauge	3.5, 3.6, 3.7
8.13	External pressure	All partly or completely immersed in gas, gas pressure $>0,5$ bar gauge	3.19, 3.20, 3.21
8.14	Dimensions	All	

7.2.3 Routine tests

- measurement of dielectric dissipation factor ($\tan \delta$) and capacitance at ambient temperature (see 9.2);
- dry lightning impulse voltage withstand test (see 9.3);
- dry power-frequency voltage withstand test (see 9.4);
- measurement of partial discharge quantity (see 9.5);
- tests of tap insulation (see 9.6);
- internal pressure test of gas-filled, gas-insulated and gas-impregnated bushings (see 9.7);
- tightness test on liquid-filled, compound-filled and liquid-insulated bushings (see 9.8);
- tightness test on gas-filled, gas-insulated and gas-impregnated bushings (see 9.9);
- tightness test at the flange or other fixing device (see 9.10);
- visual inspection and dimensional check (see 9.11).

Table 6 – Applicability of routine tests (see 7.2.3, excluding bushings according to Clause 10)

Subclause	Short title	Applicable to bushing type	Bushing defined in subclause
9.2	$\tan \delta$ / capacity	All capacitance graded	3.15
9.3	Lightning	All transformer bushings, $U_m > 72,5$ kV	
9.4	AC dry	All	
9.5	Partial discharges	All	
9.6	Tap	All with a tap	
9.7	Internal pressure	All gas-containing	3.5, 3.6, 3.7
9.8	Tightness for liquid	All liquid-containing, except with highly viscous filling	3.2, 3.4
9.9	Tightness for gas	All gas-containing with some exceptions	3.5, 3.6, 3.7 3.19, 3.20, 3.21
9.10	Tightness at flange	All partly or completely immersed in liquid or gas with some exceptions	3.19, 3.20, 3.21
9.11	Visual and dimensions	All	

7.2.4 Special tests

Special tests are only performed when contractually agreed upon between purchaser and supplier. Examples of such special tests are:

- seismic test (reference to IEC TS 61463);
- switching impulse test for voltage classes not included as routine- or type test
- artificial pollution test for porcelain insulators (reference to IEC 60507).

NOTE If the insulator is designed to IEC TS 60815-1, and IEC TS 60815-2 or IEC TS 60815-3 whichever is applicable, no artificial pollution test is required.

7.3 Condition of bushings during dielectric and thermal tests

During all tests, the temperature of the ambient air and immersion media, if any, shall be between 10 °C and 40 °C. Dielectric and thermal tests shall be carried out only on bushings complete with their fixing flanges or other fixing devices, and all accessories with which they will be fitted when in use, but without protective arcing gaps, if any. Test taps and voltage taps shall be either earthed or held near earth potential.

Liquid-insulated bushings, according to 3.4, shall be filled to the normal level with the insulating liquid of the quality specified by the supplier.

Gas-filled, gas-insulated and gas-impregnated bushings, according to 3.5, 3.6 and 3.7, shall be filled with the type of insulating gas specified by the supplier and raised to the minimum pressure according to 3.30, at the reference temperature of 20 °C. If, at the beginning of the test, the temperature differs from 20 °C, the pressure shall be adjusted accordingly.

Partly or completely immersed bushings, according to 3.19, 3.20 and 3.21, shall normally be immersed in an immersion medium which is as similar as possible to that used in normal operation. Other media shall be agreed between purchaser and supplier. In the case of bushings for direct connection between GIS and transformers it is permitted to increase the pressure in the gas enclosure during routine dielectric tests to compensate for differences in withstand requirements for GIS and transformers bushings (see Table 3).

The purchaser may request a simulation test as a special test to prove the adequacy of the bushing in a specific operating arrangement. In particular, in the case of bushings intended for use on gas-insulated switchgear and transformers, tests may be required with simulation of adjacent metal parts on the GIS or transformer side. Such tests shall be the subject of previous agreement between purchaser and supplier.

For transformer bushings special consideration should be given to the clearances under liquid, for example with a larger diameter than the intended transformer turret, to satisfy the requirements of 9.4 without any contingent breakdown in liquid.

As the dielectric routine tests (see 7.2.3) are intended to check the internal insulation only, it is permissible practice to screen the external metal parts of the bushing during these tests.

A bushing is normally tested in an arrangement having sufficient clearance to surrounding earthed parts to avoid direct flashover to them through the ambient air or the immersion medium.

Normally, GIS and transformer bushings are tested in the vertical position, with the flange earthed or held near to earth potential.

The angle of mounting of the bushing for the wet power-frequency voltage withstand test and wet switching impulse voltage withstand test may be the subject of special agreement between purchaser and supplier.

Before commencing dielectric tests, the insulator shall be clean and dry and in thermal equilibrium with the ambient air.

If the actual atmospheric conditions deviate from the values given in IEC 60060-1, correction shall be made as given in Table 7.

Table 7 – Correction of test voltages (see 7.3)

Clause	Test	Correction ^{a, b, c}
8.2	Dry power-frequency voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.2	Wet power-frequency voltage withstand test	Multiply by k_1
8.3	Long duration power-frequency withstand test	None
8.4	Dry lightning impulse voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.5	Dry switching impulse voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.5	Wet switching impulse voltage withstand test	Multiply by k_1 in the conditions indicated below
8.6	Thermal stability test	None
8.7	Electromagnetic compatibility tests	None
9.2	Measurement of dielectric dissipation factor and capacitance	None
9.4	Dry power-frequency voltage withstand test	None
9.5	Measurement of partial discharge quantity	None
9.6	Tests of tap insulation	None
<p>^a k_1 and k_2 shall be determined according to IEC 60060-1.</p> <p>^b In the case of impulse tests when the correction leads to a test voltage value lower than that specified, such correction shall be made on the polarity for which the external withstand voltage is the most critical one, whereas the opposite polarity shall be applied with at least the full voltage value.</p> <p>^c When the correction factor is higher than 1, the correction applies to both polarities, but if the correction factor is higher than 1,05 the purchaser and supplier shall agree as to whether the test shall or shall not be performed.</p>		

8 Type tests

8.1 General

The order or possible combination of the tests is at the discretion of the supplier, except the impulse voltage withstand tests which shall be made before the dry power-frequency voltage withstand test (see 9.4). Before and after the series of type tests, measurements of dielectric dissipation factor and capacitance (see 9.2) and of partial discharge quantity (see 9.5) shall be carried out in order to check whether damage has occurred.

8.2 Dry or wet power-frequency voltage withstand test

8.2.1 Applicability

The dry test is applicable to all bushings according to 3.16, 3.19 and 3.21, which are not subjected to a routine test (see 9.4).

The wet test is applicable to all outdoor bushings according to 3.17, 3.18 and 3.20, and for which U_m 245 kV and below.

8.2.2 Test method and requirements

The magnitude of the test voltage is given in Table 3. The test duration shall be 60 s, independent of test frequency, except for transformer bushings with U_m equal to or above 1100 kV where the test duration is 300 s.

8.2.3 Acceptance

The bushing shall be considered to have passed the test if no flashover or puncture occurs. If there is a puncture, the bushing shall be considered to have failed the test. For capacitance graded bushings it is assumed that a puncture has occurred if the capacitance measured after the test raises above the capacitance previously measured by about the amount attributable to the capacitance of one layer. If a flashover occurs, the test shall be repeated once only. If during the repetition of the test no flashover or puncture occurs, the bushing shall be considered to have passed the test.

8.3 Long duration power-frequency voltage withstand test (ACLD)

8.3.1 Applicability

The test is applicable to all transformer bushings with U_m 170 kV and above.

8.3.2 Test method and requirements

The voltage shall be following the profile given in Figure 5;

- raise to $1,1 U_m / \sqrt{3}$ and held for a duration of 5 min. Measure partial discharge;
- raised to $U_2 = 1,5 U_m / \sqrt{3}$ and held for a duration of 5 min. Measure partial discharge;
- raised to $U_1 = U_m$ and held for a duration of 1 min;
- immediately after the test time, reduced without interruption to U_2 and held for a duration of at least 60 min. The duration of the test shall be independent of the test frequency. Partial discharge shall be monitored during the whole application of test voltage and shall be recorded at 5 min intervals;
- reduced to $1,1 U_m / \sqrt{3}$ and held for a duration of 5 min. Measure partial discharge;
- reduced to 0 V.

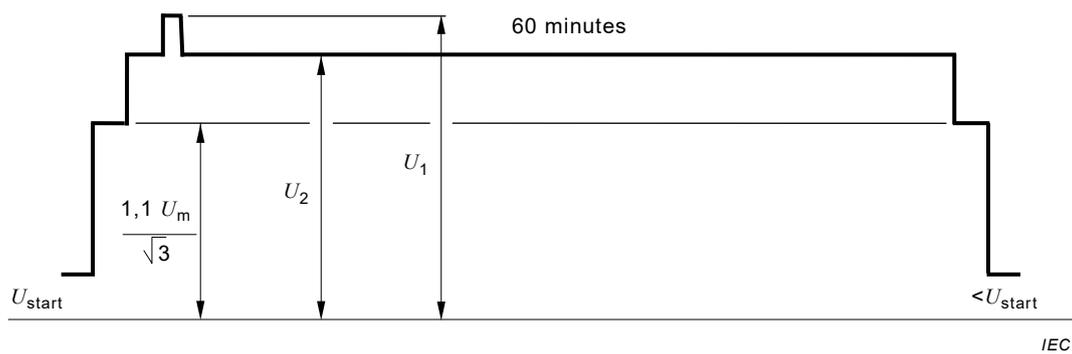


Figure 5 – Voltage profile for long duration test

where U_{start} is the switch-in voltage for test equipment.

8.3.3 Acceptance

The bushing shall be considered to have passed the test if no flashover or puncture occurs. For capacitance graded bushings it is assumed that a puncture has occurred if the capacitance measured after the test raises above the capacitance previously measured by about the amount attributable to the capacitance of one layer.

The maximum acceptable values of partial discharge quantity, according to the type of bushing, at any stage in the test shall be as given in Table 9.

8.4 Dry lightning impulse voltage withstand test

8.4.1 Applicability

The test is applicable to all types of bushings.

8.4.2 Test method and requirements

The magnitude of the test voltage is given in Table 3. The bushing shall be subjected to

- 15 full lightning impulses of positive polarity, followed by
- 15 full lightning impulses of negative polarity

of the standard lightning impulse 1,2/50 μ s.

Bushings for transformers of U_m greater than 72,5 kV shall be subjected to

- 15 full lightning impulses of positive polarity, followed by
- 1 full lightning impulse of negative polarity at 110 % of the rated withstand voltage, followed by
- 5 chopped lightning impulses of negative polarity at 121 % of the rated withstand voltage, and by
- 14 full lightning impulses of negative polarity at 110 % of the rated withstand voltage.

The time to sparkover on the chopping device shall be between 2 μ s and 6 μ s.

It is permissible, after changing polarity, to apply some impulses of minor amplitude before the application of the test impulses. The time intervals between consecutive applications of the voltage shall be sufficient to avoid effects from the previous applications of voltage. Voltage records shall be made for each impulse.

8.4.3 Acceptance

The bushings shall be considered to have passed the test, if

- no puncture occurs at either polarity, and
- the number of flashovers in air does not exceed two for each series of 15 impulses;

except for transformer bushings for which

- no flashover on liquid immersed parts,
- not more than two flashovers in air at positive polarity, and
- no flashover in air at negative polarity

are permitted.

For gas-insulated bushings

- the number of disruptive discharges shall not exceed two for each series of 15 impulses;
- no disruptive discharges on non-self-restoring insulation shall occur.

This is verified by at least five impulses without disruptive discharge following that impulse out of the series of 15 impulses of each polarity, which caused the last disruptive discharge. If this impulse is one of the last five out of the series of 15 impulses of each polarity, additional impulses shall be applied.

If disruptive discharges occur and for any reason evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, after the completion of the dielectric tests the bushing shall be dismantled and inspected. If punctures of non-self-restoring insulation are observed, the bushing has failed the test.

8.5 Dry or wet switching impulse voltage withstand test

8.5.1 Applicability

The test is applicable to all bushings of U_m equal to or greater than 300 kV.

A dry test is applicable to indoor, indoor-immersed and completely immersed bushings, according to 3.16, 3.19 and 3.21.

The wet test is applicable to outdoor bushings, according to 3.17, 3.18 and 3.20.

In addition a dry test is applicable to all transformer bushings of U_m equal to or greater than 245 kV.

8.5.2 Test method and requirements

For these tests, IEC 60060-1 may be used. To simulate service conditions, the bushing shall be mounted on an earthed plane, radially extended from the axis of the bushing at least $0,4 L$ in every direction, L being the dry arcing distance of the bushing. The high-voltage connection shall extend in line with the axis of the bushing to a point at least $0,4 L$ above the top of the bushing. In the case of bushings where one end is immersed, the details of immersion shall be subject to agreement. For bushings for gas insulated switchgear a smaller earth plane may be used subject to agreement.

The magnitude of the test voltage is given in Table 3.

The bushing shall be subjected to

- 15 impulses of positive polarity, followed by

- 15 impulses of negative polarity

of the standard switching impulse 250/2 500 μ s.

For transformer bushings U_m equal to or greater than 245 kV the additional dry test shall be 15 impulses of negative polarity at 110 % of the rated withstand voltage.

It is permissible, after changing polarity, to apply some impulses of minor amplitude before the application of the test impulses. The time intervals between consecutive applications of the voltage shall be sufficient to avoid effects from the previous application of voltage.

Voltage records shall be made of each impulse.

8.5.3 Acceptance

The bushing shall be considered to have passed the test if

- no puncture occurs at either polarity, and if
- the number of flashovers in air at either polarity does not exceed two in the series of 15 impulses;

except for transformer bushings for which

- no flashover on liquid immersed parts, and
- not more than two flashovers in air at positive polarity, and
- no flashover in air at negative polarity

are permitted.

For gas-insulated bushings

- the number of disruptive discharges shall not exceed two for each series of 15 impulses;
- no disruptive discharges on non-self-restoring insulation shall occur.

This is verified by at least five impulses without disruptive discharge following that impulse out of the series of 15 impulses of each polarity, which caused the last disruptive discharge. If this impulse is one of the last five out of the series of 15 impulses of each polarity, additional impulses shall be applied.

If disruptive discharges occur and for any reason evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, after the completion of the dielectric tests the bushing shall be dismantled and inspected. If punctures of non-self-restoring insulation are observed, the bushing has failed the test.

8.6 Thermal stability test

8.6.1 Applicability

The test is applicable to all partly or completely immersed bushings, according to 3.19, 3.20 and 3.21. The major insulation of these bushings consists of an organic material, intended for apparatus filled with an insulating medium, the operating temperature of which is equal to or above 60 °C and where U_m is greater than 300 kV for oil-, resin-impregnated paper bushings and resin-impregnated synthetics bushings, and equal to or greater than 145 kV for other types of bushings.

The test may, however, be omitted if it can be demonstrated, based on the results of comparative tests or calculations, that the thermal stability of the bushing is assured.

8.6.2 Test method and requirements

The ends of the bushings, which are intended for immersion in mineral oil, or another liquid-insulating medium, shall be immersed in liquid. The temperature of the liquid shall be maintained at the operating temperature of the apparatus ± 2 K, except for transformer bushings intended for use in mineral oil the temperature shall be $90\text{ °C} \pm 2\text{ °C}$. This temperature shall be measured by means of thermometers, immersed in liquid about 3 cm below the surface, and about 30 cm from the bushing.

The ends of the bushings, which are intended for immersion in a gaseous insulating medium other than air at atmospheric pressure, shall be appropriately immersed in insulating gas at minimum pressure as defined in 3.30. The gas shall be maintained at a temperature agreed upon between purchaser and supplier.

The conductor losses corresponding to I_r shall be simulated by appropriate means. One method is to wrap a resistive insulated wire around a conductor dummy and to feed it by a suitable supply. The resistance of the wire and the current shall be adjusted in such a way as to produce the same losses as the final conductor.

The test voltage shall be

- U_m for bushings of U_m equal to or less than 170 kV,
- $0,8 U_m$ for bushings of U_m greater than 170 kV.

The test shall not be started until thermal equilibrium between the liquid and the bushing has been reached.

During the test, the dielectric dissipation factor shall be measured frequently and the ambient air temperature shall be recorded at each measurement.

The bushing has reached thermal stability when its dielectric dissipation factor rises no more than 0,0002 over a period of 5 h.

8.6.3 Acceptance

The bushing shall be considered to have passed the test if it reaches thermal stability and subsequently withstands dielectric routine tests without significant change from previous results.

8.7 Electromagnetic compatibility tests (EMC)

8.7.1 Emission test

8.7.1.1 Applicability

This test is applicable for all indoor and outdoor bushings having highest voltage for equipment (U_m) equal to and above 123 kV.

8.7.1.2 Test method and requirements

The bushing shall be installed as stated in 7.3.

The flange and other normally earthed parts shall be connected to earth. Care should be taken to avoid influencing the measurements by earthed or unearthed objects near to the bushing and to the test and measuring circuits.

The bushing shall be dry and clean and at approximately the same temperature as the room in which the test is made. It should not be subjected to other dielectric tests within 2 h prior to the present test.

The test connections and their ends shall not be a source of radio interference voltage of higher values than those indicated below. The high-voltage connections shall extend in line with the bushing axis to a point at least $0,2 L$ above the top of the bushing, where L is the arcing distance of the bushing. The maximum diameter of this connection shall be half the diameter of the bushing head.

The measuring circuit shall comply with CISPR 18-2. The measuring circuit shall preferably be tuned to a frequency within 10 % of 0,5 MHz, but other frequencies in the range 0,5 MHz to 2 MHz may be used, the measuring frequency being recorded. The results shall be expressed in microvolts.

If measuring impedances different from those specified in CISPR publications are used, they shall be not more than 600Ω nor less than 30Ω , in any case the phase angle shall not exceed 20° . The equivalent radio interference voltage referred to 300Ω can be calculated, assuming the measured voltage to be directly proportional to the resistance, except for bushings of large capacitance, for which a correction made on this basis may be inaccurate. Therefore, a 300Ω resistance is recommended for bushings with earthed flanges.

The filter F shall have a high impedance at the measuring frequency, so that the impedance between the high-voltage conductor and earth is not appreciably shunted as seen from the bushing under test. This filter also reduces circulating radio-frequency currents in the test circuit, generated by the high-voltage transformer or picked up from extraneous sources. A suitable value for its impedance has been found to be $10\,000 \Omega$ to $20\,000 \Omega$ at the measuring frequency.

It shall be ensured by suitable means that the radio interference background level (radio interference level caused by external field and by the high-voltage transformer when magnetised at the full test voltage) is at least 6 dB and preferably 10 dB below the specified radio interference level of the bushing to be tested. Calibration methods for the measuring instrument and for the measuring circuits are given in CISPR 16-1 and CISPR 18-2 respectively.

As the radio interference level may be affected by fibres or dust settling on the insulators, it is permitted to wipe the insulators with a clean cloth before taking a measurement. The atmospheric conditions during the test shall be recorded. It is not known what correction factors apply to radio interference testing but it is known that tests may be sensitive to high relative humidity and the results of the test may be open to doubt if the relative humidity exceeds 80 %.

The following test procedure shall be followed:

A voltage of $1,1 U_m / \sqrt{3}$ shall be applied to the bushing and maintained for at least 5 min, U_m being the highest voltage for equipment. The voltage shall then be decreased by steps down to $0,3 U_m / \sqrt{3}$, raised again by steps to the initial value and finally decreased by steps to $0,3 U_m / \sqrt{3}$. At each step radio interference measurement shall be taken and the radio interference level, as recorded during the last series of voltage reductions, shall be plotted versus the applied voltage; the curve so obtained is the radio interference characteristic of the bushing. The amplitude of voltage steps shall be approximately $0,1 U_m / \sqrt{3}$.

8.7.1.3 Acceptance

The bushing shall be considered to have passed the test if the radio interference level at $1,1 U_m / \sqrt{3}$ does not exceed $2\,500 \mu\text{V}$.

If it can be shown that the bushing, without external shielding, is partial discharge free, i.e. there is no discharge above the background noise level specified in 9.5.2, it can be considered to pass the emission test.

8.7.2 Immunity test

No test is required.

8.8 Temperature rise test

8.8.1 Applicability

The test is applicable to all types of bushings, unless it can be demonstrated by a calculation based on comparative tests that specified temperature limits are met.

8.8.2 Test method and requirements

Bushings, one or both ends of which are intended to be immersed in mineral oil or another liquid-insulating medium, shall be appropriately immersed in liquid at ambient temperature, except for transformer bushings intended for use in mineral oil where the oil shall be maintained at a temperature of $60\text{ K} \pm 2\text{ K}$ above the ambient air. If the transformer is filled with another liquid-insulation medium, the temperature shall be subject to agreement.

In some applications using mineral oil (e.g. generator transformer), the transformer top-oil temperature is often restricted to values below the normal IEC limits. Subject to agreement between manufacturer and purchaser, the standard oil temperature rise of 60 K may be reduced to reflect the real transformer top oil temperature.

Bushings with a conductor drawn into the central tube shall be assembled with an appropriate conductor, the cross-section of which shall conform to I_r . When the transformer liquid is in communication with the bushing central tube, the liquid level shall not exceed one-third of the height of the external part.

The end of bushings, which are intended for immersion in a gaseous insulating medium other than air at atmospheric pressure, shall normally be appropriately immersed in an enclosure insulated with gas at minimum pressure, according to 3.30, the gas being at ambient temperature at the beginning of the test.

Gas-insulated bushings shall be at ambient temperature at the beginning of the test.

For transformer bushings operating in air-insulated ducting, the air side shall be enclosed in an appropriate chamber. During the test, the air in the chamber shall be heated to $40\text{ K} \pm 2\text{ K}$ above ambient air, either by self-heating or indirectly.

An appropriate number of thermocouples or other measuring devices shall, as far as possible, be placed along the bushing conductor, central tube and other current-carrying parts, as well as possibly on the flange or other fixing device, so as to determine the temperature rise of the bushing components in relation to the values given in table 2 with reasonable accuracy.

The ambient air temperature shall be measured with lagged thermometers placed around the bushing at mid-height and at a distance of 1 m to 2 m from it.

NOTE A satisfactory degree of lagging is obtained by placing the thermometers in liquid-filled containers with a volume of approximately 0,5 l.

The temperature of the liquid or gas shall be measured by means of thermometers placed at a distance of 30 cm from the bushing and, in the case of liquid, 3 cm below the surface of the liquid.

The test shall be carried out at $I_r \pm 2\%$ at rated frequency, all parts of the bushing being substantially at earth potential. If the frequency at the test differs from the rated frequency, the current may be adjusted to achieve equivalent losses.

Temporary external connections used for this test shall be of such dimensions that they do not contribute unduly to the cooling of the bushing under test. These conditions are assumed to be fulfilled if the temperature decrease from the bushing termination to a point at 1 m distance along the connection does not exceed 5 K, or the thermal gradient along the external conductor is 5 K per metre for short connections.

The test shall be continued until the temperature rise is sensibly constant. This is considered to be the case if the temperature does not vary more than ± 1 K during 1 h.

In order to provide data for thermal modelling of bushings, e.g. GIS-outdoor bushings, operating under different current loading and ambient temperature conditions, it is recommended by agreement to carry out overload tests and to record time functions of all temperature readings.

To avoid destruction of the insulation in the case of bushings with the conductor embedded in the insulating material, the temperature of the hottest spot may, by agreement between purchaser and supplier, be determined by suitably validated finite element calculations. (See also Annex A for an approximate method.)

8.8.3 Acceptance

The bushing shall be considered to have passed the test if the permissible temperature limits in accordance with 4.8 are met, and if there is no visible evidence of damage.

8.9 Verification of thermal short-time current withstand

8.9.1 Applicability

The verification is applicable to all types of bushings.

8.9.2 Verification method and requirements

The ability of the bushings to withstand the standard value of I_{th} shall be demonstrated by the following calculation:

$$\theta_f = \theta_o + \alpha \frac{I_{th}^2}{S_t \times S_e} \times t_{th} \quad (1)$$

where

- θ_f is the final temperature of the conductor, in degrees Celsius;
- θ_o is the temperature of the conductor in degrees Celsius, under continuous operation with I_r at an ambient temperature of 40 °C;
- α is 0,8 (K/s)/(kA/cm²)² for copper, 1,8 (K/s)/(kA/cm²)² for aluminium;
- t_{th} is the rated duration as specified, in seconds;
- I_{th} is the standard value as specified above, in kiloamperes;
- S_e is the equivalent cross-section, in square centimetres, taking account of skin effect;
- S_t is the total cross-section, in square centimetres corresponding to I_r .

For other materials the value of α used may be derived from the formula given below:

$$\alpha = \frac{\rho}{c \times \delta} \quad (2)$$

where

ρ is the resistivity of conductor, in $\mu\Omega\cdot\text{cm}$

c is the specific heat of conductor, in $\text{J}/(\text{g}\cdot\text{K})$

δ is the density of the conductor, in g/cm^3 .

Values of ρ , c and δ used in Equation (2) should be correct at an average temperature of $160\text{ }^\circ\text{C}$.

In circular conductors of diameter D (cm), the equivalent cross-section shall take skin effect into account. The skin effect may be determined by considering a depth of penetration d of current derived from the formula given below:

$$d = \frac{1}{2\pi} \times \sqrt{\frac{\rho \times 10^3}{f}} \text{ cm} \quad (3)$$

where f is the rated frequency, in hertz.

Therefore:

$$S_e = \pi d(D - d) \quad (4)$$

8.9.3 Acceptance

The bushing shall be considered to be able to withstand the standard value of I_{th} if θ_f does not exceed $180\text{ }^\circ\text{C}$.

If the calculated temperature exceeds this limit, the ability of the bushing to withstand the standard value of I_{th} shall be demonstrated by a test. The test shall be carried out as follows:

- the bushing can be installed in any position;
- a current of at least the standard value of I_{th} and of duration t_{th} , in accordance with 4.3, shall be passed through the conductor, the cross-section of which shall conform to the rated current I_r .

Before the test, the bushing shall carry a current that produces the same stable conductor temperature as the rated current at maximum ambient temperature.

The bushing shall be considered to have passed the test if there is no visual evidence of damage and if it has withstood a repetition of all routine tests without significant change from the previous results.

8.10 Cantilever load withstand test

8.10.1 Applicability

The test is applicable to the air side of bushings.

8.10.2 Test method and requirements

The test values shall be in accordance with Table 1. For bushings according to 3.22, cantilever withstand load test values shall be restricted to:

$$300 \text{ N for } I_r \leq 800 \text{ A}$$

1 000 N for $I_r > 800$ A

The bushing shall be completely assembled and, if applicable, filled with the insulating medium specified. Unless otherwise stated, the bushing shall be installed vertically and its flange rigidly fixed to a suitable device.

A pressure equal to 1 bar \pm 0,1 bar above the maximum operating pressure shall be applied inside the bushing, and also inside the central tube in the case of a bushing with a hollow stem with a gasket joint at the terminal to be tested.

For bushings with internal bellows, the pressure shall be stated by the supplier.

For bushings according to 3.5, 3.6 and 3.7 the test shall be performed with an internal gas pressure equal to the rated filling pressure.

For safety reasons on bushings with porcelain envelope the test may be performed without internal gas pressure and the relevant mechanical stress shall be replaced by an equivalent additional moment calculated in accordance with IEC 62155:2003, Annex D.

The load shall be applied perpendicular to the axis of the bushing at the mid-point of the terminal for 60 s. The load shall be in the direction which will cause the highest stress at the critical parts of the bushing in normal operation.

For bushings with more than one air side terminal, it is generally sufficient to apply the load to one terminal only.

For wall bushings the test load shall be applied to each end of the bushing separately.

Bushing types as defined in 3.5, 3.6 and 3.7 shall pass the leakage test according to 9.8 after the cantilever test.

8.10.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of damage (deformation, rupture or leakage) and if it has withstood a repetition of all routine tests without significant change from previous results.

8.11 Tightness test on liquid-filled, compound-filled and liquid-insulated bushings

8.11.1 Applicability

The test is applicable to all liquid-filled or compound-filled and liquid-insulated bushings, according to 3.2 and 3.4, except those bushings where the liquid filling has a viscosity equal to or greater than 5×10^{-4} m²/s at 20 °C.

8.11.2 Test method and requirements

The bushing shall be assembled as for normal operation, filled with the liquid specified and placed in a suitably heated enclosure, maintained at a temperature of 75 °C for 12 h. For bushings where this is not possible, alternative methods may be agreed between purchaser and supplier.

A minimum pressure of 1 bar \pm 0,1 bar above the maximum internal operating pressure according to 3.31, shall be maintained inside the bushing during the test.

For bushing with internal bellows, the pressure shall be stated by the supplier.

8.11.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of leakage. The method of detection shall be the one described in IEC 60068-2-17:1994, Clause C.2.

8.12 Internal pressure test on gas-filled, gas-insulated and gas-impregnated bushings

8.12.1 Applicability

The test is applicable to all gas-filled, gas-insulated and gas-impregnated bushings, according to 3.5, 3.6 and 3.7, where the insulating envelope is of ceramic or composite material and intended for use with a permanent gas pressure higher than 0,5 bar gauge, having an internal volume equal to or greater than 1 l (1 000 cm³).

8.12.2 Test method and requirements

The test is performed on the insulating envelope in accordance with IEC 61462 and IEC 62217 or IEC 62155 where appropriate.

The insulating envelope shall be equipped with its fixing devices and fittings, preferably as in the intended application, and with additional plates with valve and pressure gauge for the test.

The insulator shall be completely filled with an appropriate medium. The pressure shall be increased steadily without producing any shock.

Other components should be tested to their appropriate standards.

8.12.3 Acceptance

The insulator shall be considered to have passed the test if there is no evidence of cracks, neither in the ceramic nor composite nor in the fittings. Where there is no evidence of the above, the test is considered satisfactory even though the fittings may have been stressed beyond their yield point.

8.13 External pressure test on partly or completely gas-immersed bushings

8.13.1 Applicability

The test is applicable to all gas-immersed bushings, according to 3.19 to 3.21, intended for use at a permanent gas pressure higher than 0,5 bar gauge.

8.13.2 Test method and requirements

The test shall be carried out before the tightness test according to 9.10. The bushing shall be assembled as far as necessary for the test, but there shall not be any internal gas pressure. The end for immersion shall be mounted in a tank as for normal operation at ambient temperature. The tank shall be completely filled with an appropriate liquid. A pressure of three times the external maximum operating pressure (see 3.32) shall be applied for 1 min.

8.13.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of mechanical damage (e.g. deformation, rupture).

8.14 Verification of dimensions

8.14.1 Applicability

This verification is applicable to all types of bushings.

8.14.2 Acceptance

The dimensions of the bushing under test shall be in accordance with the relevant drawings, particularly with regard to any dimensions to which special tolerances apply and to details affecting interchangeability.

9 Routine tests

9.1 General

The order or possible combination of the tests is at the discretion of the supplier, except if the tests include impulse voltage withstand tests, which shall be made before the dry power-frequency voltage withstand test (see 9.4). Before and after the dielectric routine tests, measurements of dielectric dissipation factor ($\tan \delta$) and capacitance (see 9.2) shall be carried out in order to check whether damage has occurred. The measurement of partial discharge quantity (see 9.5) shall be made before the last measurement of $\tan \delta$.

9.2 Measurement of dielectric dissipation factor ($\tan \delta$) and capacitance at ambient temperature

9.2.1 Applicability

The measurement is only applicable to capacitance-graded bushings according to 3.15.

9.2.2 Test method and requirements

During this test, the bushing conductor shall not carry current. The measurement shall be made at an ambient temperature of between 10 °C and 40 °C by means of a Schering bridge, or other similar equipment, at least at:

- $1,05 U_m / \sqrt{3}$ for bushings of $U_m \leq 36$ kV;
- $1,05 U_m / \sqrt{3}$ and U_m for bushings of $U_m \geq 52$ kV.

The measurement shall not be made at a voltage exceeding the dry power-frequency withstand voltage.

A measurement of $\tan \delta$ and capacitance at a voltage between 2 kV and 20 kV shall be carried out as a reference value for measurements carried out later when the bushing is in operation.

9.2.3 Acceptance

The maximum permissible values of $\tan \delta$ and for the increase of $\tan \delta$ with voltage are given in Table 8. If the values are not acceptable, it is permitted to wait for 1 h before repeating the test.

The actual temperature during the measurement shall be stated in the test report.

Table 8 – Maximum values of $\tan \delta$ and $\tan \delta$ increase (see 9.2)

Type of bushing insulation	Maximum value of $\tan \delta^a$	
	Value at $1,05 U_m / \sqrt{3}$	Increase between $1,05 U_m / \sqrt{3}$ and U_m^b
Oil-impregnated paper	0,007	0,001
Resin-impregnated paper	0,007	0,001
Resin-impregnated synthetics	0,007	0,001
Resin-bonded paper	0,015	0,004
Gas impregnated film	0,005	0,001
Combined		c
Other		c

^a Bushings require full thermal stability at all service conditions while considering both the ohmic losses as well as the dielectric losses. For a properly designed bushing a lower dissipation factors does not necessarily contribute to the service life.

^b Not applicable to bushings where $U_m \leq 36$ kV.

^c The supplier shall indicate the values.

9.3 Dry lightning impulse voltage withstand test

9.3.1 Applicability

The test as a routine test is applicable only for transformer bushings with $U_m > 72,5$ kV.

9.3.2 Test method and requirements

The test values shall be as follows:

- five full lightning impulses of negative polarity at 105 % of the rated withstand voltage shall be applied.

Or alternatively by contractual agreement:

- one full lightning impulses of negative polarity at 105 % of the rated withstand voltage followed by:
- two chopped lightning impulses of negative polarity at 115 % of the rated withstand voltage, followed by:
- two full lightning impulses of negative polarity at 105 % of the rated withstand voltage

shall be applied.

For test conditions, 8.4 shall be followed.

9.3.3 Acceptance

For criteria, 8.4 shall be followed.

9.4 Dry power-frequency voltage withstand test

9.4.1 Applicability

The test is applicable to all types of bushings. For gas-insulated bushings according to 3.6, which are intended to be used as an integral part of a gas-insulated apparatus, of which the gas filling is common to that of the bushing, this test shall be a type test only, provided the insulating envelope of the bushing has been subjected to an adequate electrical test (e.g. wall test of the porcelain) before assembly.

9.4.2 Test method and requirements

The test shall be made or repeated after any impulse voltage withstand test, if required in a series of tests.

The magnitude of the test voltage is given in Table 3. Bushings for transformers shall be tested at least at 110 % of the induced and/or applied test voltage level of the transformer. If the transformer test level is not stated the bushing may be tested at the other bushings level given in Table 3.

The test duration shall be 60 s, independent of frequency, except for transformer bushings with U_m equal to or above 1100 kV where the test duration is 300 s.

9.4.3 Acceptance

The bushing shall be considered to have passed the test if no flashover or puncture occurs. If there is a puncture, the bushing shall be considered to have failed the test. For capacitance graded bushings it is assumed that a puncture has occurred if the capacitance measured after the test rises above the capacitance previously measured by about the amount attributable to the capacitance of one layer. If a flashover occurs the test shall be repeated once only. If, during the repetition of the test, no flashover or puncture occurs, the bushing shall be considered to have passed the test.

9.5 Measurement of partial discharge quantity

9.5.1 Applicability

The measurement shall be carried out on all types of bushings, except for bushings according to 3.6 and 3.13, for which this test shall be a type test only, provided the insulating envelope of the bushing has been subjected to an adequate electrical test (e.g. wall test of the porcelain) before assembly.

9.5.2 Test method and requirements

The test shall be made in accordance with IEC 60270.

When, as a substitute for the measurement of partial discharge quantity, the radio interference voltage, expressed in microvolts, is measured by means of a radio interference meter, the method of calibration to be used is that described in IEC 60270.

Unless otherwise stated, the elements of the test circuit shall be such that background noise and sensitivity at the measuring circuit enable a partial discharge quantity of 5 pC or 20 % of the specific value to be detected, whichever value is higher.

The measurement shall be made after the dry power-frequency withstand voltage test (see 9.4) at the values given in Table 3 during the decrease of the voltage from the dry power-frequency withstand test level.

NOTE The system for detecting partial discharge quantity does not have to be continuously connected at voltage above U_m during this test.

9.5.3 Acceptance

The maximum acceptable values of partial discharge quantity, according to the type of bushing after the last dielectric test, shall be as given in Table 9.

When the measured values at $1,5 U_m / \sqrt{3}$ are greater than those indicated in Table 9, the supplier may extend the test for a period of up to 1 h to check if the values return to the allowed limits. If the partial discharge at the end of the period is within limits, then the bushing shall be accepted.

Partial discharge measurements before dielectric tests may be requested for information purpose only, and are not subject to guarantee.

Table 9 – Maximum values of partial discharge quantity (see 8.3 and 9.5)

Type of bushing insulation	Maximum discharge quantity pC measured at		
	U_m^a	$1,5 U_m / \sqrt{3}^b$	$1,05 U_m / \sqrt{3}$ and $1,1 U_m / \sqrt{3}^e$
Oil-impregnated paper	10	10	5
Resin-impregnated paper	10	10	5
Resin-impregnated synthetics	10	10	5
Resin-bonded paper ^c	–	250	100
– with metal layers	^d	^d	300 ^c
Gas-impregnated film	10	10	5
Gas	–	10	5
Cast and moulded resin	–	10	5
Combined		^d	
Other		^d	

^a Only applicable to transformer bushings.

^b For switchgear bushings, the discharge quantities may be measured at a lower voltage, based on agreement between purchaser and supplier.

^c For resin-bonded paper bushings for use on power transformers, lower discharge quantities may be agreed between purchaser and supplier.

^d The maximum permissible values of discharge quantity shall be agreed between purchaser and supplier.

^e The value at $1,1 U_m / \sqrt{3}$ refers to 8.3 only.

NOTE The values for partial discharges are under consideration by the IEC and may be changed in coming revisions.

9.6 Tests of tap insulation

9.6.1 Applicability and test requirements

The following power-frequency voltage withstand test with respect to earth shall be applied to all taps:

- test tap (see 3.38): at least 2 kV;
- voltage tap (see 3.39): twice the rated voltage of the voltage tap but at least 2 kV.

The test duration is 60 s, independent of frequency.

After the test $\tan \delta$ and capacitance with respect to earth shall be measured at least at 1 kV.

9.6.2 Acceptance

The tap shall be considered to have passed the test if no flashover or puncture occurs.

For test taps the values of $\tan \delta$ and capacitance shall be in accordance with 4.10.

9.7 Internal pressure test on gas-filled, gas-insulated and gas-impregnated bushings

9.7.1 Applicability

The test is applicable to all gas-filled, gas-insulated and gas-impregnated bushings according to 3.5, 3.6 and 3.7.

9.7.2 Test method and requirements

The bushing, complete as for normal operation, shall be filled with gas at the choice of the supplier. A pressure of $(1,5 \times \text{maximum operating pressure}) \text{ bar} \pm 0,1 \text{ bar}$ shall be produced inside the bushing and maintained for 15 min at ambient temperature.

In the case of bushings where the insulating envelope is made of ceramic or composite material and intended to be operated under pressure, the unassembled insulating envelope shall be previously tested in accordance with IEC 62155 or IEC 61462 and IEC 62217, where appropriate. Other components should be tested to their appropriate standards.

NOTE It is allowed to remove the pressure relief devices during the test.

9.7.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of mechanical damage (e.g. deformation, rupture).

9.8 Tightness test on liquid-filled, compound-filled and liquid-insulated bushings

9.8.1 Applicability

The test is applicable to all liquid-filled or compound-filled and liquid-insulated bushings according to 3.2 and 3.4, except those bushings where the liquid filling has a viscosity equal to or greater than $5 \times 10^{-4} \text{ m}^2/\text{s}$ at 20 °C.

9.8.2 Test method and requirements

The bushing shall be assembled as for normal operation, filled with the liquid specified at ambient temperature of not less than 10 °C, except bushings for transformers, which shall be filled with the liquid having a minimum temperature of 60 °C. A pressure of 1 bar \pm 0,1 bar above the maximum operating pressure shall be applied inside the bushing as soon as possible after filling and maintained for at least 12 h.

For bushings with internal bellows, the pressure shall be stated by the supplier.

9.8.3 Acceptance

The bushing shall be considered to have passed the test if there is no evidence of leakage. The method of detection shall be as described in IEC 60068-2-17:1994, Clause C.2.

It is advisable to carry out a preliminary tightness test on components for which the test is considered useful. Special consideration may be necessary for bushings, one or both ends of which are intended to be immersed in a gaseous medium.

9.9 Tightness test on gas-filled, gas-insulated and gas-impregnated bushings

9.9.1 Applicability

The test is applicable to all gas-filled, gas-insulated and gas-impregnated bushings, according to 3.5 to 3.7 and 3.18 to 3.21.

For gas-insulated bushings, intended to form an integral part of gas-insulated equipment, and of which assembly is intended to be achieved on site, it is permitted to replace the tightness test on the assembled bushing by a tightness test on each component, completed by a tightness test on each sealing assembly. The sealing assembly method shall be agreed upon between purchaser and supplier.

9.9.2 Test method and requirements

The bushings shall be assembled as for normal operation and filled with gas at maximum operating pressure at ambient temperature. The bushing shall be enclosed in an envelope, for example a plastic bag. The concentration of gas in the air inside the envelope shall be measured twice at an interval equal to or greater than 2 h.

Alternative methods of leakage detection may be used by agreement between purchaser and supplier.

It is advisable to carry out a preliminary tightness test on such components as is considered useful.

9.9.3 Acceptance

The bushing shall be considered to have passed the test if the calculated escape of gas is equal to or less than 0,5 % per year of the equivalent amount of gas contained inside the bushing in service.

9.10 Tightness test at the flange or other fixing device

9.10.1 Applicability

The test is applicable to all partly or completely immersed bushings, according to 3.19 to 3.21 intended to be used as an integral part of an apparatus, such as switchgear or transformers, where the bushings contribute to the sealing of the complete apparatus.

The test shall be a type test only in the case of bushings with gaskets of which the final placing is not carried out by the supplier, for example the top cap gasket of draw-through conductor transformer bushings.

The test may be omitted for transformer bushings fitted with a one-piece metal flange, provided the flange has been subjected to a preliminary tightness test, and the bushing has passed the type test in accordance with 8.11 (for example oil-impregnated paper bushings) or the routine test in accordance with 9.8, or the end to be immersed does not include any gaskets.

9.10.2 Test method and requirements

The bushing shall be assembled at least as far as necessary for the test. The end for immersion shall be mounted on a tank as for normal operation at ambient temperature.

For liquid-immersed bushings, the tank shall be filled with air or any suitable gas at a relative pressure of $1,5 \text{ bar} \pm 0,1 \text{ bar}$ and maintained for 15 min, or with liquid at a relative pressure of $1 \text{ bar} \pm 0,1 \text{ bar}$ maintained for 12 h.

For gas-immersed bushings, the tank shall be filled with gas at maximum operating pressure at ambient temperature. The external part of the bushing shall be enclosed in an envelope, where necessary. Liquid-containing bushings shall remain empty and shall have an opening for free gas circulation within the envelope. The concentration of gas in the air inside the envelope shall be measured twice at an interval equal to or greater than 2 h.

9.10.3 Acceptance

An liquid-immersed bushing shall be considered to have passed the test if there is no evidence of leakage detected by visual inspection (see IEC 60068-2-17:1994, Clause C.2).

Gas-immersed bushings shall be considered to have passed the test, if:

- for all parts of a bushing where the leak gas escapes directly to the environment, the calculated total escape of gas is equal to or less than 0,5 % per year of the amount of gas contained in the adjacent switchgear compartment;
- for all parts of a liquid-containing bushing, especially liquid-insulated and oil-impregnated paper bushings, where the leak gas penetrates into the inside of the bushing, the calculated total leak rate (see 3.33) is equal to or less than $0,05 \text{ Pa} \times \text{cm}^3/\text{s} \times \text{l}$ ($5 \times 10^{-7} \text{ bar} \times \text{cm}^3/\text{s} \times \text{l}$), “l” being the quantity of liquid inside the bushing in litres;
- for all parts of a bushing, the other end of which is designed for a transformer, where the leak gas penetrates directly into the transformer, the calculated total leak rate (see 3.34) is equal to or less than $10 \text{ Pa} \times \text{cm}^3/\text{s}$ ($10^{-4} \text{ bar} \times \text{cm}^3/\text{s}$).

9.11 Visual inspection and dimensional check

9.11.1 Applicability

The inspections are applicable to all types of bushings and shall be made on the complete bushings before release. The visual inspection shall be made on each bushing.

9.11.2 Acceptance

No surface defects shall be tolerated which could affect the satisfactory performance in service.

Dimensions of parts for assembling and/or interconnection shall be in accordance with the relevant drawings, checked by sampling.

10 Requirements and tests for non-capacitance graded bushings of rated highest voltages for equipment up to and including 52 kV

10.1 General

This clause is applicable to all non-capacitance graded bushings including 3.4, 3.12 to 3.14.

10.2 Temperature requirements

Bushings that may be required to withstand the drying process of the apparatus on which they are mounted, shall be able to withstand a temperature of 140 °C for 12 h without mechanical or electrical damage, provided that no external forces are applied.

10.3 Level of immersion medium

For transformer bushings, the supplier shall specify the minimum depth of immersion medium.

10.4 Markings

Each bushing shall carry the following marking:

- supplier's name or trade mark;
- year of manufacture;
- type or minimum nominal creepage distance or highest voltage for equipment (U_m);

- rated current (I_r) or maximum current if the bushing is supplied without conductor.

It may sometimes be difficult to provide all the above markings on small bushings and, in this case, other markings may be agreed between supplier and purchaser.

An example of a marking plate is given in Figure 4.

10.5 Test requirements

10.5.1 General

The test conditions and requirements shall be equivalent to Clauses 7, 8 and 9. Reference is made in parenthesis to the relevant sub-clause.

10.5.2 Type tests

The following tests are applicable to all bushings:

- dry or wet power-frequency voltage withstand test (8.2);
- dry lightning impulse voltage withstand test (8.4);
- temperature rise test (8.8);
- verification of thermal short-time current withstand (8.9);
- cantilever load withstand test (8.10);
- verification of dimensions (8.14).

For bushings according to 3.22, precautions shall be taken to ensure that the end, which is designed to receive the movable part, will withstand the relevant test voltage, where applicable.

Table 10 – Applicability of type tests for bushings according to Clause 10 (see 10.5.1)

Short title	Applicable to bushing type	Bushing defined in subclause
AC dry	Indoor, outdoor immersed and completely immersed	3.12
AC wet	All outdoors	3.4, 3.12 to 3.14
Lightning	All	3.4, 3.12 to 3.14, 3.22
Temperature rise	All	3.4, 3.12 to 3.14, 3.22
Thermal short time	All, if calculated temperature is too high	3.4, 3.12 to 3.14, 3.22
Cantilever	All (reduced requirement for type defined in 3.22)	3.4, 3.12 to 3.14, 3.22
Dimensions	All	3.4, 3.12 to 3.14, 3.22

NOTE For fully dimensionally standardized bushing according to clause 3.4 with proven long service experience, type testing may be excluded.

10.5.3 Routine tests

The following tests are applicable to all bushings except for liquid-insulated bushings (3.4) and ceramic, glass or analogous inorganic material bushings (3.12), where only visual inspection and dimensional checks are applicable:

- dry power-frequency voltage withstand test (9.4);
- measurement of the partial discharge quantity (9.5);
- tests of tap insulation (9.6), if applicable;
- visual inspection and dimensional check (9.11).

Tables 10 and 11 show the applicability of the tests to the various types of bushings.

Table 11 – Applicability of routine tests for bushings according to Clause 10 (see 10.5.3)

Short title	Applicability to bushing type	Bushing defined in subclause
AC dry	All, except except for liquid-insulated bushings (3.4) and ceramic, glass or analogous inorganic material bushings (3.12)	3.13, 3.14, 3.22
Partial discharge	Ditto	3.13, 3.14, 3.22
Tap	Ditto, with a tap	3.13, 3.14, 3.22
Visual and dimensions	All	3.4, 3.12 to 3.14, 3.22

11 Recommendations for transport, storage, erection, operation and maintenance

11.1 General

It is essential that the transport, storage and installation of bushings, as well as their operation and maintenance in service, be performed in accordance with instructions given by the manufacturer.

Consequently, the manufacturer should provide instructions for the transport, storage, installation, operation and maintenance of bushings. The instructions for the transport and storage should be given at a convenient time before delivery, and the instructions for the installation, operation and maintenance should be given by the time of delivery at the latest.

It is impossible, here, to cover in detail the complete rules for the installation, operation and maintenance of each one of the different types of apparatus manufactured, but the following information is given relative to the most important points to be considered for the instructions provided by the manufacturer.

11.2 Conditions during transport, storage and installation

A special agreement should be made between manufacturer and user if the services conditions defined in the order, cannot be guaranteed during transport and storage. Special precautions may be essential for the protection of insulation during transport, storage and installation, and prior to energising, to prevent moisture absorption due, for instance, to rain, snow or condensation. Vibrations during transport should be considered. Appropriate instructions should be given.

Gas impregnated and gas-insulated bushings should be filled to a pressure sufficient to maintain positive pressure during transportation. A factory filling pressure of $1,3 \times 10^5$ Pa at 20 °C is appropriate for all temperature categories. If sulphur hexafluoride is used for filling the bushing during transportation it should comply with IEC 60376.

11.3 Installation

For each type of bushing the instructions provided by the manufacturer should at least include the items listed below.

11.4 Unpacking and lifting

Required Information for unpacking and lifting safely, including details of any special lifting and positioning devices necessary should be given.

At the arrival on site and before the final filling, the bushing should be checked according to the manufacturer instructions. For gas impregnated and gas insulated bushings, the gas pressure measured at ambient temperature should be above the atmospheric pressure.

11.5 Assembly

11.5.1 General

When the bushing is not fully assembled for transport, all transport units should be clearly marked. Drawings showing assembly of these parts should be provided with the bushing.

11.5.2 Mounting

Instructions for mounting of bushing, these instructions should indicate:

- the total mass of the bushing;
- the mass of the bushing (or heaviest part if to be assembled on site) if exceeding 100 kg;
- the centre of gravity.

The gas impregnated and gas insulated bushings should be filled with the specified gas, for example new sulphur hexafluoride complying with IEC 60376. The pressure of the gas at the end of filling, at the standard atmospheric air conditions (20 °C and 101,3 kPa), should be the rated filling pressure.

11.5.3 Connections

Instructions should include information on:

- connection of conductors, comprising the necessary advice to prevent overheating and unnecessary strain on the bushing and to provide adequate clearance distances;
- connection of any auxiliary circuits;
- connection of liquid or gas systems, if any, including size and arrangement of piping;
- connection for earthing.

11.5.4 Final installation inspection

Instruction should be provided for inspection and tests that should be made after the bushing has been installed and all connections have been completed.

These instructions should include:

- a schedule of recommended site tests to establish correct operation;
- procedures for carrying out any adjustment that may be necessary to obtain correct operation;
- recommendations for any relevant measurements that should be made and recorded to help with future maintenance decisions;
- instructions for final inspection and putting into service.

The results of the tests and inspection should be recorded in a commissioning report.

Gas impregnated and gas insulated bushings should be submitted to the following final checking:

- Measurement of gas pressure – the pressure of the gas measured at the end of filling and standard atmospheric air conditions (20 °C and 101,3 kPa) should be not less than the minimum functional pressure and not greater than the rated filling pressure of gas for insulation.

- Measurement of the dew point – the gas dew point at rated filling pressure should not exceed -5 °C when measured at 20 °C . Adequate corrections should be applied for measurement at the other temperatures.
- Enclosure tightness check – The check should be performed with the probing method for closed pressurised systems as specified for the routine test (see 9.9). The check should be started at least one hour after the filling of the bushing in order to reach a stabilised leakage flow. The check can be limited to gaskets, over pressure device, valves, terminals, manometers, temperature sensors, using a suitable leak detector.

11.6 Operation

The instructions given by the manufacturer should contain the following information:

- a general description of the equipment with particular attention to the technical description of its characteristics and all operation features provided, so that the user has an adequate understanding of the main principles involved;
- a description of the safety features of the equipment and their operation;
- as relevant, a description of the action to be taken to manipulate the equipment for maintenance and testing.

11.7 Maintenance

11.7.1 General

The effectiveness of maintenance depends mainly on the way instructions are prepared by the manufacturer and implemented by the user

11.7.2 Recommendation for the manufacturer

- a) The manufacturer should issue a maintenance manual including the following information:
 - 1) schedule maintenance frequency;
 - 2) detailed description of the maintenance work;
 - recommended place for the maintenance work (indoor, outdoor, in factory, on site, etc.);
 - procedures for inspection, diagnostic tests, examination, overhaul, function check out (e.g. limits of values and tolerances);
 - reference to drawings;
 - reference to part numbers (when applicable);
 - use of special equipment or tools (cleaning and degreasing agents);
 - precautions to be observed (e.g.; cleanliness).
 - 3) comprehensive drawings of the details of the bushing important for maintenance, with clear identification (part number and description) of assemblies, sub-assemblies and significant parts;
 - 4) list of recommended spare-parts (description, reference number quantities) and advice for storage;
 - 5) estimate of active scheduled maintenance time;
 - 6) how to proceed with the equipment at the end of its operating life, taking into consideration environmental requirements.
- b) The manufacturer should inform the users of a particular type of bushing about corrective actions required by possible systematic defects and failures.
- c) Availability of spares: The manufacturer should be responsible for ensuring the continued availability of recommended spare parts required for maintenance for a period not less than 10 years from the date of the final manufacture of the bushing.

11.7.3 Recommendations for the user

- a) If the user wishes to carry out his own maintenance, he should ensure that his staff has sufficient qualification as well as a detailed knowledge of the bushing.
- b) The user should record the following information:
 - the serial number and the type of bushing;
 - the date when the bushing is put in service;
 - the results of all measurements and tests including diagnostic tests carried out during the life of the bushing;
 - dates and extent of the maintenance work carried out;
 - the history of service, records of the bushing measurements during and following a special operating condition (e.g. fault and post fault operating state);
 - references to any failure report.
- c) In case of failure and defects, the user should make a failure report and should inform the manufacturer by stating the special circumstances and measures taken. Depending upon the nature of the failure, an analysis of the failure should be made in collaboration with the manufacturer.
- d) In case of disassembling for reinstallation in the future, the user must record the time and the storage conditions.

11.7.4 Failure report

The purpose of the failure report is to standardise the recording of bushing failures with the following objectives:

- to describe the failure using a common terminology;
- to provide data for the user statistics;
- to provide a meaningful feedback to the manufacturer;

The following gives guidance on how to make a failure report.

A failure report should include the following whenever such data is available:

- a) Identification of the bushing, which failed:
 - substation name;
 - identification of the bushing (manufacturer, type, serial number, ratings);
 - bushing family (oil, resin or SF6 insulation,);
 - location (indoor, outdoor).
- b) History of the Bushing:
 - history of the storage;
 - date of commissioning of the equipment
 - date of failure/defect;
 - date of last maintenance;
 - date of the last visual checking of the liquid level indicator
 - details of any changes made to the equipment since manufacture;
 - condition of the bushing when the failure/defect was discovered (in service, maintenance, etc.).
- c) Identification of the sub-assembly/component responsible for the primary failure/defect:
 - high-voltage stressed components;
 - tapping;

- other components.
- d) Stresses presumed contributing to the failure/defect
 - environmental conditions (temperature, wind, snow, ice, pollution, lightning, etc.);
 - grid conditions (switching operations, failure of other equipment...);
 - others.
- e) Classification of the failure/defect
 - major failure;
 - minor failure;
 - defect.
- f) Origin and cause of the failure/defect
 - origin (mechanical, electrical, tightness etc.);
 - cause in the opinion of the person having established the report (design, manufacture, inadequate instructions, incorrect mounting, incorrect maintenance, stresses beyond those specified, etc.).
- g) Consequences of the failures or defect
 - equipment down-time;
 - time consumption for repair;
 - labour cost;
 - spare parts cost.

A failure report may include the following information:

- drawings, sketches;
- photographs of defective components;
- single-line station diagram;
- records or plots;
- references to maintenance manual.

12 Safety

12.1 General

High-voltage equipment can be safe only when installed in accordance with the relevant installations rules, and used and maintained in accordance with the manufacturer's instructions.

High-voltage equipment is normally only accessible by instructed persons. It should be operated and maintained by skilled persons. When unrestricted access is available to bushings, additional safety features may be required.

The following specifications of this standard provide personal safety measures for equipment against various hazards:

12.2 Electrical aspects

- insulation of the isolating distance
- earthing (indirect contact)
- IP coding (direct contact)

12.3 Mechanical aspects

- pressurised components

- mechanical impact protection

12.4 Thermal aspects

- flammability

13 Environmental aspects

The need to minimise the impact of the natural environment of bushings during all phases of their life is now recognised.

IEC Guide 109 gives guidance in this respect in term of life cycle impacts and recycling and disposal at the end of life.

The manufacturer should specify information regarding the relation between operation during service life, dismantling of the equipment and environmental aspects.

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Annex A (informative)

Determination of the hottest spot in bushings with conductors embedded in the insulation material

The maximum conductor temperature θ_M is deduced by equations (A.1) and (A.2):

$$\theta_M = \frac{\left[3 \left(\frac{R_C}{R_A} \times \frac{1}{\alpha} + \theta_A \right) - \frac{3}{\alpha} - \theta_1 - \theta_2 \right]^2 - [\theta_1 \times \theta_2]}{3 \left[2 \left(\frac{R_C}{R_A} \times \frac{1}{\alpha} + \theta_A \right) - \frac{2}{\alpha} - \theta_1 - \theta_2 \right]} \quad (\text{A.1})$$

$$M = \left[3 \left(\frac{R_C}{R_A} \times \frac{1}{\alpha} + \theta_A \right) - \frac{3}{\alpha} - \theta_1 - \theta_2 \right] - \theta_M \quad (\text{A.2})$$

If the result M of equation (A.2) is positive, the higher temperature of the conductor is θ_M , and it is situated in any point of the conductor between the two extremities. If the result M is negative or zero, the higher temperature of the conductor is θ_2 .

The point of maximum conductor temperature lies at distance L_M from the cooler end.

$$L_M = \frac{L}{1 \pm \sqrt{\frac{\theta_M - \theta_2}{\theta_M - \theta_1}}} \quad (\text{A.3})$$

where

- α is the temperature coefficient of resistance at which conductor resistance R_A is measured;
- θ_1 is the measured temperature at the cooler end of the conductor, in degrees Celsius;
- θ_2 is the measured temperature at the hotter end of the conductor, in degrees Celsius;
- θ_A is the uniform reference temperature of the conductor, in degrees Celsius;
- θ_M is the maximum temperature of conductor, in degrees Celsius;
- L is the length of conductor;
- L_M is the distance from the cooler end of the conductor to the point of highest temperature;
- R_A is the resistance between the ends of the conductor at uniform temperature θ_A ;
- R_C is the resistance of the conductor carrying I_r after stabilisation of temperature.

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

**TRAVERSÉES ISOLÉES POUR TENSIONS
ALTERNATIVES SUPÉRIEURES À 1 000 V**

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La Norme internationale IEC 60137 a été établie par le sous-comité 36A: Traversées isolées, du comité d'études 36 de l'IEC: Isolateurs.

Cette septième édition annule et remplace la sixième édition parue en 2008. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- Ajout de traversées en matière synthétique imprégnée de résine (RIS – resin-impregnated synthetics).
- Ajout de traversées dont $U_m \leq 1,1$ kV, $U_m = 1\ 100$ kV et $U_m = 1\ 200$ kV.
- Intégration de l'essai d'échauffement pour les traversées à isolation liquide selon 3.4.

- Ajout de l'essai de choc de foudre à sec en tant qu'essai individuel de série pour toutes les traversées de transformateurs dont $U_m > 72,5$ kV.
- La procédure de correction d'altitude a été révisée ($> 1\ 000$ m).
- Ajout d'une explication sur le phénomène des transitoires très rapides (VFT – Very Fast transient) et sur leur impact sur les traversées.

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

FDIS	Rapport de vote
36A/187/FDIS	36A/189/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.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "<http://webstore.iec.ch>" dans les données relatives au document recherché. À cette date, le document sera

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- amendé.

Le contenu du corrigendum de mai 2018 a été pris en considération dans cet exemplaire.

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INTRODUCTION

L'élaboration de la présente édition de l'IEC 60137 a accordé une plus grande attention aux exigences d'essai pour les transformateurs de puissance spécifiées dans l'IEC 60076-3:2013.

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TRAVERSÉES ISOLÉES POUR TENSIONS ALTERNATIVES SUPÉRIEURES À 1 000 V

1 Domaine d'application

La présente Norme internationale spécifie les caractéristiques et les essais applicables aux traversées isolées.

La présente norme s'applique aux traversées, telles qu'elles sont définies à l'Article 3, destinées à être utilisées dans les dispositifs électriques, les machines, les transformateurs, les appareillages de connexion et les installations pour des systèmes à courant alternatif triphasé possédant une tension plus élevée pour le matériel dépassant 1 000 V et des fréquences industrielles comprises entre 15 Hz et 60 Hz (inclus).

Sous réserve d'un accord spécifique entre l'acheteur et le fournisseur, cette norme peut être appliquée, en partie ou en totalité, aux éléments suivants:

- traversées utilisées dans d'autres systèmes que ceux à courant alternatif triphasé;
- traversées pour les systèmes à courant continu haute tension;
- traversées pour les transformateurs d'essai;
- traversées pour les condensateurs.

Les exigences spéciales et les essais concernant les traversées de transformateurs spécifiées dans la présente norme s'appliquent également aux traversées pour bobines d'inductance.

La présente norme s'applique aux traversées fabriquées et commercialisées séparément. Il convient que les traversées qui font partie intégrante d'un appareillage, et qui ne peuvent être soumises à l'essai selon la présente norme, soient soumises à l'essai avec l'appareillage dont elles font 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 60038, *Tensions normales de la CEI*

IEC 60050-212:2010, *Vocabulaire Électrotechnique International – Partie 212: Isolants électriques solides, liquides et gazeux*

IEC 60059, *Caractéristiques des courants normaux de la CEI*

IEC 60060-1, *Technique des essais à haute tension – Partie 1: Définitions et exigences générales*

IEC 60068-2-17:1994, *Essais fondamentaux climatiques et de robustesse mécanique – Partie 2-17: Essais – Essai Q: Étanchéité*

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

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

IEC 60076-7, *Transformateurs de puissance – Partie 7: Guide de charge pour transformateurs immergés dans l'huile*

IEC 60216-2, *Matériaux isolants électriques – Propriétés d'endurance thermique – Partie 2: Détermination des propriétés d'endurance thermique de matériaux isolants électriques – Choix de critères d'essai*

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

IEC 60296, *Fluides pour applications électrotechniques – Huiles minérales isolantes neuves pour transformateurs et appareillages de connexion*

IEC 60376, *Spécifications de la qualité technique de l'hexafluorure de soufre (SF₆) pour utilisation dans les appareils électriques*

IEC 60422, *Huiles minérales isolantes dans les matériels électriques – Lignes directrices pour la maintenance et la surveillance*

IEC 60480, *Lignes directrices relatives au contrôle et au traitement de l'hexafluorure de soufre (SF₆) prélevé sur le matériel électrique et spécification en vue de sa réutilisation*

IEC 60505, *Évaluation et qualification des systèmes d'isolation électrique*

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 TS 60815-2, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 2: Ceramic and glass insulators for a.c. systems (disponible en anglais seulement)*

IEC TS 60815-3, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 3: Polymer insulators for a.c. systems (disponible en anglais seulement)*

IEC 61099, *Liquides isolants – Spécifications relatives aux esters organiques de synthèse neufs destinés aux matériels électriques*

IEC 61462, *Isolateurs composites creux – Isolateurs avec ou sans pression interne pour utilisation dans des appareillages électriques de tensions nominales supérieures à 1 000 V – Définitions, méthodes d'essais, critères d'acceptation et recommandations de conception*

IEC TS 61463, *Traversées – Qualification sismique*

IEC 62155:2003, *Isolateurs creux avec ou sans pression interne, en matière céramique ou en verre, pour utilisation dans des appareillages prévus pour des tensions nominales supérieures à 1 000 V*

IEC 62217, *Isolateurs polymériques à haute tension pour utilisation à l'intérieur ou à l'extérieur – Définitions générales, méthodes d'essai et critères d'acceptation*

IEC 62271-1, *Appareillage à haute tension – Partie 1: Spécifications communes*

Guide IEC 109, *Aspects liés à l'environnement – Prise en compte dans les normes électrotechniques de produits*

CISPR 16-1 (toutes les parties), *Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques*

CISPR 18-2, *Caractéristiques des lignes et des équipements à haute tension relatives aux perturbations radioélectriques – Partie 2: Méthodes de mesure et procédure d'établissement des limites*

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

traversée

dispositif servant à faire passer un ou plusieurs conducteurs à travers une paroi, telle qu'un mur ou une cuve, en isolant le(s) conducteur(s) de cette paroi; les moyens de fixation (bride ou autre dispositif) sur la paroi font partie de la traversée

Note 1 à l'article: Le conducteur peut être solidaire de la traversée ou démontable.

[SOURCE: IEC 60050-471:2007, 471-02-01]

3.2

traversée à remplissage de liquide

traversée dont l'espace entre la surface intérieure de l'enveloppe isolante et l'isolation solide principale est rempli d'huile minérale ou d'un autre liquide isolant

3.3

traversée à remplissage de mélange

traversée dont l'espace entre la surface intérieure de l'enveloppe isolante et l'isolation solide principale est rempli d'un mélange isolant

3.4

traversée à isolation liquide

traversée dont l'isolation principale est assurée par de l'huile minérale ou par un autre liquide isolant, délimitée par une enveloppe isolante

Note 1 à l'article: Ces traversées, souvent ouvertes, exigent un traitement approprié après installation afin d'éviter tout emprisonnement de l'air et les décharges partielles ultérieures lors d'essais ou en fonctionnement.

3.5

traversée à remplissage de gaz

traversée dont l'espace entre la surface intérieure de l'enveloppe isolante et l'isolation solide principale est rempli de gaz (autre que l'air ambiant) à une pression supérieure ou égale à la pression atmosphérique

Note 1 à l'article: Cette définition comprend les traversées destinées à faire partie intégrante d'un matériel à isolation gazeuse pour lequel le gaz du matériel communique avec celui de la traversée.

3.6

traversée à isolation gazeuse

traversée dont l'isolation principale est assurée par un gaz (autre que l'air ambiant) à une pression supérieure ou égale à la pression atmosphérique

Note 1 à l'article: Cette définition comprend les traversées destinées à faire partie intégrante d'un matériel à isolation gazeuse pour lequel le gaz du matériel communique avec celui de la traversée.

Note 2 à l'article: Une traversée qui comporte des matériaux isolants solides autres que l'enveloppe contenant le gaz (par exemple un support pour des couches conductrices ou un cylindre isolant) est une traversée à isolation composite (voir 3.14).

Note 3 à l'article: Une traversée dans laquelle la répartition de tension souhaitée est obtenue par la disposition de couches conductrices ou semi-conductrices incorporées au matériau isolant (par exemple film plastique) est désignée par une traversée à isolation gazeuse à répartition capacitive.

3.7

traversée à imprégnation gazeuse

traversée dont l'isolation principale est assurée par un corps enroulé en papier ou en film plastique (GIF) et ensuite traité et imprégné d'un gaz (autre que l'air ambiant) à une pression supérieure ou égale à la pression atmosphérique

Note 1 à l'article: Le corps est contenu dans une enveloppe isolante. L'espace entre le corps et l'enveloppe isolante est rempli du même gaz que celui employé pour l'imprégnation.

3.8

traversée en papier imprégné d'huile

OIP

traversée dont l'isolation principale est assurée par un corps enroulé en papier ultérieurement traité et imprégné d'un liquide isolant, généralement de l'huile minérale

Note 1 à l'article: Le corps est placé dans une enveloppe isolante, l'espace entre le corps et l'enveloppe isolante étant rempli du même liquide isolant que celui employé pour l'imprégnation.

Note 2 à l'article: L'abréviation «OIP» est dérivée du terme anglais développé correspondant «oil-impregnated paper».

3.9

traversée en papier enduit de résine

RBP

traversée dont l'isolation principale est assurée par un corps enroulé en papier enduit de résine

Note 1 à l'article: Lors de l'enroulement, chaque couche de papier est liée à la précédente par l'enduit de résine et la cohésion obtenue par le durcissement de la résine.

Note 2 à l'article: Une traversée en papier enduit de résine peut comporter une enveloppe isolante. Dans ce cas, l'espace intermédiaire peut être rempli d'un liquide isolant ou d'un autre milieu isolant.

Note 3 à l'article: L'abréviation «RBP» est dérivée du terme anglais développé correspondant «resin-bonded paper»

3.10

traversée en papier imprégné de résine

RIP

traversée dont l'isolation principale est assurée par un corps enroulé en papier non traité et ensuite imprégné de résine durcissable

Note 1 à l'article: Une traversée en papier imprégné de résine peut comporter une enveloppe isolante. Dans ce cas, l'espace intermédiaire peut être rempli d'un liquide isolant ou d'un autre milieu isolant.

Note 2 à l'article: L'abréviation «RIP» est dérivée du terme anglais développé correspondant «resin-impregnated paper».

3.11

traversée en matière synthétique imprégnée de résine RIS

traversée dont l'isolation principale est assurée par un corps enroulé en synthétique et ensuite imprégné de résine durcissable

Note 1 à l'article: Une traversée en matière synthétique imprégnée de résine peut comporter une enveloppe isolante. Dans ce cas, l'espace intermédiaire peut être rempli d'un liquide isolant ou d'un autre milieu isolant.

Note 2 à l'article: Sauf indication contraire du fabricant, les traversées conformes à 3.11 doivent être considérées comme des traversées RIP selon 3.10.

Note 3 à l'article: L'abréviation «RIS» est dérivée du terme anglais développé correspondant «resin-impregnated synthetics».

3.12

traversée en matière céramique, en verre ou en matière inorganique analogue

traversée dont l'isolation principale est assurée par de la céramique, du verre ou par une matière inorganique analogue

3.13

traversée à isolation en résine coulée ou moulée

traversée dont l'isolation principale est assurée par une matière organique coulée ou moulée avec ou sans addition d'une charge en matière inorganique

3.14

traversée à isolation combinée

traversée dont l'isolation principale est assurée par une association d'au moins deux isolants différents

3.15

traversée à répartition capacitive

traversée dans laquelle une répartition déterminée des potentiels est obtenue au moyen de couches conductrices ou semi-conductrices disposées dans le matériau isolant

[SOURCE: IEC 60050-471:2007, 471-02-03]

3.16

traversée d'intérieur

traversée dont les deux extrémités sont destinées à être dans l'air ambiant à la pression atmosphérique mais non soumises aux conditions atmosphériques extérieures

[SOURCE: IEC 60050-471:2007, 471-02-05]

3.17

traversée d'extérieur

traversée dont les deux extrémités sont destinées à être dans l'air ambiant à la pression atmosphérique et soumises aux conditions atmosphériques extérieures

[SOURCE: IEC 60050-471:2007, 471-02-07]

3.18

traversée d'extérieur-intérieur

traversée dont les deux extrémités sont destinées à être dans l'air ambiant à la pression atmosphérique. L'une est destinée à être soumise aux conditions atmosphériques extérieures et l'autre ne l'est pas

[SOURCE: IEC 60050-471:2007, 471-02-09]

3.19**traversée immergée d'intérieur**

traversée dont l'une des extrémités est destinée à être dans l'air ambiant mais non soumise aux conditions atmosphériques extérieures et l'autre à l'immersion dans un milieu isolant autre que l'air ambiant (par exemple, liquide ou gaz)

Note 1 à l'article: Cette définition comprend les traversées utilisées dans l'air à une température supérieure au milieu ambiant, comme cela se produit avec les conduits isolés à l'air.

[SOURCE: IEC 60050-471:2007, 471-02-06]

3.20**traversée immergée d'extérieur**

traversée dont l'une des extrémités est destinée à être dans l'air ambiant et soumise aux conditions atmosphériques extérieures et l'autre à l'immersion dans un milieu isolant autre que l'air ambiant (par exemple liquide ou gaz)

[SOURCE: IEC 60050-471:2007, 471-02-08]

3.21**traversée immergée totalement**

traversée dont les deux extrémités sont destinées à l'immersion dans un milieu isolant autre que l'air ambiant (par exemple liquide ou gaz)

[SOURCE: IEC 60050-421:2007, 471-02-04]

3.22**traversée de type embrochable**

traversée pour connecteur séparable

traversée dont l'une des extrémités est immergée dans un milieu isolant et l'autre conçue pour recevoir un connecteur séparable de câble isolé sans lequel la traversée ne peut pas fonctionner

[SOURCE: IEC 60050-471:2007, 471-02-02]

3.23**tension la plus élevée pour le matériel**

U_m

valeur efficace la plus élevée de la tension entre phases pour laquelle le matériel est spécifié en ce qui concerne son isolement ainsi que certaines autres caractéristiques qui sont rattachées à cette tension dans les normes de matériel applicables

[SOURCE: IEC 60050-614:2016, 614-03-01]

3.24**tension phase-terre assignée**

valeur efficace maximale de la tension que la traversée supporte en permanence entre son conducteur intérieur et sa bride ou autre dispositif de fixation mis à la terre, dans les conditions de service spécifiées à l'Article 5

3.25**courant assigné**

I_r

valeur efficace maximale du courant par lequel le conducteur de la traversée peut être parcouru en service continu, dans les conditions de service spécifiées à l'Article 5, sans que l'échauffement excède les limites données dans le Tableau 2

3.26**courant thermique de courte durée assigné** I_{th}

valeur efficace du courant symétrique que la traversée supporte thermiquement pendant la durée assignée (t_h), immédiatement après un service permanent au courant assigné, avec des températures maximales de l'air ambiant et des milieux d'immersion conformes à 5.3

3.27**courant dynamique assigné** I_d

valeur de crête du courant que la traversée supporte mécaniquement

3.28**échauffement**

différence entre la température mesurée au point le plus chaud des pièces métalliques de la traversée en contact avec un matériau isolant et la température de l'air ambiant (voir 4.8)

3.29**fréquence assignée** f_r

fréquence à laquelle la traversée est destinée à fonctionner

[SOURCE: IEC 60050-421:1990, 421-04-03, modifiée (remplacement de «le transformateur ou la bobine d'inductance» par «la traversée»)]

3.30**pression assignée de remplissage du gaz isolant**

pression en pascal (Pa) pour l'isolement, rapportée aux conditions atmosphériques normales de +20 °C et 101,3 kPa (ou densité), qui peut être exprimée en termes relatifs ou absolus, à laquelle la traversée est remplie avant sa mise en service, ou regarnie automatiquement

3.31**pression maximale interne de service du gaz**

pression, lorsque la traversée est en service et parcourue par le courant assigné, aux températures maximales, conformément à 5.3

3.32**pression maximale externe de service du gaz**

pression maximale du milieu gazeux isolant dans lequel la traversée est immergée partiellement ou totalement lorsqu'elle est en service

3.33**pression de calcul** (de l'enveloppe)

pression utilisée pour déterminer l'épaisseur de l'enveloppe

3.34**taux de fuite** (des traversées à remplissage de gaz, à isolation gazeuse, à imprégnation gazeuse et à immersion gazeuse)

quantité de gaz sec, à une température donnée, qui traverse une fuite par unité de temps et pour une valeur connue de la différence de pression à travers la fuite

Note 1 à l'article: L'unité de base du taux de fuite dans le système SI est le «pascal x mètre cube par seconde ($\text{Pa} \times \text{m}^3/\text{s}$)». Les unités dérivées « $\text{Pa} \times \text{cm}^3/\text{s}$ » et « $\text{bar} \times \text{cm}^3/\text{s}$ » sont utilisées dans la présente norme, du fait qu'elles correspondent mieux aux ordres de grandeur employés dans la pratique industrielle courante. Il convient de rappeler que: $1 \text{ Pa} \times \text{m}^3/\text{s} = 10^6 \text{ Pa} \times \text{cm}^3/\text{s} = 10 \text{ bar} \times \text{cm}^3/\text{s}$.

[SOURCE: IEC 60068-2-17:1994, 1.1)

3.35**isolateur creux**

isolateur creux, ouvert de part en part, muni ou non d'ailettes

Note 1 à l'article: Une enveloppe isolante peut être constituée d'un dispositif d'isolation ou de deux ou plusieurs dispositifs d'isolation assemblés d'une façon permanente.

[SOURCE: IEC 60050-471:2007, 471-01-8, modifiée (suppression de «incluant les armatures d'extrémité», Note 1 à l'article modifiée)]

3.36**ligne de fuite**

distance la plus courte, le long de la surface d'un isolateur, entre deux parties conductrices

Note 1 à l'article: La surface du ciment ou de toute autre matière de scellement non isolante n'est pas considérée comme faisant partie de la ligne de fuite.

Note 2 à l'article: Si un revêtement à haute résistance est appliqué sur certaines parties isolantes d'un isolateur, ces parties sont considérées comme surfaces isolantes effectives et la distance mesurée à la surface de ces parties est incluse dans la ligne de fuite.

[SOURCE: IEC 60050-471:2007, 471-01-04]

3.37**distance d'arc**

plus courte distance dans l'air à l'extérieur de l'isolateur entre les parties métalliques sur lesquelles on applique normalement la tension de service

Note 1 à l'article: Les termes «distance d'arc à sec» ou «distance sur fil tendu» sont également utilisés.

Note 2 à l'article: La distance d'arc peut être plus courte que les valeurs applicables aux distances d'isolement dans l'air indiquées dans l'IEC 60076-3.

[SOURCE: IEC 60050-471:2007, 471-01-01, modifiée (ajout de Notes à l'article)]

3.38**prise de mesure****prise de dimensions****prise de tan δ**

connexion accessible de l'extérieur de la traversée, isolée de la bride ou autre dispositif de fixation, reliée à une des couches conductrices extérieures d'une traversée à répartition capacitive pour permettre des mesures du facteur de dissipation, de la capacité et des décharges partielles, lorsque la bride de la traversée est reliée à la terre

Note 1 à l'article: Il convient de mettre cette connexion directement à la terre lorsqu'elle n'est pas employée.

Note 2 à l'article: Lorsque la prise de mesure est utilisée pour une surveillance d'état, en fonctionnement, il convient de veiller à éviter un circuit ouvert.

3.39**prise de tension****prise de potentiel****prise capacitive**

connexion accessible de l'extérieur de la traversée, isolée de la bride ou autre dispositif de fixation, reliée à une des couches conductrices extérieures d'une traversée à répartition capacitive de façon à obtenir une source de tension lorsque la traversée est en service

Note 1 à l'article: Il convient de mettre cette connexion directement à la terre lorsqu'elle n'est pas employée.

Note 2 à l'article: Cette prise peut être également employée pour mesurer le facteur de dissipation, la capacité et les décharges partielles.

3.40**tension assignée de la prise de tension**

tension maximale pour laquelle la prise est conçue en vue d'alimenter le matériel qui lui est associé, lorsqu'elle est connectée à la charge assignée et lorsque la traversée est soumise à sa tension phase-terre assignée à la fréquence nominale

3.41**traversée composite**

traversée possédant une enveloppe isolante constituée d'un tube de fibres imprégnées de résine avec ou sans revêtement en mélange polymère

Note 1 à l'article: Pour les traversées définies de 3.9 à 3.13, le mélange polymère peut être appliqué directement sur l'isolation principale de la traversée.

3.42**capacité (de traversée)****3.42.1****capacité principale C_1**

capacité d'une traversée à répartition capacitive entre le conducteur haute tension et la prise de mesure ou la prise de tension

3.42.2**capacité de prise C_2**

capacité d'une traversée à répartition capacitive entre la prise de mesure ou la prise de tension et la collerette de montage

3.42.3**capacité C**

capacité d'une traversée sans prise de tension ou prise de mesure entre le conducteur haute tension et la collerette de montage

4 Caractéristiques assignées**4.1 Tension assignée la plus élevée pour le matériel (U_m)**

Les valeurs de U_m d'une traversée doivent être choisies parmi les valeurs de la tension la plus élevée pour le matériel, définies dans l'IEC 60038 et indiquées ci-après, en kilovolts:

3,6 – 7,2 – 12 – 17,5 – 24 – 36 – 52 – 72,5 – 100 – 123 – 145 – 170 – 245 – 300 – 362 – 420 – 550 – 800 – 1 100 – 1 200 kV.

NOTE La tension phase-terre assignée est $U_m / \sqrt{3}$ pour les réseaux triphasés normaux.

4.2 Courant assigné (I_r)

Les valeurs de I_r d'une traversée doivent être choisies parmi les valeurs indiquées ci-après, en ampères:

100 – 250 – 315 – 400 – 500 – 630 – 800 – 1 000 – 1 250 – 1 600 – 2 000 – 2 500 – 3 150 – 4 000 – 5 000 – 6 300 – 8 000 – 10 000 – 12 500 – 16 000 – 20 000 – 25 000 – 31 500 – 40 000 A.

La série de courants susmentionnée est conforme aux valeurs indiquées dans l'IEC 60059.

Dans le cas des traversées de transformateurs avec le conducteur introduit dans le tube central (conducteur démontable), le fournisseur doit indiquer la valeur de la section efficace,

le diamètre maximum, le matériau du conducteur, ainsi que le matériau et l'épaisseur d'isolation, correspondant à I_r , conformément à 4.8.

Les traversées de transformateurs dont I_r est au moins égal à 120 % du courant assigné du transformateur, et dont la température maximale et la température moyenne quotidienne maximale sont conformes au Tableau 4, sont considérées comme étant capables de supporter les surcharges conformes à l'IEC 60076-7 sans d'autres éclaircissements ou essais.

4.3 Courant thermique de courte durée assigné (I_{th})

Sauf spécification contraire, la valeur de I_{th} doit être de 25 fois I_r , t_{th} étant de 1 s. Dans le cas des traversées pour lesquelles I_r est supérieur ou égal à 4 000 A, I_{th} doit toujours être de 100 kA.

Dans le cas des traversées de transformateurs, t_{th} doit être de 2 s, sauf spécification contraire, conformément à l'IEC 60076-5.

Pour des durées de t_{th} supérieures à 1 s, par hypothèse, la relation entre le courant et le temps est conforme à

$$I_{th}^2 \times t_{th} = \text{constante}$$

Dans le cas des traversées de transformateurs pour lesquelles le conducteur est introduit dans le tube central, la section efficace du conducteur correspondant au courant de fonctionnement peut être inférieure à celle indiquée en 4.2. Dans un tel cas, il convient que le courant de fonctionnement et la section efficace soient conformes aux exigences de 8.8.

4.4 Courant dynamique assigné (I_d)

La valeur normale de I_d doit avoir une amplitude de la première crête égale à 2,5 fois la valeur de I_{th} conformément à 4.3.

Dans certains cas, des valeurs supérieures à 2,5 fois la valeur de I_{th} indiquée en 4.3 peuvent être nécessaires en fonction des caractéristiques du transformateur. Il convient que le fabricant du transformateur stipule de telles exigences dans les renseignements à fournir lors de la commande des traversées (voir 6.1.4).

4.5 Valeurs minimales de la tenue à la charge de flexion

Les traversées doivent supporter la charge de flexion donnée dans le Tableau 1, Niveau I ou II. Le Niveau I est une charge normale et doit généralement être appliqué, sauf si l'acheteur spécifie une charge plus sévère de Niveau II.

Tableau 1 – Valeurs minimales de la tenue à la charge de flexion (voir 4.5 et 8.10)

Tension la plus élevée pour le matériel (U_m) kV	Courant assigné A							
	≤ 800	1 000	2 000	≥ 3 150	1 600	2 500		
	Charge de flexion de service N							
	Traversée installée ≤ 30° par rapport à la verticale							
	I	II	I	II	I	II	I	II
≤ 36	500	500	625	625	1 000	1 000	1 575	1 575
52	500	800	625	800	1 000	1 250	1 575	1 575
72,5 à 100	500	1 000	625	1 000	1 000	1 575	2 000	2 000
123 à 145	625	1 575	800	1 575	1 250	2 000	2 000	2 000
170 à 245	625	2 000	800	2 000	1 250	2 500	2 000	2 500
≥ 300	1 250	2 000	1 250	2 000	1 575	2 500	2 500	2 500
	Charge d'essai de flexion N							
	I	II	I	II	I	II	I	II
≤ 36	1 000	1 000	1 250	1 250	2 000	2 000	3 150	3 150
52	1 000	1 600	1 250	1 600	2 000	2 500	3 150	3 150
72,5 à 100	1 000	2 000	1 250	2 000	2 000	3 150	4 000	4 000
123 à 145	1 250	3 150	1 600	3 150	2 500	4 000	4 000	4 000
170 à 245	1 250	4 000	1 600	4 000	2 500	5 000	4 000	5 000
≥ 300	2 500	4 000	2 500	4 000	3 150	5 000	5 000	5 000

Les charges de flexion de service comprennent l'effort sur les bornes et la pression du vent (70 Pa), se reporter à l'IEC TS 61463.

Pour les traversées fonctionnant avec un angle > 30° par rapport à la verticale, il convient de prendre en compte l'effet du propre poids de la traversée lors de la sélection de la charge et de la procédure d'essai. Les valeurs données ci-dessus correspondent à des traversées verticales, qui doivent être soumises à l'essai en position verticale. Lorsqu'une traversée inclinée ou horizontale doit être soumise à l'essai verticalement, il convient alors d'ajouter une force équivalente pour réaliser le moment de flexion au niveau de la bride, du fait du poids de la traversée dans sa position de fonctionnement. Si une traversée verticale doit être soumise à l'essai horizontalement, la charge d'essai peut alors être réduite de la même manière.

Niveau I = charge normale, Niveau II = charge élevée.

Pour les traversées pour lesquelles les enveloppes isolantes supérieure et inférieure sont montées par effort de serrage sur le conducteur de fixation central, il est recommandé de choisir la charge d'essai de flexion en tenant compte de la dilatation thermique du conducteur due au passage du courant assigné.

4.6 Angle de montage

Toutes les traversées doivent être conçues pour un montage avec un angle d'inclinaison ne dépassant pas 30° par rapport à la verticale. Tout autre angle de montage doit faire l'objet d'un accord entre l'acheteur et le fournisseur.

NOTE Une traversée fonctionnant avec un angle d'inclinaison inférieur ou égal à 30° par rapport à la verticale est considérée comme verticale. Une traversée fonctionnant avec un angle d'inclinaison supérieur ou égal à 70° par rapport à la verticale est considérée comme horizontale. Une traversée fonctionnant avec tout autre angle est considérée comme étant inclinée (voir 6.1.5).

4.7 Ligne de fuite nominale minimale

Sauf accord contraire entre l'acheteur et le fournisseur, ou à moins d'une démonstration par essai, la ligne de fuite pour les enveloppes isolantes doit être conforme à l'IEC TS 60815-2 ou à l'IEC TS 60815-3.

Si des essais sous pollution artificielle sont nécessaires, ils doivent être effectués conformément à l'IEC 60507.

NOTE 1 La valeur réelle de la ligne de fuite peut être nettement supérieure, mais non inférieure, à la valeur indiquée dans l'IEC 62155.

NOTE 2 L'IEC TS 60815-1 définit la ligne de fuite spécifique unifiée comme la ligne de fuite totale divisée par la tension phase-terre de fonctionnement la plus élevée selon 3.24. La tension entre phases permettait précédemment de calculer la ligne de fuite spécifique. Cela signifie que le rapport entre les deux valeurs de ligne de fuite est de $\sqrt{3}$.

4.8 Limites de température et échauffement

Les limites de température des pièces métalliques en contact avec le matériau isolant dans les conditions de service normales sont les suivantes:

- 105 °C pour le papier imprégné d'huile: Classe A;
- 120 °C pour le papier enduit de résine ou imprégné de résine, ainsi que la matière synthétique imprégnée de résine: Classe E;
- 130 °C pour l'isolation gazeuse: Classe B.

L'échauffement au-dessus de la température maximale journalière moyenne de l'air ambiant conforme à 5.3 (30 °C), du point le plus chaud, ne doit pas dépasser les valeurs données dans le Tableau 2. Dans le cas d'autres matériaux isolants, les limites de température doivent être spécifiées par le fournisseur. Il doit être fait référence à l'IEC 60216-2 et à l'IEC 60505.

Pour les bornes et les connexions des traversées, les limites d'échauffement sont également données dans le Tableau 2.

Les traversées faisant partie intégrante d'un appareil, tel qu'un appareillage de connexion ou des transformateurs, doivent satisfaire aux exigences thermiques de l'appareil pris en considération. Pour les traversées de transformateurs, il doit être fait référence à 4.2.

La température de l'air ambiant et celle des milieux d'immersion sont définies dans le Tableau 4.

Dans le cas des traversées fonctionnant dans des transformateurs de puissance immergés dans du liquide utilisant des matériaux isolants haute température conformément à l'IEC 60076-14, les limites de température des traversées doivent être convenues entre les parties concernées.

Pour les joints d'étanchéité en contact avec les parties métalliques, il convient d'accorder une attention particulière à la capacité du matériel à supporter l'échauffement.

4.9 Niveaux d'isolement

Les valeurs du niveau d'isolement doivent être choisies dans le Tableau 3.

Les valeurs spécifiées du niveau d'isolement sont conformes à l'IEC 60038 et à l'IEC 60071-1.

Tableau 2 – Valeurs maximales de la température et de l'échauffement au-dessus de la température de l'air ambiant (voir 4.8)

Description du composant		Échauffement maximal K	Température maximale °C	Commentaires ^a
Contacts à ressort	Cuivre et alliages en cuivre, nus:			d
	– dans l'air	45	75	
	– dans le SF ₆	65	95	b
	– dans l'huile	50	80	
	Étamés, dans l'air, dans le SF ₆ ou dans l'huile ^f	60	90	
	Argentés ou nickelés:			
– dans l'air ou dans le SF ₆	75	105	b	
– dans l'huile	65	95		
Contacts vissés	Cuivre, aluminium et leurs alliages, nus:			
	– dans l'air	60	90	
	– dans le SF ₆	75	105	b
	– dans l'huile	70	100	
	Étamés: ^f			
	– dans l'air ou dans le SF ₆	75	105	b
	– dans l'huile	70	100	
	Argentés ou nickelés:			
	– dans l'air ou dans le SF ₆	85	115	b
	– dans l'huile	70	100	
Bornes à raccorder à des conducteurs extérieurs par des vis ou des boulons	Cuivre, aluminium et leurs alliages:			
	– nues	60	90	c
	– étamées ^f	75	105	
	– argentées ou nickelées	75	105	
Pièces métalliques conductrices et non conductrices en contact avec	Classe d'isolation:			
	– A (OIP)	75	105	
	– E (RBP, RIP, RIS)	90 ^e	120 ^e	
	– (GIF)			
	– SF ₆	100	130	
	– Huile	85	115	b, g
		110	140	h

^a Les valeurs d'échauffement sont basées sur l'IEC 60943 avec une température maximale journalière moyenne de 30 °C. Pour d'autres informations, il convient de se référer au Tableau 6 de l'IEC 60943.

^b L'huile mentionnée dans le tableau ci-dessus fait référence à l'huile minérale. Pour les autres liquides isolants (par exemple, silicone, ester naturel ou synthétique), des valeurs plus élevées peuvent faire l'objet d'un accord entre l'acheteur et le fournisseur.

^c S'il doit se produire une forte oxydation, l'échauffement doit être limité à 50 K.

^d Un contact à ressort est une connexion maintenue par la pression d'un ressort, par exemple un contact embrochable.

^e Les limites de température doivent être indiquées par le fournisseur.

^f La température des contacts étamés ne doit pas dépasser la température maximale indiquée de 105 °C. Dans le cas contraire, une destruction très rapide ou immédiate se produit.

^g Applicable aux traversées à isolation liquide selon 3.4.

^h Applicable aux traversées de transformateurs avec un conducteur (solide ou flexible) introduit dans le tube central.

NOTE A et E font référence à la classe thermique conformément à l'IEC 60085.

Tableau 3 – Niveaux d'isolement pour la tension la plus élevée pour le matériel (U_m)
(voir 4.9, 8.2, 8.4, 8.5, 9.3 et 9.4)

Tension la plus élevée pour le matériel U_m	Tension de tenue assignée aux chocs de foudre (BIL)	Tension de tenue assignée aux chocs de manœuvre (SIL)	Tension de tenue à fréquence industrielle ^f			
			kV (valeur efficace)			
kV (valeur efficace)	kV (valeur de crête)	kV (valeur de crête)	Traversées de transformateurs ^a	Traversées GIS ^b (à sec)	Autres traversées ^c (à sec)	Toutes les traversées ^d (sous pluie)
≤ 1,1	20		10		10	10
3,6	40		11		10	10
7,2	60		22		20	20
12	75		30		28	28
17,5	95		42		38	38
24	125		55		50	50
36	170		77		70	70
52	250		105		95	95
72,5	325		155		140	140
100	380		165		150	150
	450		205		185	185
123	450		205		185	185
	550		255		230	230
145	450		205		185	185
	550		255		230	230
	650		305		275	275
170	550		255		230	230
	650		305		275	275
	750		355	325	325	325
245	950	650	435	435	395	395
		750				
		850				
	1 050	750	505	460	460	460
300	1 050	850	505	460	460	-
		950	505	460	460	-
362	1 175	950	560	520	510	-
		950	560	520	510	-
420	1 300	1 050	625	595	570	-
		1 050	695	650	630	-
		1 175	750	-	680	-
550 ^e	1 425	1 050	695	650	630	-
		1 175				
	1 550	1 175	750	710	680	-
		1 175	750	-	680	-
800 ^e	1 800	1 300	870	830	790	-
		1 425				-
		1 550				-
	1 950	1 550	915	960	830	-

Tension la plus élevée pour le matériel U_m	Tension de tenue assignée aux chocs de foudre (BIL)	Tension de tenue assignée aux chocs de manœuvre (SIL)	Tension de tenue à fréquence industrielle ^f			
			Traversées de transformateurs ^a	Traversées GIS ^b (à sec)	Autres traversées ^c (à sec)	Toutes les traversées ^d (sous pluie)
kV (valeur efficace)	kV (valeur de crête)	kV (valeur de crête)	kV (valeur efficace)			
	2 100	1 425	970	960	880	-
	2 400	1 550	1 075	960	975	-
1 100	2 250	1 800	1 200 ^g	1 100	-	-
	2 400	1 950				
1 200	2 250	1 800	1 320 ^g	1 200	-	-
	2 550	1 950				

^a Valeurs conformes à l'IEC 60071-1 et à l'IEC 60076-3, augmentées de 10 %, conformément à 9.3.

^b Valeurs conformes à l'IEC 62271-1.

^c Valeurs conformes à l'IEC 60071-1 et à l'IEC 62271-1.

^d Valeurs conformes à l'IEC 60071-1.

^e Les valeurs de la tension la plus élevée pour chaque matériel sont conformes à l'Amendement 2 (1997) de l'IEC 60038.

^f Les tensions de tenue à fréquence industrielle indiquées sont les valeurs minimales exigées basées sur le BIL du système ou du matériel auquel la traversée est appliquée. Pour les applications de transformateurs dans lesquelles une traversée est choisie avec une classe de BIL plus élevée, la traversée peut être soumise à l'essai conformément à la colonne 6, à condition que l'exigence d'une tension d'essai de tenue à fréquence industrielle de 10 % supérieure à celle de son transformateur soit satisfaite.

^g La durée d'essai doit être de 300 s conformément à l'IEC 60076-3.

4.10 Prise de mesure des traversées de transformateurs

Une prise de mesure conforme à 3.38 doit être fournie sur toutes les traversées de transformateurs à répartition capacitive selon 3.15. Afin de pouvoir utiliser la prise de mesure pour les mesurages des décharges partielles sur les transformateurs, les valeurs qui lui sont applicables ne doivent pas dépasser:

- une capacité à la terre de 10 000 pF;
- un facteur de dissipation diélectrique ($\tan \delta$) de 0,05 mesuré à la fréquence industrielle.

Les autres valeurs de capacité à la terre de la prise de mesure peuvent être déterminées par accord entre l'acheteur et le fournisseur.

La traversée ne doit pas comprendre de capacités importantes à la terre qui peuvent dériver le courant dû aux décharges partielles et rendre ainsi incorrects ou erronés les mesurages des décharges partielles sur le transformateur.

5 Conditions de service

5.1 Surtensions temporaires

La tension maximale phase-terre du système peut dépasser U_m divisée par $\sqrt{3}$. Pour les durées ne dépassant pas 8 h par période de 24 h et dont la durée totale ne dépasse pas 125 h par an, les traversées doivent pouvoir supporter une tension phase-terre de

- U_m pour les traversées dont U_m est inférieure ou égale à 170 kV;

- $0,8 U_m$ pour les traversées dont U_m est supérieure à 170 kV.

Dans les réseaux avec lesquels des surtensions supérieures à cette valeur peuvent se présenter, il est conseillé de choisir une traversée avec une valeur de U_m plus élevée.

5.2 Altitude

Bien que le niveau d'isolement fasse référence au niveau de la mer, les traversées qui correspondent à la présente norme sont déclarées adaptées à une utilisation à toute altitude ne dépassant pas 1 000 m. Pour s'assurer que les tensions de tenue extérieures de la traversée sont suffisantes à des altitudes supérieures à 1 000 m, la distance d'arc normalement nécessaire doit être augmentée selon une valeur appropriée. Il n'est pas nécessaire d'adapter l'épaisseur radiale de l'isolation ni la dimension de l'extrémité immergée. La tension de perforation et la tension de contournement dans le milieu d'immersion d'une traversée ne sont pas affectées par l'altitude.

Pour des installations à une altitude supérieure à 1 000 m, la distance d'arc dans les conditions atmosphériques normales de référence doit être déterminée afin de résister aux tensions obtenues en multipliant les tensions de tenue exigées à l'emplacement de service par un facteur k_a .

$$k_a = e^{m \frac{(H-1000)}{8150}}$$

où

H est l'altitude (en mètres), ne dépassant pas 4 000 mètres.

$m = 1$ pour la tension de tenue aux chocs de foudre

$m = 1$ pour la tension de tenue à fréquence industrielle pour laquelle $U_m \leq 245$ kV. Une correction d'altitude n'est pas applicable pour des valeurs U_m plus élevées, étant donné que les traversées sont soumises à l'essai avec des chocs de manœuvre ayant déjà fait l'objet d'une correction d'altitude.

m est conforme à la Figure 1 pour la tension de tenue aux chocs de manœuvre.



Figure 1 – Facteur *m* de la tension de tenue aux chocs de manœuvre de coordination

Une distance d'arc augmentée effectivement basée sur une distance d'arc vérifiée peut être considérée comme valable sans essai supplémentaire.

5.3 Température de l'air ambiant et des milieux d'immersion

Les traversées doivent être conçues pour être utilisées à des températures qui ne dépassent pas les limites données dans le Tableau 4. Il convient de prendre en compte les conditions de service en dehors des limites données dans le Tableau 4, ainsi que leur influence sur le courant assigné. Exemples de traversées de ce type: traversées immergées totalement, traversées fonctionnant dans des conditions d'air ambiant à température élevée ou traversées fonctionnant dans des conduits isolés à l'air.

La condensation d'humidité à la surface de la partie de la traversée située à l'intérieur doit être évitée, si nécessaire par ventilation ou par chauffage.

Tableau 4 – Température de l'air ambiant et des milieux d'immersion

Sujet	Température °C
Air ambiant: <ul style="list-style-type: none"> – maximale – maximale journalière moyenne (en plein air) – maximale journalière moyenne (dans des conduits isolés à l'air) – maximale annuelle moyenne – minimale <ul style="list-style-type: none"> • Traversées d'intérieur ^a • Traversées d'extérieur ^a 	40 30 70 20 -5 -15 -25 -10 -25 -40
Huile minérale dans les transformateurs: <ul style="list-style-type: none"> – maximale <ul style="list-style-type: none"> • pour un régime de charge normal ^b • pour un régime de charge de secours de courte et de longue durée ^b – maximale journalière moyenne 	100 115 90
Autres milieux: (gazeux et non gazeux)	^c
^a Sauf indication contraire, la température minimale de l'air ambiant est de -5 °C pour les traversées d'intérieur et de -25 °C pour les traversées d'extérieur.	
^b Les valeurs applicables aux transformateurs sont conformes à l'IEC 60076-1 et à l'IEC 60076-2 et sont associées à l'huile minérale. Pour les autres liquides isolants (par exemple, silicone, ester naturel ou synthétique), des valeurs plus élevées peuvent faire l'objet d'un accord entre l'acheteur et le fournisseur. Les valeurs applicables au régime de charge de secours de courte et de longue durée sont conformes à l'IEC 60076-7.	
^c En l'absence d'autres informations, il convient en principe de se référer à la norme d'appareils IEC correspondante pour laquelle la traversée est prévue. Il convient par ailleurs d'accorder une attention particulière aux traversées dont une des extrémités doit être immergée dans le gaz.	
NOTE 1 Il convient de calculer la température journalière moyenne du milieu d'immersion par un calcul de la moyenne de 24 relevés horaires consécutifs.	
NOTE 2 D'autres plages de températures peuvent être adoptées par un accord entre l'acheteur et le fournisseur.	

5.4 Conditions sismiques

Il convient de se référer à l'IEC TS 61463 lorsque la qualification sismique est exigée.

5.5 Transitoires très rapides (VFT – very fast transients)

Dans le cas de contraintes transitoires inhabituelles observées dans les traversées à répartition capacitive connectées à des appareillages de connexion à isolation gazeuse, des analyses particulières peuvent être convenues entre l'acheteur et le fournisseur afin de prendre en compte le comportement des traversées.

La signification des essais est avérée uniquement tant que toutes les parties concernées appréhendent les limites dans lesquelles le dispositif d'essai simule au mieux les conditions de service.