

INTERNATIONAL STANDARD



Insulated bushings for alternating voltages above 1 000 V



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IEC 60137

Edition 7.0 2017-06
REDLINE VERSION

INTERNATIONAL STANDARD



Insulated bushings for alternating voltages above 1 000 V

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.080.20

ISBN 978-2-8322-4517-0

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INSULATED BUSHINGS FOR ALTERNATING
VOLTAGES ABOVE 1 000 V

FOREWORD

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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- withdrawn,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.~~

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:~~1999~~ 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. ~~oil~~ 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. ~~oil~~ 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.

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

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 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	^b
Terminals to be connected to exterior conductors by screws or bolts	– in SF ₆	75	105	
	– in oil	70	100	
	Tinned: ^f			
	– in air or SF ₆	75	105	^b
	– in oil	70	100	
Current carrying and non-current carrying metallic parts in contact with	Silver/nickel-plated:			
	– in air or SF ₆	85	115	^b
	– in oil	70	100	
	Copper, aluminium and their alloys:			
	– uncoated	60	90	^c
Insulation class:	– tinned ^f	75	105	
	– silver or nickel-plated	75	105	
	– A (OIP)	75	105	
	– E (RBP, RIP, RIS)	90 _e	120 _e	
	– (GIF)			
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.	– SF ₆	100	130	^{b, g}
	– Oil	85	^e 115	^h
		110	140	
^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. ^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. ^c If heavy oxidation is to be expected, the temperature rise shall be limited to 50 K. ^d A spring contact is a connection maintained by spring pressure for example a plug-in connection. ^e The temperature limits shall be stated by the supplier. ^f Tinned contacts must not exceed the given max temperature of 105 °C, if so very rapid or immediate destruction will occur. ^g Applicable to liquid-insulated bushings according to 3.4. ^h Applicable to transformer bushings with a conductor (solid or flexible) drawn into the central tube. NOTE A and E refers to thermal class according to IEC 60085.				

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)	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)
$\leq 1,1$	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		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				
245	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	-

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.

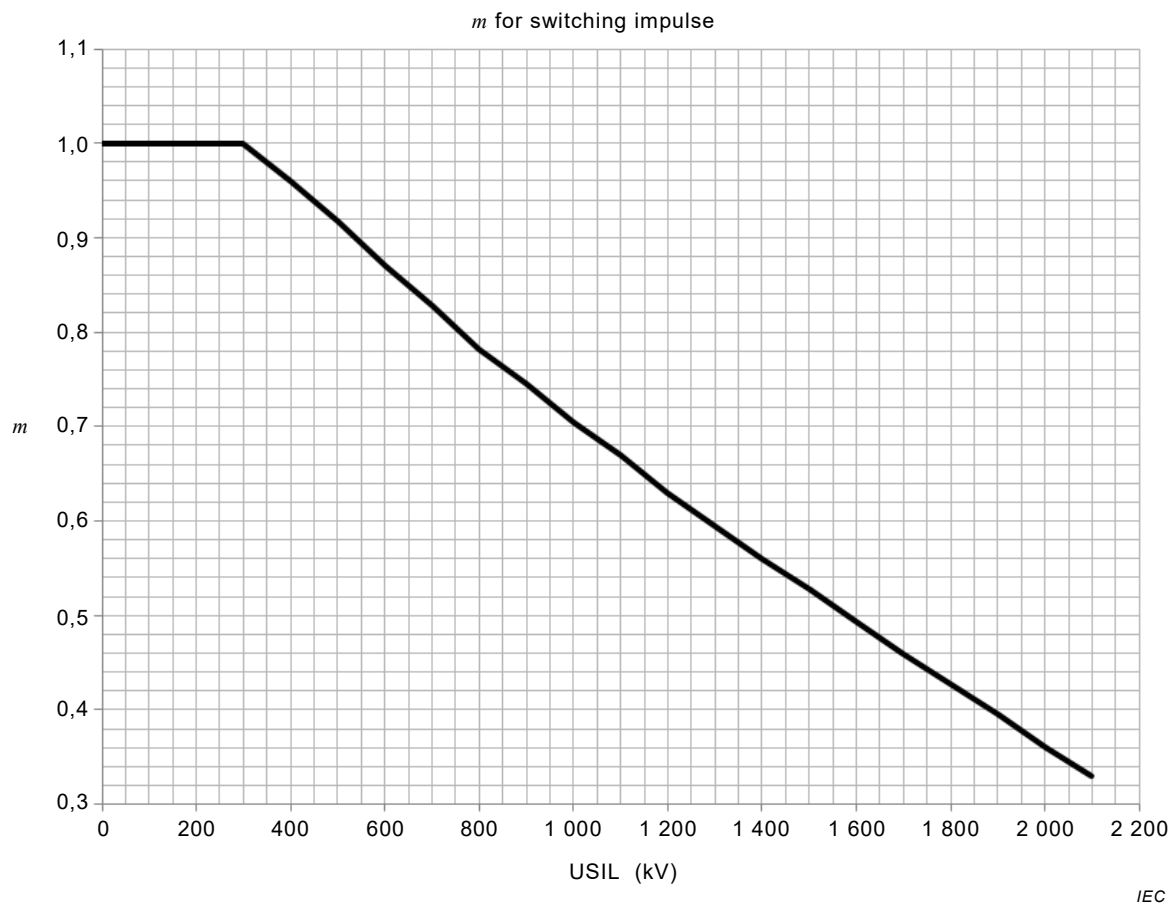


Figure 1 – Factor m on the co-ordination switching impulse withstand voltage

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

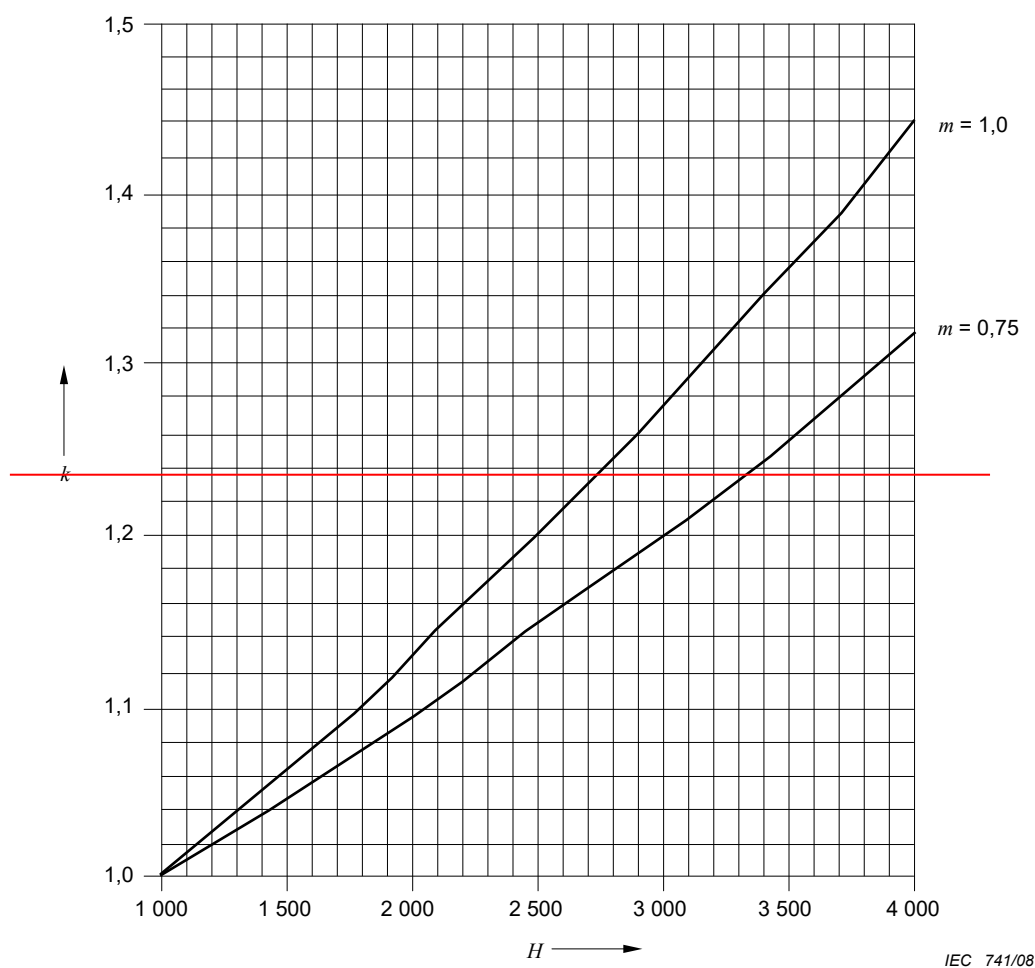


Figure 1 — Altitude correction factor

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 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 ~~duty~~ 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 ~~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_m kV	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_r A

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: ~~1999~~ 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 $\geq 60^\circ \text{C}$ 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 ≥ 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.

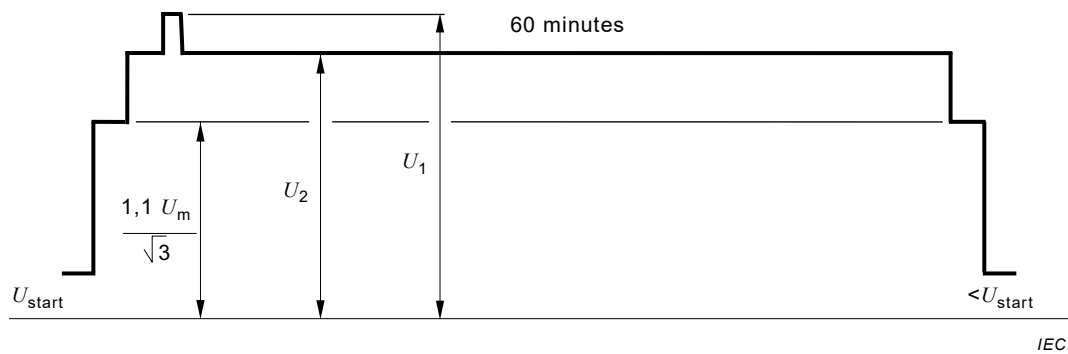


Figure 5 – Voltage profile for long duration test ~~ACLD~~

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 μs .

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 μs and 6 μs .

~~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_f 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 1~~ 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 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.