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Edition 3

IEC 60137:2008

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SOUTH AFRICAN NATIONAL STANDARD

Insulated bushings for alternating voltages above 1 000 V

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Table of changes

Change No.	Date	Scope

National foreword

This South African standard was approved by National Committee SABS/TC 067/SC 04, *Electricity distribution systems and components – Insulators,* in accordance with procedures of the SABS Standards Division, in compliance with annex 3 of the WTO/TBT agreement.

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Insulated bushings for alternating voltages above 1 000 V

Traversées isolées pour tensions alternatives supérieures à 1 000 V

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INSULATED BUSHINGS FOR ALTERNATING VOLTAGES ABOVE 1 000 V

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60137 has been prepared by sub-committee 36A: Insulated bushings, of IEC technical committee 36: Insulators.

This sixth edition cancels and replaces the fifth edition, published in 2003, and constitutes a technical revision.

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

- Long duration power-frequency for transformer bushings.
- Special requirements for type and acceptance tests applicable to transformer and GIS bushings.
- Specific insulation levels for bushings fitted to transformers and GIS.
- According to IEC Guide 111, clauses relating to safety and the environment have been added.
- The altitude correction procedure has been revised (> 1 000 m).

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

FDIS	Report on voting
36A/134/FDIS	36A/135/RVD

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

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

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

INTRODUCTION

In the preparation of this standard further consideration has been given to the test requirements for power transformers as described in IEC 60076-3:2000. 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 referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 60050(212):1990, *International Electrotechnical Vocabulary – Part 212: 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: 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 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 60376, *Specification of technical grade sulfur hexafluoride (SF6) for use in electrical equipment*

IEC 60480, *Guidelines for the checking and treatment of sulphur 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 61462, *Composite insulators – Hollow insulators for use in outdoor and indoor electrical equipment – Definitions, test methods, acceptance criteria and design recommendations*

IEC 61463, *Bushings – Seismic qualification*

IEC 62155, *Hollow pressurised and unpressurised ceramic and glass insulators for use in electrical equipment with rated voltages greater than 1 000 V*

IEC 62217, *Polymeric 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.

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

[IEV 471-02-01]

NOTE 1 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.

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 oil

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 oil or another insulating liquid

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 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 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 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 3.13).

NOTE 3 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 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, the space between the core and the insulating envelope being filled with the same gas

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 oil

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

3.12
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

3.13
combined insulation bushing
bushing in which the major insulation consists of a combination of at least two different insulating materials

3.14
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

[IEV 471-02-03]

3.15
indoor bushing
bushing, both ends of which are intended to be in ambient air at atmospheric pressure, but not exposed to outdoor atmospheric conditions

[IEV 471-02-05]

3.16
outdoor bushing
bushing, both ends of which are intended to be in ambient air at atmospheric pressure and exposed to outdoor atmospheric conditions

[IEV 471-02-07]

3.17
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

[IEV 471-02-09]

3.18
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 or gas)

[IEV 471-02-06]

NOTE This definition includes bushings operating in air at temperatures above ambient, such as occur with air-insulated ducting.

3.19
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 or gas)

[IEV 471-02-08]

3.20
completely immersed bushing
bushing, both ends of which are intended to be immersed in an insulating medium other than ambient air (e.g. oil or gas)

[IEV 471-02-04]

3.21
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

[IEV 471-02-02]

3.22
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

[IEV 604-03-01]

3.23
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

3.24
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

3.25
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

3.26
rated dynamic current
I_d
peak value of a current which the bushing withstands mechanically

3.27
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)

3.28
rated frequency
f_r
frequency at which the bushing is designed to operate

[IEV 421-04-03, modified]

3.29
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

3.30
maximum internal operating gas pressure
pressure, when the bushing is in operation, carrying rated current at the highest temperatures in accordance with 5.3

3.31
maximum external operating gas pressure
maximum pressure of the gaseous insulating medium in which the bushing is partially or completely immersed when in operation

3.32
design pressure (of the enclosure)
pressure used to determine the thickness of the enclosure

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

3.33
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

(see IEC 60068-2-17)

NOTE The basic SI unit for leak rate is "Pascal cubic metre per second (Pa $\times$ m^3/s)". The derived units "Pa $\times$ cm^3/s" and "bar $\times$ cm^3/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 Pa $\times$ m^3/s = 10^6 Pa $\times$ cm^3/s = 10 bar $\times$ cm^3/s.

3.34
hollow insulator
insulator which is open from end to end, with or without sheds

[IEV 471-01-8 modified]

NOTE An insulating envelope may consist of one insulator unit or two or more permanently assembled insulator units.

3.35
creepage distance
shortest distance along the surface of an insulator between two conductive parts

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

NOTE 2 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.

[IEV 471-01-04]

3.36
arcing distance
shortest distance in air external to the insulator between metallic parts which normally have the operating voltage between them

[IEV 471-01-01]

NOTE The terms "dry arcing distance" or "taut string distance" are also used.

3.37
test tap
measuring tap
tan δ 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 This connection should be earthed directly when it is not used.

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

3.38
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 This connection should be earthed directly when it is not used.

NOTE 2 This tap can also be used for the measurement of dissipation factor, capacitance and partial discharge.

3.39
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

3.40
composite bushing
bushing with an insulating envelope consisting of a resin impregnated fibre tube with or without a rubber compound covering

NOTE For bushings defined in 3.9 to 3.12, the rubber may be applied directly on to the bushing major insulation.

3.41
capacitance (of bushing)

3.41.1
main capacitance C_1
capacitance between the high-voltage conductor and the test tap or the voltage tap of a capacitance-graded bushing

3.41.2
tap capacitance C_2
capacitance between the test tap or the voltage tap and the mounting flange of a capacitance-graded bushing

3.41.3
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 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 kV.

NOTE The values 525 kV and 765 kV are also used.

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, the supplier shall indicate the value of the cross-section, and the material of the conductor, 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 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

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

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 8.7.

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 6.1.3).

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 8.9)

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 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 6.1.4).

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 60815.

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 stated in IEC 62155.

NOTE 2 Requirements for composite insulators are under consideration by TC 36: Insulators.

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: 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 ºC) 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.

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

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	90	
	- in oil	50	80	b
	Tinned in air, SF_6 or oil	60	90	
	Silver/nickel-plated:			
	- in air or SF_6	75	105	
	- in oil	60	90	b
Screwed contacts	Copper, aluminium and their alloys, uncoated:			
	- in air	60	90	
	- in SF_6	75	105	
	- in oil	70	100	b
	Tinned:			
	- in air or SF_6	75	105	
	- in oil	70	100	b
	Silver/nickel-plated:			
	- in air or SF_6	85	115	
	- in oil	70	100	b
Terminals to be connected to exterior conductors by screws or bolts	Copper, aluminium and their alloys:			
	- uncoated	60	90	c
	– tinned	75	105	
	- silver or nickel-plated	75	105	
Metallic parts in contact with	Insulation class:			
	- A (OIP)	75	105	
	- E (RBP and RIP)	90	120	
	- (GIF)	e	e	
	- SF_6	100	130	
	- Oil		e	

[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] For synthetic insulating liquids (silicone, esters), 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.

Table 3 – 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	Class 1 [a]	–5
		Class 2	–15
		Class 3	–25
•	Outdoors	Class 1 [a]	–10
		Class 2	–25
		Class 3	–40
Oil in transformers:			
– maximum			
•	for normal load		100
•	for emergency duty [b]		115
– maximum daily mean			90
Other media:			
(gaseous and non-gaseous)			[c]

[a] The normal minimum ambient air temperature is Class 1.

[b] The values for oil in transformers are in accordance with IEC 60076-1 and IEC 60076-2. The value for emergency duty is 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.

4.9 Standard insulation levels

The standard values of insulation level shall be chosen from the values given in Table 4.

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

Table 4 – Insulation levels for highest voltage for equipment (see 4.9, 8.1, 8.3, 8.4, 9.2 and 9.3)

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)
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	450 550		205 255		185 230	185 230
	650		305		275	275
170	550 650		255 305		230 275	230 275
	750		355	325	325	325
245	950	650 750 850	435	435	395	395
	1050	750 850	505	460	460	460
300	1050	850	505	460	460	-
362	1050	850	505	460	460	-
		950				
	1175	950	560	520	510	-
420	1300	1050	625	595	570	-
	1425	1050	695	650	630	-
	1550	1175	750	-	680	-
550[e]	1425	1050	695	650	630	-
		1175				
	1550	1175	750	710	680	-
	1675	1175	750	-	680	-
	1800	1300	870	-	790	-
800[e]	1800	1300	870	830	790	-
		1425				-
		1550				-
	1950	1550	915	960	830	-
	2100	1425	970	960	880	-
	2400	1550	1075	960	975	-

[a] Values in accordance with IEC 60071-1 and IEC60076-3 enhanced by 10 % in accordance with 9.3.

[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.

4.10 Test tap on transformer bushings

A test tap according to 3.37 shall be provided on transformer bushings of U_m equal to or greater than 72,5 kV. 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 δ) 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 in accordance with Figure 1.

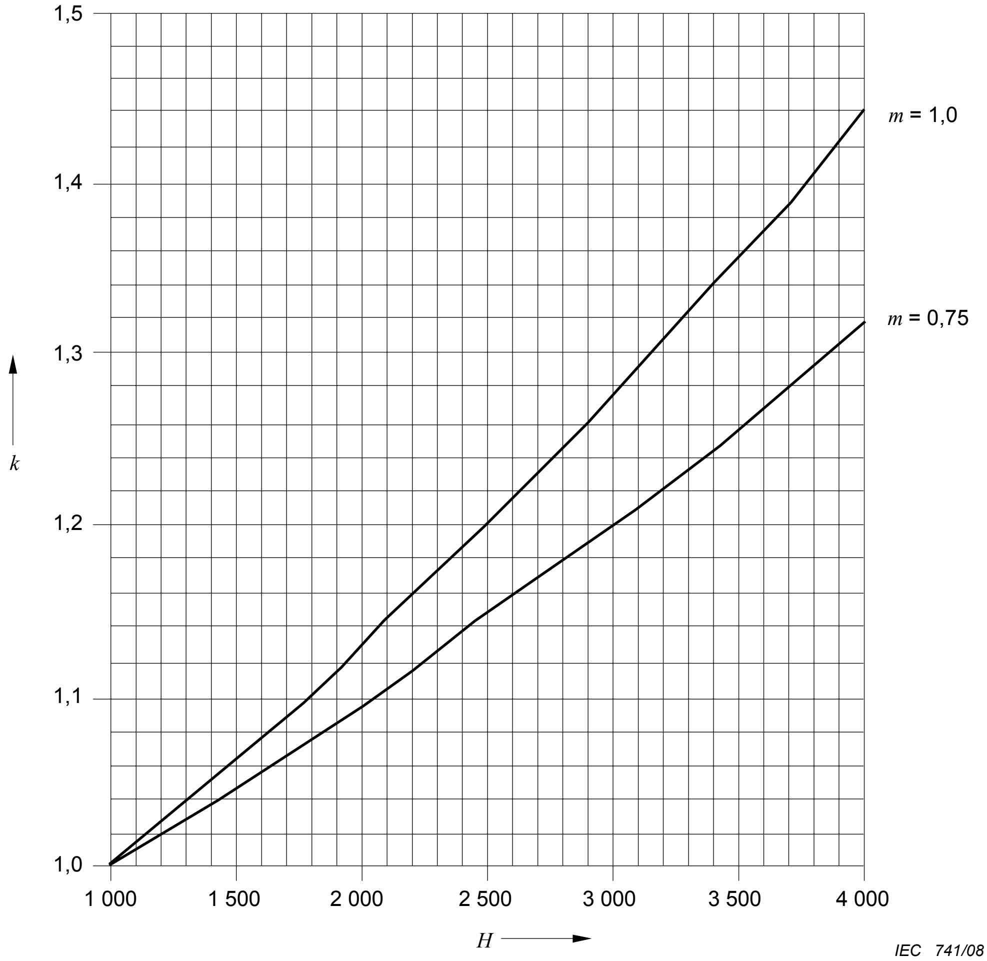

Figure 1 – Altitude correction factor

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 3. Consideration should be given to the operating conditions of completely immersed bushings and bushings operating in 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.

5.4 Seismic conditions

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

6 Ordering information and markings

6.1 Enumeration of characteristics

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.

6.1.1 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).

6.1.2 Classification of bushings

Classification according to 3.2 to 3.21.

6.1.3 Ratings

The ratings shall be as follows:

- highest voltage for equipment (U_m) (see 3.22);
- rated phase-to-earth voltage (see 3.23);
- standard insulation level (see 4.9) and the induced and/or applied test voltage level of the transformer (see 9.3);
- rated current (I_r) (see 3.24);
- 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 3.28);
- 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.

6.1.4 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 3.15 to 3.19);
- ambient air and immersion media temperature if deviating from normal values (see 5.3 and Table 3) (relevant to bushings according to 3.15 to 3.21);
- type of immersion medium (relevant only to partly or completely immersed bushings according to 3.18 to 3.21);

- minimum level of immersion medium (relevant only to partly or completely immersed bushings according to 3.18 to 3.21);
- maximum operating pressure of immersion media (relevant only to partly or completely immersed bushings according to 3.18 to 3.21);
- 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 3.29) (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 3.30) (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 external operating gas pressure (see 3.31) (relevant only to partly or completely gas-immersed bushings according to 3.18 to 3.20);
- 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 3.16, 3.17 and 3.19);
- unusual climatic conditions (extreme high and low temperatures, tropical humidity, severe contamination, high wind);
- seismic conditions, if qualification is required (see 5.4).

6.1.5 Design

The design shall cover:

- 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 3.37 and 3.38);
- 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 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 8.7);
- provision of an oil sample valve.

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

- IEC 60376 for new SF_6 or IEC 60480 for used SF_6.
- IEC 60296 for oil, or
- IEC 60836 or IEC 60867 for synthetic fluid.

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.

- ■ supplier's name or trade mark;
- ■ year of manufacture and serial number;
- ■ supplier’s type designation;
- ■ highest voltage for equipment (U_m) (see 3.22) or rated phase-to-earth voltage (see 3.23) and rated frequency (see 3.28);
- ■ rated current (I_r) (see 3.24). If the bushing is supplied without conductor, the conductor section shall be specified by the supplier (see 4.2);
- lightning impulse (BIL) and switching impulse (SIL) and power-frequency withstand test voltages (AC) (see 4.9);
- bushing capacitance (see 3.41) and dielectric dissipation factor;
- type of insulating gas and rated filling pressure (see 3.29), if applicable;
- mass if above 100 kg;
- maximum angle of mounting if exceeding 30° from vertical (see 4.6).

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

NOTE 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.

	MANUFACTURER	
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
Minimum gas pressure at 20 °C ....bar gauge

IEC 2001/03

Figure 2 – Marking plate for bushings for highest voltage for equipment greater than 100 kV

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

IEC 2002/03

Figure 3 – Marking plate for bushings for highest voltage for equipment equal to or less than 100 kV, except for bushings for which Figure 2 is applicable

MANUFACTURER		
Year	U_m .... kV	I_r ....A

IEC 2003/03

Figure 4 – Marking plate for bushings for highest voltage for equipment 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 8.1 to 8.4, 9.2 and 9.3 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. 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 4. 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 not be damaged by the tolerated flashover in air when tested in accordance with 8.1, 8.3, 8.4, 9.2 and 9.3, but slight marks remaining on the surface of the porcelain insulating parts are acceptable.

A definition of the terms "flashover" and "puncture" is given in IEC 60050(212):1990, definition 212-01-37 and definition 212-01-38, respectively.

7.2 Test classification

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.

7.2.1 Type tests

- dry or wet power-frequency voltage withstand test (see 8.1);
- long duration power-frequency voltage withstand test (ACLD) (see 8.2);
- dry lightning impulse voltage withstand test (see 8.3);
- dry or wet switching impulse voltage withstand test (see 8.4);
- thermal stability test (see 8.5);
- electromagnetic compatibility test (see 8.6);
- temperature rise test (see 8.7);
- verification of thermal short-time current withstand (see 8.8);
- cantilever load withstand test (see 8.9);
- tightness test on liquid-filled, compound-filled and liquid-insulated bushings (see 8.10);
- internal pressure test on gas-filled, gas-insulated and gas-impregnated bushings (see 8.11);
- external pressure test on partly or completely gas-immersed bushings (see 8.12);
- verification of dimensions (see 8.13).

Table 5 – Applicability of type tests (see 7.2.1, excluding bushings according to Clause 10)

Subclause	Short title	Applicable to bushing type	Bushing defined in subclause
8.1	AC dry	All indoor, indoor immersed and completely immersed <300 kV	3.15, 3.18, 3.20
8.1	AC wet	All outdoor <300 kV	3.16, 3.17, 3.19
8.2	ACLD	All transformer bushings ≥170kV	3.18, 3.19, 3.20
8.3	Lightning	All	
8.4	Switching	All ≥300 kV	
	– dry	– indoor, indoor immersed and completely immersed and all transformer bushings ≥245kV	3.15, 3.18, 3.20
	– wet	– outdoor	3.16, 3.17, 3.19
8.5	Thermal stability	All partly or completely immersed, immersion medium ≥60 °C and >300 kV for OIP and RIP ≥145 kV for others	3.18, 3.19, 3.20
8.7	Temperature rise	All, except liquid-insulated as in 3.4	
8.8	Thermal short-time	All, if calculated temperature is too high	
8.9	Cantilever	All	
8.10	Tightness	All liquid-filled and insulated, except with highly viscous filling	3.2, 3.4
8.11	Pressure	All containing gas of ≥1 l and >0,5 bar gauge	3.5, 3.6, 3.7
8.12	External pressure	All partly or completely immersed in gas, gas pressure >0,5 bar gauge	3.18, 3.19, 3.20
8.13	Dimensions	All	

7.2.2 Routine tests

- measurement of dielectric dissipation factor (tan δ) and capacitance at ambient temperature (see 9.1);
- dry lightning impulse voltage withstand test (see 9.2);
- dry power-frequency voltage withstand test (see 9.3);
- measurement of partial discharge quantity (see 9.4);
- tests of tap insulation (see 9.5);
- internal pressure test of gas-filled, gas-insulated and gas-impregnated bushings (see 9.6);
- tightness test on liquid-filled, compound-filled and liquid-insulated bushings (see 9.7);
- tightness test on gas-filled, gas-insulated and gas-impregnated bushings (see 9.8);
- tightness test at the flange or other fixing device (see 9.9);
- visual inspection and dimensional check (see 9.10).

Table 6 – Applicability of routine tests (see 7.2.2, excluding bushings according to Clause 10)

Subclause	Short title	Applicable to bushing type	Bushing defined in subclause
9.1	tan δ / capacity	All capacitance graded	3.14
9.2	Lightning	All transformer bushings, BIL ≥245 kV	
9.3	AC dry	All	
9.4	Partial discharges	All	
9.5	Tap	All with a tap	
9.6	Internal pressure	All gas-containing	3.5, 3.6, 3.7
9.7	Tightness for liquid	All liquid-containing, except with highly viscous filling	3.2, 3.4
9.8	Tightness for gas	All gas-containing with some exceptions	3.5, 3.6, 3.7 3.18, 3.19, 3.20
9.9	Tightness at flange	All partly or completely immersed in oil or gas with some exceptions	3.18, 3.19, 3.20
9.10	Visual and dimensions	All	

7.2.3 Special tests

Special tests are only performed when contractually agreed upon between purchaser and supplier.

- seismic test (reference to IEC 61463);
- artificial pollution test for porcelain insulators (reference to IEC 60507). If the insulator is designed to IEC 60815 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 3.2 and 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 3.29, 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 3.18, 3.19 and 3.20, 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 4).

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, for example with a larger diameter than the intended transformer turret, to satisfy the requirements of 9.3 without any contingent breakdown in oil.

As the dielectric routine tests (see 7.2.2) 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]
8.1	Dry power-frequency voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.1	Wet power-frequency voltage withstand test	Multiply by k_1
8.2	Long duration power-frequency withstand test	None
8.3	Dry lightning impulse voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.4	Dry switching impulse voltage withstand test	Multiply by $k_1 \times k_2$ in the conditions indicated below
8.4	Wet switching impulse voltage withstand test	Multiply by k_1 in the conditions indicated below
8.5	Thermal stability test	None
8.6	Electromagnetic compatibility tests	None
9.1	Measurement of dielectric dissipation factor and capacitance	None
9.3	Dry power-frequency voltage withstand test	None
9.4	Measurement of partial discharge quantity	None
9.5	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

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 9.3). Before and after the series of type tests, measurements of dielectric dissipation factor and capacitance (see 9.1) and of partial discharge quantity (see 9.4) shall be carried out in order to check whether damage has occurred.

8.1 Dry or wet power-frequency voltage withstand test

8.1.1 Applicability

The dry test is applicable to all bushings according to 3.15, 3.18 and 3.20, which are not subjected to a routine test (see 9.3).

The wet test is applicable to all outdoor bushings according to 3.16, 3.17 and 3.19, and for which U_m is less than or equal to 245 kV.

8.1.2 Test method and requirements

The magnitude of the test voltage is given in Table 4. The test duration shall be 60 s, independent of frequency.

8.1.3 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.

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

8.2.1 Applicability

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

8.2.2 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 (A) of 5 min:
- raised to U_2 = 1,5 $U_m/\sqrt{3}$ and held for a duration (B) of 5 min;
- raised to $U_1 = U_m$ and held for a duration (C) of 1 min;
- immediately after the test time, reduced without interruption to U_2 and held for a duration (D) of at least 60 min when U_m ≥300 kV or 30 min for U_m <300 kV to measure partial discharges;
- reduced to 1,1 $U_m/\sqrt{3}$ and held for a duration (E) of 5 min;
- reduced to 0 V.

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.

8.2.3 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.

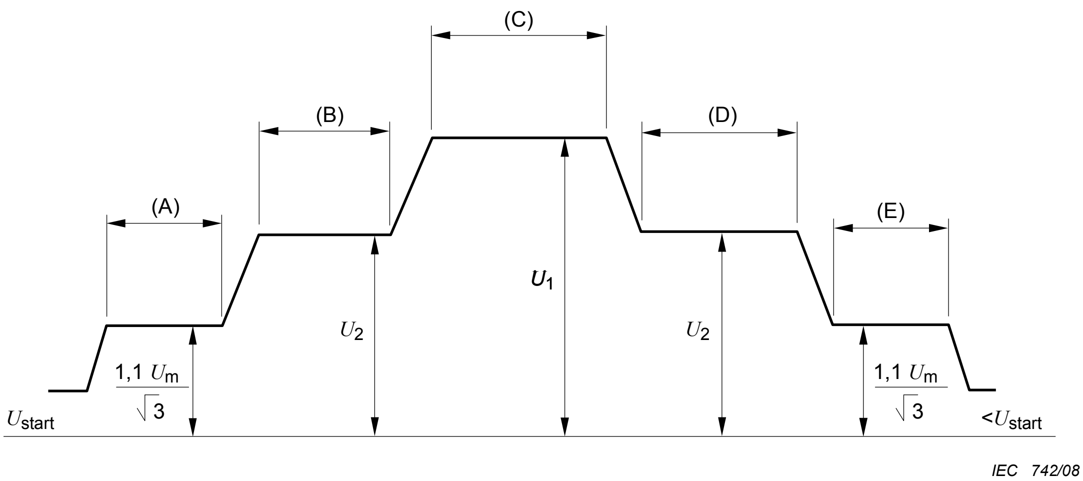

Figure 5 – Voltage profile for long duration test ACLD

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

8.3 Dry lightning impulse voltage withstand test (BIL)

8.3.1 Applicability

The test is applicable to all types of bushings.

8.3.2 Test method and requirements

The magnitude of the test voltage is given in Table 4. 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, followed by
– 5 chopped lightning impulses of negative polarity at 121 % of the rated BIL, and by
– 14 full lightning impulses of negative polarity at 110 % of the rated BIL.

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.

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.

Voltage records shall be made for each impulse.

8.3.3 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,
– 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.

8.4 Dry or wet switching impulse voltage withstand test (SIL)

8.4.1 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 3.15, 3.18 and 3.20.

The wet test is applicable to outdoor bushings, according to 3.16, 3.17 and 3.19.

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

8.4.2 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.

The magnitude of the test voltage is given in Table 4.

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 µs.

For transformer bushings the dry, negative polarity test shall be at 110 % of the rated SIL.

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.

8.4.3 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, 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.

8.5 Thermal stability test

8.5.1 Applicability

The test is applicable to all partly or completely immersed bushings, according to 3.18, 3.19 and 3.20. 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- and resin-impregnated paper 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.

8.5.2 Test method and requirements

The ends of the bushings, which are intended for immersion in oil, or another liquid-insulating medium, shall be immersed in oil. The temperature of the oil shall be maintained at the operating temperature of the apparatus ±2 K, except for transformer bushings where the oil temperature shall be 90 °C ± 2 °C. This temperature shall be measured by means of thermometers, immersed in oil 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 3.29. The gas shall be maintained at a temperature agreed upon between purchaser and supplier.

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

The test voltage shall be

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

The test shall not be started until thermal equilibrium between the oil 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 a period of 5 h.

8.5.3 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.

8.6 Electromagnetic compatibility tests (EMC)

8.6.1 Emission test

8.6.1.1 Applicability

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

8.6.1.2 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 $U_m / \sqrt{3}$

8.6.1.3 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 9.4.2, it can be considered to pass the emission test.

8.6.2 Immunity test

No test is required.

8.7 Temperature rise test

8.7.1 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.

8.7.2 Test method and requirements

Bushings, one or both ends of which are intended to be immersed in oil or another liquid-insulating medium, shall be appropriately immersed in oil at ambient temperature, except for transformer bushings, where the oil shall be maintained at a temperature of 60 K ± 2 K above the ambient air.

NOTE 1 In some applications (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 is in communication with the bushing central tube, the oil 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 3.29, 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 K ± 2 K above ambient air, either by self-heating or indirectly.

An appropriate number of thermocouples or other measuring devices shall, as far as possible, be placed along the bushing conductor, central tube and other current-carrying parts, as well as possibly on the flange or other fixing device, so as to determine the hottest spot of the bushing metal parts in contact with insulating material 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-filled containers with a volume of approximately 0,5 l.

The temperature of the oil 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, 3 cm below the surface of the oil.

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

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

The test shall be continued until the temperature rise is sensibly constant. This is considered to be the case if the temperature does not vary more than ± 1 K during 1 h.

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

To avoid destruction of the insulation in the case of bushings with the conductor embedded in the insulating material, the temperature of the hottest spot may, by agreement between purchaser and supplier, be determined as follows:

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

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

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

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

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

$$L_M = \frac{L}{1\pm\sqrt{\frac{\theta_M-\theta_2}{\theta_M-\theta_1}}} \tag{3}$$

where

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

8.7.3 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.

8.8 Verification of thermal short-time current withstand

8.8.1 Applicability

The verification is applicable to all types of bushings.

8.8.2 Verification method and requirements

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

$$\theta_f = \theta_o + \alpha\frac{I_{th}^2}{S_t\times S_e}\times t_{th} \tag{4}$$

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/cm^2)^2 for copper, 1,8 (K/s)/(kA/cm^2)^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:

$$\alpha = \frac{\rho}{c \times \delta} \tag{5}$$

where

ρ is the resistivity of conductor, in µΩ·cm

c is the specific heat of conductor, in J/(g·K)

δ is the density of the conductor, in g/cm^3.

Values of ρ, c and δ used in Equation (5) 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:

$$d = \frac{1}{2\pi} \times \sqrt{\frac{\rho \times 10^3}{f}} \text{ cm} \tag{6}$$

where f is the rated frequency, in hertz.

Therefore:

$$S_e = \pi d(D - d) \tag{7}$$

8.8.3 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.

8.9 Cantilever load withstand test

8.9.1 Applicability

The test is applicable to the air side of bushings.

8.9.2 Test method and requirements

The test values shall be in accordance with Table 1. For bushings according to 3.21, cantilever withstand load test values shall be restricted to:

300 N for I_r ≤800 A

1 000 N for I_r >800 A

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

A pressure equal to 1 bar ± 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, 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.

8.9.3 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.

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

8.10.1 Applicability

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

8.10.2 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 ± 0,1 bar above the maximum internal operating pressure according to 3.30, shall be maintained inside the bushing during the test.

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

8.10.3 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, Annex C, Clause C.2.

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

8.11.1 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 cm^3).

8.11.2 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.

8.11.3 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.

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

8.12.1 Applicability

The test is applicable to all gas-immersed bushings, according to 3.18 to 3.20, intended for use at a permanent gas pressure higher than 0,5 bar gauge.

8.12.2 Test method and requirements

The test shall be carried out before the tightness test according to 9.9. 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 3.31) shall be applied for 1 min.

8.12.3 Acceptance

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

8.13 Verification of dimensions

8.13.1 Applicability

This verification is applicable to all types of bushings.

8.13.2 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

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 9.3). Before and after the dielectric routine tests, measurements of dielectric dissipation factor (tan δ) and capacitance (see 9.1) shall be carried out in order to check whether damage has occurred. The measurement of partial discharge quantity (see 9.4) shall be made before the last measurement of tan δ.

9.1 Measurement of dielectric dissipation factor (tan δ) and capacitance at ambient temperature

9.1.1 Applicability

The measurement is only applicable to capacitance-graded bushings according to 3.14.

9.1.2 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 δ and capacitance at a voltage between 2 kV and 20 kV shall be carried out as a reference value for measurements carried out later when the bushing is in operation.

9.1.3 Acceptance

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

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

Table 8 – Maximum values of tan δ and tan δ increase (see 9.1)

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

[a] Not applicable to bushings where $U_m \leq 36$ kV.

[b] The supplier shall indicate the values.

9.2 Dry lightning impulse voltage withstand test (BIL)

9.2.1 Applicability

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

9.2.2 Test method and requirements

The test values shall be as follows:

– five full lightning impulses of negative polarity shall be applied or, by contractual agreement;

– one full lightning impulses of negative polarity followed by:

– two chopped lightning impulses of negative polarity at 110 % of the full wave value, followed by:

– two full lightning impulses of negative polarity

shall be applied.

For test conditions, 8.3 shall be followed.

9.2.3 Acceptance

For criteria, 8.3 shall be followed.

9.3 Dry power-frequency voltage withstand test

9.3.1 Applicability

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

9.3.2 Test method and requirements

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

The magnitude of the test voltage is given in Table 4. Bushings for transformers shall be tested at least at 110 % of the induced and/or applied test voltage level of the transformer. If the transformer test level is not stated the bushing may be tested at the other bushings level given in Table 4.

The test duration shall be 60 s, independent of frequency.

9.3.3 Acceptance

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

9.4 Measurement of partial discharge quantity

9.4.1 Applicability

The measurement shall be carried out on all types of bushings, except for bushings according to 3.6 and 3.11, for which this test shall be a type test only, provided the insulating envelope of the bushing has been subjected to an adequate electrical test (e.g. wall test of the porcelain) before assembly.

9.4.2 Test method and requirements

The test shall be made in accordance with IEC 60270.

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

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

The measurement shall be made after the dry power-frequency withstand voltage test (see 9.3) at the values given in Table 4 during the decrease of the voltage from the dry power-frequency withstand test level; depending on test facilities, the voltage level could be reduced to $2\ U_m/\sqrt{3}$ by agreement between the manufacturer and purchaser.

9.4.3 Acceptance

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

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

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

Table 9 – Maximum values of partial discharge quantity (see 8.2 and 9.4)

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

[a] Only applicable to transformer bushings.

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

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

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

[e] The value at 1,1 $U_m/\sqrt{3}$ refers to 8.2 only.

9.5 Tests of tap insulation

9.5.1 Applicability and test requirements

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

– test tap (see 3.37): at least 2 kV;

– voltage tap (see 3.38): twice the rated voltage of the voltage tap but at least 2 kV.

The test duration is 60 s, independent of frequency.

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

9.5.2 Acceptance

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

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

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

9.6.1 Applicability

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

9.6.2 Test method and requirements

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

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

9.6.3 Acceptance

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

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

9.7.1 Applicability

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

9.7.2 Test method and requirements

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

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

9.7.3 Acceptance

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

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

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

9.8.1 Applicability

The test is applicable to all gas-filled, gas-insulated and gas-impregnated bushings, according to 3.5 to 3.7 and 3.18 to 3.20.

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

9.8.2 Test method and requirements

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

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

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

9.8.3 Acceptance

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

9.9 Tightness test at the flange or other fixing device

9.9.1 Applicability

The test is applicable to all partly or completely immersed bushings, according to 3.18 to 3.20 intended to be used as an integral part of an apparatus, such as switchgear or transformers, where the bushings contribute to the sealing of the complete apparatus.

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

The test may be omitted for transformer bushings fitted with a one-piece metal flange, provided the flange has been subjected to a preliminary tightness test, and the bushing has passed the type test in accordance with 8.10 (for example oil-impregnated paper bushings) or the routine test in accordance with 9.7, or the end to be immersed does not include any gaskets.

9.9.2 Test method and requirements

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

For oil-immersed bushings, the tank shall be filled with air or any suitable gas at a relative pressure of 1,5 bar ± 0,1 bar and maintained for 15 min, or with oil at a relative pressure of 1 bar ± 0,1 bar maintained for 12 h.

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

9.9.3 Acceptance

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

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

– for all parts of a bushing where the leak gas escapes directly to the environment, the calculated total escape of gas is equal to or less than 0,5 % per year of the amount of gas contained in the adjacent switchgear compartment;

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

9.10 Visual inspection and dimensional check

9.10.1 Applicability

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

9.10.2 Acceptance

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

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

10 Requirements and tests for bushings of highest voltages for equipment equal to or less than 52 kV made of ceramic, glass or inorganic materials, resin or combined insulation

This clause is applicable to all bushings where the major insulation consists of ceramic, glass or analogous inorganic materials, cast and moulded resin, or combined insulation, as defined in 3.11 to 3.13.

10.1 Temperature requirements

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

10.2 Level of immersion medium

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

10.3 Markings

Each bushing shall carry the following marking:

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

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

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

10.4 Test requirements

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

10.4.1 Type tests

The following tests are applicable to all bushings:

- dry or wet power-frequency voltage withstand test (8.1);
- dry lightning impulse voltage withstand test (8.3);
- temperature rise test (8.7);
- verification of thermal short-time current withstand (8.8);
- cantilever load withstand test (8.9);
- verification of dimensions (8.13).

For bushings according to 3.21, cantilever withstand load test values are reduced.

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

Table 10 – Applicability of type tests for bushings according to Clause 10 (see 10.4.1)

Short title	Applicable to bushing type	Bushing defined in subclause
AC dry	Indoor, outdoor immersed and completely immersed	3.11
AC wet	All outdoors	3.11 to 3.13
Lightning	All	3.11 to 3.13, 3.21
Temperature rise	All	Ditto
Thermal short time	All, if calculated temperature is too high	Ditto
Cantilever	All (reduced requirement for type defined in 3.21)	Ditto
Dimensions	All	Ditto

10.4.2 Routine tests

The following tests are applicable to all bushings except for ceramic and glass bushings (3.11), where only visual inspection and dimensional checks are applicable:

- dry power-frequency voltage withstand test (9.3);
- measurement of the partial discharge quantity (9.4);
- tests of tap insulation (9.5), if applicable;
- visual inspection and dimensional check (9.10).

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

Table 11 – Applicability of routine tests for bushings according to Clause 10 (see 10.4.2)

Short title	Applicability to bushing type	Bushing defined in subclause
AC dry	All, except ceramic and glass as in 3.11	3.12, 3.13, 3.21
Partial discharge	Ditto	Ditto
Tap	Ditto, with a tap	Ditto
Visual and dimensions	All	3.11 to 3.13, 3.21

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

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

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

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

11.1 Conditions during transport, storage and installation

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

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

11.2 Installation

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

11.3 Unpacking and lifting

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

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

11.4 Assembly

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

11.4.1 Mounting

Instructions for mounting of bushing, these instructions should indicate:

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

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

11.4.2 Connections

Instructions should include information on:

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

11.4.3 Final installation inspection

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

These instructions should include:

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

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

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

– Measurement of gas pressure - the pressure of the gas measured at the end of filling and standard atmospheric air conditions (20 °C and 101,3 kPa) should be not less than the minimum functional pressure and not greater than the rated filling pressure of gas for insulation.

– Measurement of the dew point - the gas dew point at rated filling pressure should not exceed – 5 °C when measured at 20 °C. Adequate corrections should be applied for measurement at the other temperatures.

– Enclosure tightness check - The check should be performed with the probing method for closed pressurised systems as specified for the routine test (see 9.8). The check should be started at least one hour after the filling of the bushing in order to reach a stabilised leakage flow. The check can be limited to gaskets, over pressure device, valves, terminals, manometers, temperature sensors, using a suitable leak detector.

11.5 Operation

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

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

11.6 Maintenance

11.6.1 General

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

11.6.2 Recommendation for the manufacturer

a) The manufacturer should issue a maintenance manual including the following information:

   1) schedule maintenance frequency;

   2) detailed description of the maintenance work;

      – recommended place for the maintenance work (indoor, outdoor, in factory, on site,...);

      – procedures for inspection, diagnostic tests, examination, overhaul, function check out (e.g. limits of values and tolerances);

      – reference to drawings;

      – reference to part numbers (when applicable);

      – use of special equipment or tools (cleaning and degreasing agents);

      – precautions to be observed (e.g.; cleanliness).

   3) comprehensive drawings of the details of the bushing important for maintenance, with clear identification (part number and description) of assemblies, sub-assemblies and significant parts;

NOTE Expended detail drawing which indicate the relative position of components in assemblies and subassemblies are a recommended illustration method.

   4) list of recommended spare-parts (description, reference number quantities) and advice for storage;

   5) estimate of active scheduled maintenance time;

   6) how to proceed with the equipment at the end of its operating life, taking into consideration environmental requirements.

b) The manufacturer should inform the users of a particular type of bushing about corrective actions required by possible systematic defects and failures.

c) Availability of spares: The manufacturer should be responsible for ensuring the continued availability of recommended spare parts required for maintenance for a period not less than 10 years from the date of the final manufacture of the bushing.

11.6.3 Recommendations for the user

a) If the user wishes to carry out his own maintenance, he should ensure that his staff has sufficient qualification as well as a detailed knowledge of the bushing.

b) The user should record the following information:

- the serial number and the type of the bushing;
- the date when the bushing is put in service;
- the results of all measurements and tests including diagnostic tests carried out during the life of the bushing ;
- dates and extent of the maintenance work carried out ;
- the history of service, records of the bushing measurements during and following a special operating condition (e.g. fault and post fault operating state) ;
- references to any failure report.

c) In case of failure and defects, the user should make a failure report and should inform the manufacturer by stating the special circumstances and measures taken. Depending upon the nature of the failure, an analysis of the failure should be made in collaboration with the manufacturer.

d) In case of disassembling for reinstallation in the future, the user must record the time and the storage conditions.

11.6.4 Failure report

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

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

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

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

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

– origin (mechanical, electrical, tightness etc.);
– cause in the opinion of the person having established the report (design, manufacture, inadequate instructions, incorrect mounting, incorrect maintenance, stresses beyond those specified, etc.).
g) Consequences of the failures or defect
– equipment down-time;
– time consumption for repair;
– labour cost;
– spare parts cost.

A failure report may include the following information:

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

12 Safety

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

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

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

12.1 Electrical aspects

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

12.2 Mechanical aspects

- pressurised components
- mechanical impact protection

12.3 Thermal aspects

- flammability

13 Environmental aspects

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

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

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

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