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IEEE Standard for General Requirements and Test Procedure for Power Apparatus Bushings

STANDARDS

IEEE Power and Energy Society

Developed by the
Transformers Committee

IEEE Std C57.19.00™-2023
(Revision of IEEE Std C57.19.00-2004)

IEEE

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Transformers Committee
of the
IEEE Power and Energy Society

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IEEE SA Standards Board

Abstract: Bushings that have basic impulse insulation levels of above 110 kV for use as components of liquid-immersed transformers and liquid-immersed reactors are addressed by this standard.

Keywords: apparatus bushings, bushings, IEEE C57.19.00™, liquid-filled transformers, liquid-filled reactors

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Introduction

This introduction is not part of IEEE Std C57.19.00-2023, IEEE Standard for General Requirements and Test Procedure for Power Apparatus Bushings.

This document is based on the standard practices in the United States for power apparatus bushings. It is the result of joint efforts of professional engineers, manufacturers, and users working together under the Bushing Subcommittee of the IEEE Transformers Committee. This standard applies to a rapidly changing technology. It is anticipated that frequent revision may be desirable. At the end of this section, information pertaining to the latest revision can be found.

In 1942, the original document, Standard 21, was approved by the American Institute of Electrical Engineers (AIEE). The document was prepared by the Joint Committees of the AIEE and the National Electrical Manufacturers Association (NEMA). The American National Standards Institute (ANSI) Accredited Standards Committee, C76, was the sponsor of the standard document which became ANSI C76.1-1943, American National Standard for Apparatus Bushings.

In 1958, a supplement and partial revision, ANSI C76.1a-1958, Electrical and Dimensional Characteristics of Outdoor Apparatus Bushings (used with Power Circuit Breakers and Outdoor Transformers), was prepared by the NEMA Joint Sections Committee on Outdoor Apparatus Bushings. It resulted from work by the regional associations of electrical utilities and filled the needs of the user for dimensional interchangeability.

In 1963, the AIEE merged with the Institute of Radio Engineers (IRE) to form the Institute of Electrical and Electronics Engineers (IEEE).

In 1964, the revised standard was approved as IEEE Std 21™-1964 and as ANSI C76.1-1964. For this revision, Committee C76 had appointed a special working group for the revision of ANSI C76.1-1943 to consolidate several proposals and recommendations from AIEE and NEMA.

In 1970, the document was reaffirmed; however, in 1968, a revision had already been initiated in Committee C76 to separate the standard into three parts. The first part, C76.1 (now known as IEEE Std C57.19.00™), was to cover the general requirements and test procedures, the second part, C76.2 (now known IEEE Std C57.19.01™), was to cover explicit ratings and dimensions, and the third part was to be an application guide, C76.3. The ANSI C76 committee was disbanded prior to the publishing of C76.3; therefore, the first version of the application guide was published as IEEE Std C57.19.100™-1995 [B4].[6]

In 1976, the revised standard was approved as IEEE Std 21-1976 and as ANSI C76.1-1976. Changes in this revision included test procedure updating, adding 362-kV through 800-kV maximum system voltage bushing electrical ratings with wet switching impulse test values and coordination with switching surge sparkover values of arresters and establishing dual current ratings for 115-kV through 196-kV insulation class bushings, since circuit breakers have a lower temperature rise than transformers, permitting a larger current rating for a given maximum ambient temperature when applied to circuit breakers.

In 1991, the revised standard was approved as IEEE Std C57.19.00-1991 (reaffirmed 1997). The work was completed under the Bushing Subcommittee, which was formed in October 1979, under the sponsorship of the IEEE Transformers Committee. Extensive changes to the standard included a new standard designation, IEEE Std C57.19.00, which is indicative of its new IEEE Sponsor Committee. Other major changes were made to improve the test sequence to allow apparent charge measurements to be made in addition to radio influence voltage measurements during the low-frequency dry withstand tests and to provide for special tests, such as thermal stability tests.

[6]Information on references can be found in Clause 2.

In 2004, the revised standard was approved as IEEE Std C57.19.00-2004 (reaffirmed 2010), which supersedes IEEE Std C57.19.00-1991 (reaffirmed 1997), and includes the following significant changes:

- Reorganization and rearrangement to meet the requirements of the *IEEE SA Standards Board Style Manual*
- Expansion of the scope to include indoor bushings
- Addition of new definitions
- Redefinition and clarification of the thermal basis of rating
- Addition of short-time current and thermal ratings and associated test requirements
- Revision of existing test requirements and test procedures
- Addition of a special front of wave lightning impulse test
- Elimination of bushings for oil-filled circuit breakers, which are listed in Annex A of IEEE Std C57.19.01-2000

This latest revision of the standard, IEEE Std C57.19.00-2023, supersedes IEEE Std C57.19.00-2004 (reaffirmed 2010) and includes the following significant changes:

- Expansion of the scope to include high current power transformer bushings with rated continuous current in excess of 5000 A in bus enclosures (IEEE Std C57.19.04™-2018)
- Addition of new definitions: *dry type bushing*; *ground layer*; and *resin-impregnated synthetic-insulated bushing*
- Revision of existing definitions for more clarity: *ambient temperature*; *bottom connected bushing*; *bushing voltage tap*; and *tap capacitance*
- Introduction of dry switching impulse testing
- Updated electrical testing per IEEE Std 4™-2013
- Addition of test requirements for dry type bushings
- Renaming of 7.4.5 “Internal pressure and vacuum tests” to “Leak tests”

Contents

IEEE Standard for General Requirements and Test Procedure for Power Apparatus Bushings

1. Overview

1.1 Scope

This standard applies to bushings for use as components of liquid-immersed transformers and liquid-immersed reactors.

This standard does not apply to the following:

— High-voltage cable terminations (potheads)

— Bushings for circuit breakers

— Bushings for instrument transformers, including station service voltage transformers

— Bushings for test transformers

— Bushings in which the internal insulation is provided by a gas

— Bushings applied with gaseous insulation (other than air at atmospheric pressure) external to the bushing

— Bushings for automatic circuit reclosers and line sectionalizers

— Bushings for oil-less and oil-poor apparatus

— Bushings for dc applications (see IEC/IEEE 65700-19-03™ [B3][7])

1.2 Purpose

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).[8,9]

[7]The numbers in brackets correspond to those of the bibliography in Annex A.
[8]The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.
[9]The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI C63.2, American National Standard for Specifications of Electromagnetic Interference and Field Strength Measuring Instrumentation in the Frequency Range 9 kHz to 40 GHz.[10]

ASTM D3487, Standard Specification for Mineral Insulating Oil Used in Electric Apparatus.[11]

IEC 60270, High-voltage test techniques—Partial discharge measurements.[12]

IEEE Std 4™, IEEE Standard Techniques for High-Voltage Testing.[13,14]

IEEE Std 693™, IEEE Recommended Practice for Seismic Design of Substations.

IEEE Std C57.19.01™, IEEE Standard for Performance Characteristics and Dimensions for Power Transformer and Reactor Bushings.

IEEE Std C57.19.04™, IEEE Standard for Performance Characteristics and Dimensions for High Current Power Transformer Bushings with Rated Continuous Current in Excess of 5000 A in Bus Enclosures.

IEEE Std C57.113™, IEEE Recommended Practice for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.

NEMA 107, Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus.[15]

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[16]

[10]ANSI publications are available from the American National Standards Institute (https://www.ansi.org/).
[11]ASTM publications are available from the American Society for Testing and Materials (https://www.astm.org/).
[12]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (https://www.iec.ch/).
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[16]*IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

ambient temperature: The temperature of the surrounding air that comes in contact with the apparatus onto which the bushing is mounted but not inside bus ducts or enclosures.

apparent charge: The charge that, if injected instantaneously between the terminals of the test object, would momentarily change the voltage between the terminals by the same amount as the partial discharge inside the test object. It is usually expressed in picocoulombs.

arcing distance: The shortest external tight-string distance measured over the insulating envelope between the metal parts at line voltage and ground. Previously referred to as *striking distance* or *flashover distance*.

bottom connected bushing: A bushing that will allow the connection of the transformer or reactor winding lead to a suitable connector at the inboard end of the bushing for the transfer of current.

bushing: An insulating structure, including a through conductor or providing a central passage for such a conductor, with provision for mounting on a barrier, conducting or otherwise, for the purpose of insulating the conductor from the barrier and conducting current from one side of the barrier to the other.

bushing voltage tap: A connection to one of the capacitance layers, which divides the layers into sections C_1 and C_2 such that the capacitance-graded internal insulation forms a voltage divider, which when connected to other equipment to safely control the output voltage can be used to measure the voltage applied to the bushing's high-voltage terminal.

NOTE—Additional equipment can be designed, connected to this tap, and calibrated to indicate the voltage applied to the bushing. This tap can also be used for measurement of partial discharge, power factor, and capacitance values.[17]

bushing test tap: A connection to one of the conducting layers of a capacitance-graded bushing for measurement of partial discharge, power factor, and capacitance values.

capacitance (of bushing): The capacitance, C, of a bushing without a voltage or test tap is the capacitance between the high-voltage conductor and the mounting flange (ground).

capacitance-graded bushing: A bushing in which metallic or nonmetallic conducting layers are arranged within the insulating material for the purpose of controlling the distribution of the electric field of the bushing, both axially and radially.

cast insulation bushing: A bushing in which the internal insulation consists of a solid cast material with or without an inorganic filler.

composite bushing: A bushing with an insulating envelope consisting of a resin-impregnated fiber tube with or without a rubber compound covering.

compound-filled bushing: A bushing in which the radial space between the internal insulation (or conductor where no internal insulation is used) and the inside surface of the insulating envelope is filled with an insulating compound.

creep distance: The distance measured along the external contour of the insulating envelope that separates the metal part operating at the high voltage and the grounded metal flange.

[17]Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

current transformer pocket length: The maximum length, as specified by the manufacturer's drawing, suitable for the mounting of current transformers on the inboard end, as measured from the mounting flange gasket surface. This area may have a visible metal or conductive surface or may be protected by an internal shield.

draw-lead bushing: A bushing that will allow the use of a draw-lead conductor.

draw-lead conductor: A cable or solid conductor that has one end connected to the transformer or reactor winding and the other end drawn through the bushing and connected to the top terminal of the bushing.

draw-rod bushing: A bushing that allows the use of a noncurrent carrying rod drawn though the hollow tube of the bushing, enabling a connection between the bushing's inboard-end terminal and the transformer or reactor winding.

dry type bushing: A bushing for which the internal insulation does not contain dielectric liquids.

ground layer: Outermost conductive layer of bushing, which is intended to be solidly grounded during operation.

inboard end (oil-side end): End of bushing that is inserted into apparatus.

inboard-end ground layer length: The inboard-end portion of the ground layer measured axially along the bushing from the gasket surface of the mounting flange to the inboard end of the ground layer.

inboard-end metal sleeve length: The inboard-end portion of the mounting flange measured axially along the flange from the gasket surface to the end of the flange.

indoor bushing: A bushing that is intended for use where the air side is physically protected from exposure to weather and sunlight.

insulating envelope: An envelope of inorganic or organic material, such as a ceramic, cast resin, or silicone rubber, placed around the energized conductor and internal insulation material.

internal insulation: Insulating material provided in a radial direction around the energized conductor in order to insulate it from the ground potential.

main capacitance (of a capacitance-graded bushing): Capacitance between the high-voltage conductor and the voltage tap or the test tap and typically referred to as C_1.

NOTE—Refer to 6.2 of this document for further clarification.

major insulation: The insulating material providing the dielectric, which is necessary to maintain proper isolation between the energized conductor and the ground potential. It consists of the internal insulation and the insulating envelope(s).

oil: A specially refined petroleum product for use as an insulating liquid and coolant in transformers. Generally conforms to ASTM D3487 when new.[18]

oil-filled bushing: A bushing in which the radial space between the inside surface of the insulating envelope and the internal insulation (or the conductor where no internal insulation is used) is filled with oil.

[18]Information on references can be found in Clause 2.

oil-impregnated paper-insulated bushing: A bushing in which the internal insulation consists of a core wound from paper and subsequently impregnated with oil. The core is contained in an insulating envelope; the space between the core and the insulating envelope is filled with oil.

open bushing: A bushing whose internal parts are exposed to the interior of the apparatus in which it is mounted; for example, an oil-filled bushing in which oil is free to circulate between the inside of the bushing and the apparatus.

outdoor bushing: A bushing that is intended for use where the air side is exposed to weather and sunlight without physical protection.

partial discharge: An electric discharge that only partially bridges the internal insulation.

NOTE—The term *corona* is preferably reserved for partial discharges in air around a conductor but not within the bushing assembly.

power factor (of insulation): The ratio of the power dissipated in the insulation, in watts, to the product of the effective voltage and current, in volt amperes, when tested under a sinusoidal rms voltage and prescribed conditions.

NOTE—The insulation power factor is equal to the cosine of the phase angle between the voltage and the resulting current when both the voltage and current are sinusoidal.

radio influence voltage (RIV): A high-frequency voltage generated as a result of partial discharge or corona, which may be propagated by conduction, induction, radiation, or a combined effect of all three. RIV is usually expressed in microvolts at a frequency of 1 MHz.

resin-bonded paper-insulated bushing: A bushing in which the internal insulation consists of a core wound from resin-coated paper. During the winding process, each paper layer is bonded to the previous layer by its resin coating, and the bonding is achieved by curing the resin.

NOTE—A resin-bonded paper-insulated bushing may be provided with an insulating envelope, in which case the intervening space may be filled with another insulating medium.

resin-impregnated paper-insulated bushing: A bushing in which the internal insulation consists of a core wound from untreated paper and subsequently impregnated under vacuum with a curable resin.

NOTE—A resin-impregnated paper-insulated bushing may be provided with an insulating envelope, in which case the intervening space may be filled with another insulating medium.

resin-impregnated synthetic-insulated bushing: A bushing in which the internal insulation consists of a wound core of synthetic polymer and (subsequently) impregnated with a filled or unfilled curable resin.

sealed bushing: A bushing that is self-contained; for example, an oil-filled bushing in which the bushing oil is completely separated from the apparatus oil and the atmosphere.

solid bushing: A noncapacitance-graded bushing in which the major insulation is provided by a ceramic or analogous material placed around the energized conductor.

tap capacitance (of a capacitance-graded bushing): The capacitance between the voltage tap or test tap and the flange (ground) and typically referred to as C_2.

NOTE—Refer to 6.2 for further clarification.

4. Service conditions

4.1 Usual service conditions

Apparatus bushings conforming to this standard shall be suitable for operation at their ratings, provided the following:

- The temperature of the ambient air does not exceed 40 °C, and the average temperature of the ambient air for any 24-h period does not exceed 30 °C.
- The temperature of the ambient air is not lower than –30 °C.
- The altitude does not exceed 1000 m.
- The temperature of the transformer insulating oil in which the inboard end of the bushing is immersed and the temperature of the bushing mounting surface do not exceed 95 °C averaged over a 24-h period.
- The external terminal and bus connections do not exceed a 30-K rise over ambient.
- Oil-filled bushings are to be mounted at an angle of inclination to the vertical not exceeding 20° unless specifically indicated by the bushing manufacturer. Dry type bushings can be mounted at any angle to the vertical unless specifically indicated by the bushing manufacturer.

4.2 Unusual service conditions

Bushings complying with this standard may be applied in unusual service conditions, but their performance may be affected.

4.2.1 Applications at altitudes greater than 1000 m

The dielectric strength of bushings that depend in whole or in part upon air for insulation decreases as the altitude increases due to the effect of decreased air density. When specified, bushings shall be designed with larger arcing distances using the correction factors from Table 1 to obtain adequate air dielectric strength at altitudes above 1000 m. The minimum insulation necessary at the required altitude can be obtained by dividing the standard insulation at 1000 m by the appropriate correction factor from Table 1.

Table 1—Dielectric-strength correction factors for altitudes greater than 1000 m

Altitude (m)	Altitude correction factor for dielectric strength
1000	1.00
1200	0.98
1500	0.95
1800	0.92
2100	0.89
2400	0.86
2700	0.83
3000	0.80
3600	0.75
4200	0.70
4500	0.67

NOTE—An altitude of 4500 m is considered a maximum for bushings conforming to this standard.

4.2.2 Other conditions that may affect design, testing, and application

Where other unusual conditions exist, they shall be brought to the attention of those responsible for the design, testing, and application of the equipment. Examples of such conditions are as follows:

— Damaging fumes or vapors, excessive abrasive or conducting dust, explosive mixtures of dust or gases, steam, salt spray, wet conditions, icing, and so forth
— Tilting in excess of 20° from vertical
— Abnormal vibration, shocks, or seismic requirements
— Applications where seismic conditions must be accounted for; see IEEE Std 693
— Unusual transportation or storage conditions
— Unusual space limitations
— Unusual temperature applications such as when located within bus enclosures (i.e., isophase or nonsegmented bus duct, air terminal chamber); refer to IEEE Std C57.19.04 for such service conditions
— Proximity of installation adapters and tank walls
— Ambient air temperatures outside the temperature range as defined in 4.1

5. Rating

A designation of performance characteristics based upon definite conditions shall include the following where applicable.

5.1 Rated maximum line-to-ground voltage

The rated maximum line-to-ground voltage is the highest rms rated frequency voltage between the conductor and the mounting flange at which the bushing is designed to operate on a continuous basis.

5.2 Rated frequency

The rated frequency is the frequency at which the bushing is designed to operate.

5.3 Rated dielectric strength

The rated dielectric strength of a bushing is expressed in terms of specified values of voltage withstand tests (shown in Table 1 of IEEE Std C57.19.01-2017 and Table 1 of IEEE Std C57.19.04-2018).

5.3.1 Rated frequency test voltage

5.3.1.1 Dry withstand test

The dry withstand test for a bushing is the test voltage that a new bushing shall be capable of withstanding for 1 min when tested under the conditions specified in 7.4.3.

5.3.1.2 Wet test

The wet withstand test for a bushing is the test voltage that a new bushing shall be capable of withstanding for 60 s when tested under the conditions specified in 7.2.1.1. Wet tests are not required for indoor bushings.

5.3.2 Rated full-wave lightning-impulse voltage

The rated full-wave lightning-impulse voltage is the crest value of a standard 1.2 × 50 µs impulse voltage wave that a new bushing shall be capable of withstanding when tested under the conditions specified in 7.2.1.2.

5.3.3 Rated chopped-wave lightning-impulse voltage

The rated chopped-wave lightning-impulse voltage is the crest value of a standard 1.2 × 50 µs impulse voltage that a new bushing shall be capable of withstanding for a specified time from the start of the wave at virtual time zero until flashover of a rod gap or coordinating gap occurs when tested under the conditions specified in 7.2.1.3.

5.3.4 Rated switching-impulse voltage

5.3.4.1 Rated dry switching-impulse voltage

The rated dry switching-impulse voltage is the crest value of a 250 × 2500 µs switching-impulse voltage wave that a new bushing shall be capable of withstanding when tested under the conditions specified in 7.2.1.4.1.

5.3.4.2 Rated wet switching-impulse voltage

The rated wet switching-impulse voltage is the crest value of a 250 × 2500 µs switching-impulse voltage wave that a new bushing shall be capable of withstanding when tested under the conditions specified in 7.2.1.4.2.

5.4 Rated continuous current

The rated continuous current is the rms current at rated frequency that a bushing shall be required to carry continuously under specified conditions without exceeding the permissible temperature limitations when tested under the conditions specified in 7.2.3.

5.4.1 Thermal basis of rating

The hottest-spot temperature rise above ambient air of any part of the bushing in contact with temperature index 105 insulation shall not exceed 75 K when the inboard end is immersed in oil within 50 mm of the mounting flange with the oil having a rise of 65 K above the ambient air and the bushing is carrying rated current at rated frequency.

Bushings that pass the above thermal basis of rating test are suitable for use in 65-K rise oil-filled transformers. On the adoption of this standard, the retesting of existing acceptable bushing designs shall be optional rather than required.

For insulating materials with a temperature index greater than 105, the hottest spot temperature rise should be chosen accordingly and agreed upon between the purchaser and the manufacturer.

For bushings in excess of 5000 A that are located within bus enclosures, refer to IEEE Std C57.19.04 for requirements.

5.4.2 Draw-lead applications

When a draw-lead is used, the central tube of the bushing does not carry current. The continuous current rating is limited by the draw-lead terminal rating stated on the bushing nameplate and by the size of the draw-lead conductor (rod or cable) applied to the bushing.

6. General requirements

This standard includes a number of general requirements that are applicable to certain ratings of power apparatus bushings. Specific values for these requirements are listed elsewhere in this standard or in IEEE Std C57.19.01 and IEEE Std C57.19.04 under corresponding headings.

6.1 Electrical requirements

The following are electrical requirements:

— Dielectric withstand voltages
— Partial discharge
— Power factor
— Capacitance

6.2 Physical requirements

The following are physical requirements:

— Dimensions.
— Cantilever strength.
— Internal pressure and vacuum.
— Sealed bushings shall be designed to withstand full vacuum when mounted in the apparatus to which they are applied. Open bushings shall be designed to withstand both full vacuum and the positive gauge pressure of 103 kPa (15 psig) as the apparatus to which they are applied.
— Draw-lead bushing cap pressure.
— Bushing voltage tap: All bushings above 350-kV basic lightning-impulse insulation level (BIL) shall be provided with a bushing voltage tap. This tap shall be the normally grounded type as shown in Figure 1 of IEEE Std C57.19.01-2017.
— Bushing test tap: All capacitance-graded bushings with BIL up to and including 350 kV shall be provided with a bushing test tap. This tap is normally grounded and is intended for measurement of power factor, capacitance from conductor to tap, and partial discharge. Since the capacitance from tap to ground (C_2) is not controlled and is influenced by factors external to the bushing, this test tap is not to be used as a voltage divider during normal operation.

6.3 Thermal requirements

Temperature rise tests shall be considered done at 60 Hz unless otherwise agreed between the purchaser and the manufacturer.

6.4 Nameplate markings

The following information shall appear on all bushing nameplates on bushings rated above 110-kV basic lightning-impulse level (BIL):

— Name of the manufacturer, identification number, type, year of manufacture, weight in kilograms (pounds), and serial number

— Rated maximum line-to-ground voltage

— Rated continuous current

NOTE—Where bushings have a dual continuous current rating, the nameplate shall indicate the rating for draw-lead application and bottom connected application.

— Rated full-wave basic lightning-impulse withstand voltage (BIL)

— Capacitance C_1 and C_2 on all bushings equipped with voltage taps and C_1 on all bushings equipped with test taps

— Power factor measured from conductor to tap, where applicable, at 10 kV and referred to 20 °C, by the ungrounded specimen test (UST) method

— Length of inboard (oil-side) end (L)

— Rated frequency

7. Test procedure

This test procedure summarizes the various tests that are made on power apparatus bushings, describes accepted methods used in making the tests, specifies the tests that will demonstrate ratings in this standard, and lists the tests in the recommended sequence for routine and design tests. It does not preclude the use of other equivalent or more effective methods of demonstrating ratings. These tests are divided into the following classifications as listed in Table 2, Table 3, and Table 4.

Table 2—Design tests for bushings

Test	Subclause number
Leak test	7.4.5
Draw-lead bushing cap pressure	7.2.2.1
Cantilever strength	7.2.2.2
Capacitance measurement	7.4.1
Power factor	7.4.2
Tap withstand voltage	7.4.4
Full-wave lightning-impulse withstand voltage	7.2.1.2
Chopped-wave lightning-impulse withstand voltage	7.2.1.3
Rated frequency wet withstand voltage (900-kV BIL and below)	7.2.1.1
Switching-impulse withstand voltage	7.2.1.4
Rated frequency dry withstand test with partial discharge measurement	7.2.1.5
Capacitance measurement	7.4.1
Power factor	7.4.2
Temperature rise	7.2.3
Verification of nameplate markings	6.4

Table 3—Routine tests for bushings

Test	Subclause number
Leak test	7.4.5
Capacitance measurement	7.4.1
Power factor	7.4.2
Tap withstand voltage	7.4.4
Rated frequency dry withstand with partial discharge measurement	7.4.3
Capacitance measurement	7.4.1
Power factor	7.4.2
Verification of nameplate markings	6.4

Table 4—Special tests for bushings

Test	Subclause number
Thermal stability	7.3.1
Front of wave lightning impulse	7.3.2
Seismic	7.3.3

Sequence for special tests to be agreed upon between the purchaser and the manufacturer.

7.1 Test conditions

7.1.1 General requirements

Bushings shall be prepared for dielectric tests and measurements, and corrections for conditions shall be made in accordance with appropriate clauses of this standard. The following shall be in accordance with applicable clauses in IEEE Std 4-2013:

— Definitions of tests
— General test procedures
— Characteristics and tolerance of wave shapes
— Method of measurement
— Standard atmospheric and precipitation conditions

7.1.2 Test specimen requirements

The test specimen shall comply with the following requirements:

a) For electrical tests, bushings shall be mounted on a supporting structure and with their ends in the media of the type in which they are intended to operate. Regardless of actual mounting angles, bushings may be electrically tested in vertical position in manufacturers' facilities.
b) Bushings shall be completely assembled with all elements normally considered essential parts of the bushings.
c) The bushing shall be dry (except for wet tests) and clean.

d) Voltage withstand tests shall be made with the following provisions:

   1) It is recommended to mount the bushing on a relatively flat metallic grounded mounting plate that extends outward from the bushing flange to a distance that would reduce an arc from striking any grounded object other than the grounded parts of the bushing or the mounting plate.

   2) The test connection to the bushing shall be made such that it does not affect the test results.

e) For partial discharge tests, suitable external shielding may be applied to eliminate external discharges.

7.1.3 Test conditions

7.1.3.1 Air temperature

The ambient temperature at the time of test shall be between 10 °C and 40 °C.

7.1.3.2 Humidity

The absolute humidity at the time of test should preferably be between 7.0 g/m^3 and 15.0 g/m^3. Refer to Figure 37 of IEEE Std 4-2013 for determination of absolute humidity.

7.1.4 Correction factors

When actual test conditions vary from standard test conditions as specified in IEEE Std 4-2013, correction factors k_1 for variation in relative air density and k_2 for variation in humidity may be applied to correct applied withstand voltages to withstand voltages at standard conditions. For bushings rated 69 kV and below, k_2 shall not be applied. Correction factors shall be determined in accordance with 13.2 of IEEE Std 4-2013 and shall be applied as follows:

— Dry 1-min rated frequency withstands tests: No corrections.

— Wet 60-s rated frequency withstand tests: Correction factor k_1 may be applied.

— Full-wave lightning-impulse withstand tests: Correction factors k_1 and k_2 may be applied at either positive or negative polarity but not at both.

— Chopped-wave lightning impulse test: No correction.

— Wet switching-impulse withstand tests: Correction factor k_1 may be applied.

7.1.5 Atmospheric conditions and correction factors used in previous tests

Retest of existing equipment designs that were previously tested in accordance with ANSI C68.1-1968 [B1] or previous editions of IEEE Std C57.19.00 shall not be required as a result of minor changes in standard atmospheric conditions or correction factors now used in IEEE Std 4.

7.2 Design tests

Design tests are those made to determine the adequacy of the design of a particular type, style, or model of power apparatus bushing to meet its assigned ratings; to operate satisfactorily under usual service conditions, or under special conditions, if specified; and to demonstrate compliance with appropriate standards of the industry.

Design tests are made only on representative bushings to substantiate the ratings assigned to all other bushings of the same design. These tests are not intended to be made as a part of normal production. The applicable portions of these design tests may also be used to evaluate modifications of a previous design and to help assure that performance has not been adversely affected. Test data from previous designs may be used for current designs where appropriate. Once made, the tests need not be repeated unless the design is changed so as to modify performance.

During these tests, the bushing will be subjected to stresses higher than usually encountered in service and the bushings shall withstand these tests without evidence of partial or complete failure. Hidden damage that may occur during the dielectric withstand voltage tests can usually be detected by comparing values of certain electrical characteristics before and after the withstand voltage tests. The characteristics usually measured are capacitance, power factor, and apparent charge or, for bushings rated 350-kV BIL and below, radio influence voltage (RIV) is allowed. These diagnostic tests may be associated with individual withstand tests or a group of withstand tests. The criteria for acceptance are given in Table 5 and Table 6 of IEEE Std C57.19.01-2017.

Design tests shall include the following plus all routine tests specified in 7.4, except that the rated frequency dry withstand test with partial discharge measurements (7.4.3) shall be made as modified according to 7.2.1.5

7.2.1 Dielectric withstand voltage tests

7.2.1.1 Rated frequency wet withstand voltage

Wet withstand tests shall apply only to outdoor bushings rated 900-kV BIL and below and shall be applied under wet conditions described in 11.2 (“Standard test procedure” in Table 5) of IEEE Std 4-2013.

If the bushing withstands the specified test voltage for 60 s, it shall be considered as having passed the test. If a flashover occurs on the outside of the insulating envelope, the test may be repeated. If the repeat test also results in flashover, the bushing shall be considered to have failed.

The existing wet test results of bushings per the “conventional procedure - practice in USA” (Table 3 of IEEE Std 4-1995) for 10 s are still considered valid and equivalent, and there is no need to repeat the tests under the new “Standard test procedure” (Table 5 of IEEE Std 4-2013).

7.2.1.2 Full-wave lightning-impulse withstand voltage

Both positive and negative standard 1.2 × 50 µs waves as described in IEEE Std 4 shall be used. The procedure (“Withstand voltage test—procedure B”) shown under 8.4.2.2 of IEEE Std 4-2013 shall be used.

7.2.1.3 Chopped-wave lightning-impulse withstand voltage

A minimum of three chopped-wave impulses of each polarity shall be applied to the bushing in accordance with IEEE Std 4 with a 3-µs minimum time to flashover per Table 1 of IEEE Std C57.19.01-2017.

7.2.1.4 Switching-impulse withstand voltage

7.2.1.4.1 Dry switching-impulse withstand voltage

This test shall apply to bushings if required by other IEEE standards, for example, IEEE Std C57.19.04-2018. A minimum of three negative polarity standard 250 × 2500 µs impulse per IEEE Std 4 shall be applied at a peak voltage of 83% of the rated BIL unless otherwise defined.

7.2.1.4.2 Wet switching-impulse withstand voltage

This test shall apply only to outdoor bushings rated above 900-kV BIL. As described in IEEE Std 4-2013, a positive polarity standard 250 × 2500 µs impulse, shall be applied under wet conditions described in 11.2 (“Standard test procedure” in Table 5). Procedures shown under 8.4.2.2 (“Withstand voltage test—procedure B”) of IEEE Std 4-2013 shall be used.

7.2.1.5 Rated frequency dry withstand test with partial discharge measurements, either apparent charge or RIV

This test shall be performed as specified in 7.4.3, except that the voltage at 1.5 times rated maximum line-to-ground voltage in item c) shall be applied for 1 h. Partial discharge measurements—either apparent charge or, for bushings rated 350-kV BIL and below, RIV is allowed—shall be made at 5-min intervals with limits specified in Table 5 of IEEE Std C57.19.01-2017.

7.2.2 Physical tests

7.2.2.1 Draw-lead bushing cap pressure test

The bushing cap assembly and draw-lead central tube shall withstand an internal gauge pressure test of 140 kPa for 1 h without leakage.

7.2.2.2 Cantilever strength test

The bushing shall be rigidly mounted with load applied normal to the longitudinal axis of the bushing and at the midpoint of the thread or threaded terminals and at the lower terminal plate on bushings so equipped. Tests shall be applied to the top and bottom (where applicable) terminals of the bushing but not simultaneously.

During the cantilever test, the bushing temperature shall be approximately 20 °C. The specified load—see Table 4 of IEEE Std C57.19.01-2017 or Clause 5c) of IEEE Std C57.19.04-2018—shall be applied for a period of 1 min. Permanent deformation, measured at the bottom end 1 min after removal of the load, shall not exceed the values stated in IEEE Std C57.19.01 or IEEE Std C57.19.04. For liquid-filled bushings, the bushing internal gauge pressure shall be set to 70 kPa (10 psig) and there shall be no leakage at any point on the bushing at any time during the test or within 10 min after removal of the load.

7.2.3 Temperature rise test

The temperature rise test shall apply to inboard end-connected bushings where the current is carried by the conductor tube/rod. The test shall be carried out as follows:

a) The bushing shall be prepared by suitably attaching thermocouples on the current carrying conductor in sufficient number and at regular intervals so that the temperature of the hottest part of the conductor in contact with the insulating materials can be determined and measured.

b) The temporary external connections to the bushing shall be such that they do not unduly affect the bushing temperature rise. The cross section of the air end bus should be such that at rated current, the temperature rise at a location 1 m away from the bushing should be at least 30 K above the ambient air.

c) The bushing shall be mounted so that the bushing ends are immersed in the medium in which they are intended to operate.

d) For liquid-immersed bushing, the temperature of the liquid bath shall be measured by a thermocouple immersed approximately 30 mm below the liquid surface and located 300 mm plus one-half the “D” dimension from the bushing centerline, ± 50 mm per Figure 2(a) and Figure 3(a) of IEEE Std C57.19.01-2017. The liquid level shall be maintained within 50 mm of the flange mounting surface. The temperature rise of the liquid bath shall be maintained as per the requirement outlined in 5.4.1.

e) The surrounding air temperature shall be determined by taking the average reading of three lagged thermocouples placed at heights corresponding to mounting flange, midheight, and top end of the bushing. The thermocouples shall be located 1 m to 2 m away from the bushing. The test shall be made in a draft-free area with an ambient air temperature between 10 °C and 40 °C.

f) The test shall be carried out with alternating current at the rated current and frequency and continued until thermal conditions become constant. This is considered to be the case when the measured temperatures do not increase by more than 1-K rise in 2 h for bushings up through 900-kV BIL and not more than 1-K rise in 4 h for bushings above 900-kV BIL. ºThe thermocouple readings should be taken at appropriate intervals.

g) The bushing shall be considered to have passed the test if the requirements outlined in 5.4.1 are fulfilled.

For draw-lead bushings, a temperature rise test shall be done when the bushing manufacturer supplies the draw-lead conductor. A test similar to the bottom end connected bushing shall be carried out.

NOTE—For temperature rise test of bushings rated over 5000 A and operated within a bus enclosure, refer to IEEE Std C57.19.04.

7.2.4 Tap withstand voltage

A rated frequency withstand test shall be applied to or induced at the tap for 1 min with the bushing mounting flange grounded. Voltage tap shall be tested at 20 kV. Test tap shall be tested at 2 kV.

7.3 Special tests

Special tests are not a part of routine or design tests. These tests shall be done only when agreed upon between the purchaser and the manufacturer.

7.3.1 Thermal stability tests

Availability of comparative test data and/or successful field service experience on similar designs should be considered when determining the need for a thermal stability test.

The test shall be made using the following procedure:

— The ends and parts of bushings that are intended for immersion in dielectric liquid shall be immersed in liquid. The temperature of the liquid shall be maintained at 95 °C ±2 °C and shall be measured by means of a thermocouple immersed in liquid approximately 30 mm below the surface and located 300 mm plus one-half the “D” dimension from the bushing centerline, ± 50 mm per Figure 2(a) and Figure 3(a) of IEEE Std C57.19.01-2017.

— Rated continuous current at rated frequency shall be applied throughout the test. Conductor losses corresponding to rated continuous current at rated frequency can be generated by applying rated continuous current at rated frequency to the final conductor. The conductor and main insulation shall be raised to and maintained at the same temperature as that calculated for full rated load at the standard conditions specified in 5.4.1 during all the following testing.

— The test voltage shall be equal to a minimum of 1.2 times the rated maximum line-to-ground voltage as specified by Table 1 of IEEE Std C57.19.01-2017.

— Voltage shall not be applied until thermal equilibrium between the liquid and the bushing has been reached.

— During the test, the power factor shall be measured periodically and the ambient air temperature shall be recorded at each measurement.

— The bushing has reached thermal stability when its power factor rises no more than 0.02, when expressed as a percentage, over a period of five hours.

NOTE—The bushing shall be considered to have successfully passed the test if it has reached thermal stability and if it has withstood a repetition of all dielectric routine tests without significant change from the previous results.

7.3.2 Front of wave lightning impulse test

This special test is to be performed on one bushing of a particular design when agreed upon.

The wave shapes shall meet the requirements of IEEE Std 4 and of 7.2.1 of this standard. The test shall be done with negative polarity using the following or any agreed-upon sequence:

— One reduced full wave

— Two front of waves

— Two 3- µs chopped waves

— One full wave

The test level for chopped wave and full wave shall be as specified in IEEE Std C57.19.01 and IEEE Std C57.19.04. The test level and the sparkover time for the front of wave shall be as per Table 5.

Table 5—Front of wave lightning impulse test levels

BIL (kV)	Minimum crest voltage, *MCV* (kV)	Specific time to sparkover, *T* (µs)
110	195	0.50
150	260	0.50
200	345	0.50
250	435	0.50
350	580	0.58

In order to provide some tolerance in practical testing, a tolerance of –0.1 µs to the tabulated sparkover time in Table 5 shall be permitted. Since the test is more severe with duration, the maximum permissible positive tolerance shall be 0.3 µs. If, in making any front of wave test, the tolerance of –0.1 µs is exceeded, the test requirement may be considered as having been met provided the crest voltage attained during the test is equal to or more than the voltage determined by Equation (1).

$$\text{Voltage} = MCV \times \left(1 + ((T - 0.1) - T)/(A \times T_1)\right) \tag{1}$$

where:

MCV = minimum crest voltage in kV from Table 5
T = specific time to sparkover in µs from Table 5
T_1 = actual sparkover time measured in µs
A = 3 for BIL up to 250 kV and 4 for 350-kV BIL

7.3.3 Seismic tests

For information on the seismic testing, see IEEE Std 693, IEEE Recommended Practice for Seismic Design of Substations.

7.4 Routine tests

Routine tests are those tests made to check the quality and uniformity of the workmanship and the materials used in the manufacture of power apparatus bushings. Insofar as the bushing construction allows, the following tests shall be made on each bushing.

7.4.1 Capacitance (C_1 and C_2) measurement

Capacitance C_1 between the bushing high-voltage conductor and the voltage or test tap shall be measured at 10 kV before and after the rated-frequency withstand tests. Tolerance for acceptable change is specified in Table 6 of IEEE Std C57.19.01-2017.

Capacitance C_2 between the voltage tap and grounded flange shall be measured at 2 kV after the rated frequency voltage withstand test.

7.4.2 Power factor

The power factor between the bushing conductor and the bushing tap shall be measured at 10 kV by the ungrounded specimen test (UST) method before and after the rated frequency withstand voltage test.

If specified, solid bushings not equipped with taps shall be tested by the grounded specimen test (GST) method after the rated frequency withstand voltage test. The bushings not equipped with taps could also be tested in the UST method with the bushing flange temporarily isolated from the ground during testing

Limits and tolerance of acceptable change are specified in Table 6 of IEEE Std C57.19.01-2017.

7.4.3 Rated frequency dry withstand tests with partial discharge measurements

The test shall be made with the bushing clean and dry. If the bushing withstands the specified test voltage and meets the partial discharge limits, as specified below, it shall be considered to have passed the test.

Partial discharges generated within the bushing during test shall be determined by apparent charge measurement; for bushings rated 350-kV BIL and below, RIV is allowed.

General principles and circuits for RIV measurement, which is only allowed for bushings rated 350-kV BIL and below, are described in NEMA 107. A radio noise and field-strength meter conforming to ANSI C63.2 shall be used to measure the RIV generated by any internal partial discharges. The measurement shall be made on a quasi-peak basis at a nominal frequency of 1 MHz, although any frequency from 0.85 MHz to 1.15 MHz may be used to discriminate against local radio station signal interference.

General principles and circuits for apparent charge measurement are described in IEC 60270, and a particular type of wide-band measurement is described in IEEE Std C57.113.

Measurements may be made by using either the bushing voltage tap or the coupling capacitor method. The following test procedures shall be used:

a) Measure apparent charge—for bushings rated 350 kV and below, RIV is allowed—at 1.5 times the rated maximum line-to-ground voltage specified by Table 1 in IEEE Std C57.19.01-2017 and IEEE Std C57.19.04-2018. Partial discharge limits are specified in Table 5 of IEEE Std C57.19.01-2017 and IEEE Std C57.19.04-2018.

b) Perform a 1-min dry withstand test at the voltage specified in Table 1 of IEEE Std C57.19.01-2017. If a flashover occurs outside the insulating envelope, the test may be repeated by restarting the test. If the repeat test also results in a flashover, the bushing shall be considered to have failed. No partial discharge measurements are required at this test level.

c) Repeat measurements of apparent charge—for bushings rated 350 kV and below, RIV is allowed—at 1.5 times rated maximum line-to-ground voltage. Table 5 of IEEE Std C57.19.01-2017 specifies partial discharge limits.

7.4.4 Tap withstand voltage

A rated frequency withstand test shall be applied to or induced at the tap for 1 min with the bushing mounting flange grounded. Voltage tap shall be tested at 20 kV. Test tap shall be tested at 2 kV.

7.4.5 Leak tests

Liquid-filled bushings shall be verified for leakage by applying an internal gauge pressure of 140 kPa for a minimum of 1 h and a full vacuum applied for 1 h without resultant leakage.

If agreed between the purchaser and manufacturer, an alternative internal pressure test may be carried out where the bushing, without liquid and under the required pressure, is submerged in water for a minimum of 15 min. During this alternative procedure, no evidence of leakage shall be visible.

Dry type bushings that do not have internal cavities, such that leak testing cannot be performed (as it is with liquid-filled bushings), shall be tested for leakage by applying pressure or vacuum across the flange and core interface using helium leak testing equipment. Helium leak testing of the flange shall include both vacuum and pressure and shall be performed before any dielectric filler, external insulator, or sheds are added to the bushing (unless these are part of the casting). For helium leak testing, the leak rate for vacuum and pressure testing at one atmosphere of differential pressure shall not exceed 10^{-5} mL/s as detected with a mass spectrometer.

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] ANSI C68.1-1968, American National Standard Techniques for Dielectric Testing.[19]

[B2] IEC 60137, Insulated bushings for alternating voltages above 1000 V.[20]

[B3] IEC/IEEE Std 65700-19-03™, IEC/IEEE International Standard—Bushings for DC application.[21]

[B4] IEEE Std C57.19.100™, IEEE Guide for Application of Power Apparatus Bushings.

[19]ANSI publications are available from the American National Standards Institute (https://www.ansi.org/).
[20]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (https://www.iec.ch/).
[21]IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (https://standards.ieee.org/).

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