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(Revision of
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C57.19.00™

IEEE Standard General Requirements and Test Procedure for Power Apparatus Bushings

IEEE Power Engineering Society

Sponsored by the
Transformers Committee

IEEE

3 Park Avenue, New York, NY 10016-5997, USA

8 June 2005

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Transformers Committee
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IEEE Power Engineering Society

Approved 8 December 2004

IEEE-SA Standards Board

Abstract: This standard applies to power apparatus bushings that have basic impulse insulation levels of 110 kV and above for use as components of oil-filled transformers and oil-filled reactors.
Keywords: apparatus bushings, bushings, oil-filled reactors, oil-filled transformers

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Introduction

This introduction is not part of IEEE Std C57.19.00-2004, IEEE Standard 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 in the Bushing Subcommittee of the IEEE Transformers Committee.

The related IEC standard is IEC-60137 (1995), *Insulated bushings for alternating voltages above 100 V.*

This revision of the standard, which supersedes IEEE Std C57.19.00-1991 (R1995), includes the following significant changes:

- Reorganization and rearrangement to meet the requirements of the IEEE 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.

The original standard, approved in 1942 as AIEE Standard 21 (which became American National Standard for Apparatus Bushings, ANSI C76.1-1943) was prepared by the Joint Committee on Bushing Standardization of the Electric Machinery, Power Transmission and Distribution, and Protection Devices Committees of the American Institute of Electrical Engineers (AIEE) [now the Institute of Electrical and Electronics Engineers (IEEE)] and the National Electrical Manufacturers Association (NEMA). The American National Standards Institute (ANSI) Accredited Standards Committee, C76, was the sponsor of the standard.

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 (composed of representatives of the High Voltage Insulation Section, Power Circuit Breakers Group, Switchgear Section, and the Transformers Section). It resulted from work by the regional associations of electrical utilities and filled the needs of the user for dimensional interchangeability.

At the time of this supplement, Committee C76 foresaw the need for a general revision and updating of the standard and asked AIEE and NEMA to submit recommendations. In NEMA, implementation of this request was undertaken by a Subcommittee of the Joint Sections Committee on Outdoor Apparatus Bushings and resulted in a proposal, which was approved in February 1960 by the Codes and Standards Committee for submission to Committee C76 as the NEMA recommendation. In the AIEE, a Joint Working Group consisting of members of the Transformer and Dielectric Test Committee, of the Transformers Committee and of the Power Circuit Breaker Committee, was established and developed a recommendation that was submitted to Committee C76 in July 1960. The West Coast Subcommittee of the AIEE Transformers Committee, which developed additional recommendations and submitted them to Committee C76 in November 1960, subsequently reviewed the AIEE proposal. Committee C76 appointed a special Working Group for Revision of ANSI C76.1-1943 to consolidate the several proposals and recommendations. This became IEEE Std 21™-1964 and was approved June 9, 1964, as ANSI C76.1-1964. It was reaffirmed in 1970.

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Work on a revision was initiated in Committee C76 in August 1968. A decision was made to separate the standard into three parts: the first (C76.1) to cover the general requirements and test procedures, the second (C76.2) to cover explicit ratings and dimensions, and the third to be an application guide (IEEE Std C57.19.100™), published in 1995. Other 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.

The revised standard was approved as IEEE Std 21-1976 on June 3, 1976, and as ANSI C76.1-1976 on July 23, 1976.

Work on the revision approved in 1991 (reaffirmed in 1996) was initiated in the then newly formed Bushing Subcommittee of the Transformers Committee in October 1979. Extensive changes to the standard included a new standard number, 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.This standard applies to systems used to communicate between intelligent electronic devices (IEDs) for substation integrated protection, control and data acquisition. The requirements of this standard are in addition to those contained in standards for individual devices (e.g., relays, switchgear).

This standard applies to a rapidly changing technology. It is anticipated that frequent revision may be desirable.

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IEEE Standard General Requirements and Test Procedure for Power Apparatus Bushings

1. Overview

1.1 Scope

This standard applies to power apparatus bushings that have basic impulse insulation levels of 110 kV and above for use as components of oil-filled transformers and oil-filled reactors.

This standard does not apply to the following:

- High-voltage cable terminations (potheads)
- Bushings for oil circuit breakers
- Bushings for instrument 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 distribution-class circuit breakers and transformers
- Bushings for automatic circuit reclosers and line sectionalizers
- Bushings for oil-less and oil-poor apparatus
- Bushings for dc applications

1.2 Purpose

This standard defines the special terms used, service conditions, rating, general requirements, and test procedure for apparatus bushings. See IEEE Std C57.19.01™ for specific listings of values of electrical and mechanical characteristics, dimensions, and other related requirements that are defined or described in this standard.

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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 or corrigenda) applies.

ANSI C63.2, American National Standard for Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz Specifications.[1]

ASTM D3487-00, Specification for Mineral Insulating Oil Used in Electric Apparatus.[2]

IEC 60137, Insulated bushings for alternating voltages above 1000 V.[3]

IEC 60270, High voltage test techniques—partial discharge measurements.

IEEE Std C57.19.01™, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.[4, 5]

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

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

IEEE Std 4™, IEEE Standard Techniques for High Voltage Testing.

IEEE Std 454™, IEEE Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Tests.[6]

IEEE Std 693™, IEEE Recommended Practices for Seismic Design of Substations

NEMA Publication 107, Methods for Measurement for Radio Influence Voltage (RIV) of High-Voltage Apparatus.[7]

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3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition,* should be referenced for terms not defined in this clause.

3.1 ambient temperature: The temperature of the surrounding air that comes in contact with the bushing and device or equipment in which the bushing is mounted.

3.2 apparent charge: The charge which, 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. Apparent charge is usually expressed in picocoulombs.

3.3 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.

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

3.5 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.

3.6 bushing voltage tap: A connection to one of the conducting layers of a capacitance-graded bushing, providing a capacitance voltage divider.

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.[8]

3.7 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.

3.8 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).

3.9 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.

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

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

3.12 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.

3.13 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.

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

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3.14 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.

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

3.16 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.

3.17 draw-rod bushing: A bushing that allows the use of a non–current 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.

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

3.19 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.

3.20 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.

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

3.22 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.

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

3.24 main capacitance (of a capacitance graded bushing): Capacitance between the high-voltage conductor and the voltage tap or the test tap (if no voltage tap is present).

3.25 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).

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

3.27 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.

3.28 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 being filled with oil.

3.29 open bushing: A bushing the internal parts of which 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.

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

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3.31 partial discharge: Within the terms of this standard, 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.

3.32 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.

3.33 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.

3.34 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.

3.35 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.

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

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

3.38 tap capacitance (of a capacitance graded bushing): The capacitance between the voltage tap and mounting flange (ground).

4. Service conditions

4.1 Usual service conditions

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

- The temperature of the ambient air does not exceed 40°C, and the average temperature of the ambient air for any 24 hour 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 does 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.
- The bushing is mounted at an angle of inclination to the vertical not exceeding 20°.

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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	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 must be brought to the attention of those responsible for the design, testing, and application of the equipment. Examples of such conditions are:

- Damaging fumes or vapors, excessive abrasive or conducting dust, explosive mixtures of dust or gases, steam, salt spray, wet conditions, icing, etc.
- Tilting in excess of 20° from vertical
- Abnormal vibration or shocks
- Unusual transportation or storage conditions
- Unusual space limitations
- Unusual temperature applications such as isolated phase bus duct applications
- Proximity of installation adapters and tank walls

5. Rating

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

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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).[9]

5.3.1 Rated frequency test voltage

5.3.1.1 Dry test

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

5.3.1.2 Wet test

The wet test for a bushing is the test voltage that a new bushing shall be capable of withstanding for 10 seconds when tested under the conditions specified in 7.2.1.1. Wet tests are not required for indoor bushings or the indoor end of an air to air bushing.

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 x 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 x 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 wet switching-impulse voltage

The rated wet switching-impulse voltage is the crest value of a 250 x 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.

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

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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 re-testing of existing acceptable bushing designs shall be optional rather than required.

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

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 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 under corresponding headings.

6.1 Electrical requirements

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

6.2 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 same positive pressure as the apparatus to which they are applied.
- Draw lead bushing cap pressure.

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— Bushing voltage tap. All bushings above 350 kV 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.

— 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 is not controlled, the tap is not intended for use 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 lightning-impulse level (BIL).

— Name of the manufacturer, identification number, type, year of manufacture, weight in 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 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.

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Table 2—Design tests for bushings

Test	Clause Number
Internal pressure and vacuum	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 (230 kV and below)	7.2.1.1
Wet switching-impulse withstand voltage (345 kV and above)	7.2.1.4
Rated frequency dry withstand test	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	Clause Number
Internal pressure and vacuum	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	Clause 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™:

— Definitions of tests

— General test procedures

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— 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:

— Except for mechanical tests, bushings shall be mounted on a supporting structure and in the position approximating that for which they were designed and with their ends in the media of the type in which they are intended to operate.

— Bushings shall be completely assembled with all elements normally considered essential parts of the bushings.

— The bushing shall be dry (except for wet tests) and clean.

— Voltage withstand tests shall be made with the following provisions: 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 prevent an arc from striking any grounded object other than the grounded parts of the bushing or the mounting plate. The test connection to the bushing shall be made such that it does not affect the test results.

— 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 35 of IEEE Std 4 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, 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. Correction factors shall be determined in accordance with 16.2 of IEEE Std 4 and shall be applied as follows:

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

— Wet 10-second 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.

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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 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 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 must 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 RIV and/or apparent charge. 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.

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 14.2 (conventional procedure-practice in USA in Table 3) of IEEE Std 4.

If the bushing withstands the specified test voltage for 10 seconds, 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.

7.2.1.2 Full-wave lightning-impulse withstand voltage

Both positive and negative standard 1.2 x 50 μs waves as described in IEEE Std 4 shall be used. Procedure shown under 7.8.2 (Withstand voltage test-procedure B) of IEEE Std 4 shall be used.

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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 microsecond minimum time to flashover per Table 1 in IEEE Std C57.19.01.

7.2.1.4 Wet switching-impulse withstand voltage

This test shall apply only to outdoor bushings rated above 900 kV BIL. A positive polarity standard 250 x 2500 μs impulse, as described in IEEE Std 4, shall be applied under wet conditions described in 14.2 (conventional procedure-practice in USA in Table 3). Procedures shown under 7.8.2.2 (withstand voltage test-procedure B) 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 item c) of 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 hour. Partial discharge measurements, either apparent charge or RIV, shall be made at 5-minute intervals with limits specified in Table 5 of IEEE Std C57.19.01.

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 pressure test of 140 kPa (gage) for 1 hour 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 internal pressure (gage) shall be 70 kPa. The temperature shall be approximately 20°C. The specified load shall (see Table 4 of IEEE Std C57.19.01) be applied for a period of 1 minute. Permanent deformation, measured at the bottom end 1 minute after removal of the load, shall not exceed the values stated in IEEE Std C57.19.01.There shall be no leakage at either end at any time during the test or within 10 minutes after removal of the load.

7.2.3 Temperature rise test

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

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 detected.

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.

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d) For an oil-immersed bushing, the temperature of the oil bath shall be measured by a thermocouple immersed approximately 30 mm below the oil surface and located 300 mm away from the bushing. The oil level shall be maintained within 50 mm of the flange mounting surface. The temperature rise of the oil 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, mid-height and top end of the bushing. The thermocouples shall be located 1 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 can considered to be the case when the measured temperatures do not increase by more than 1°C in 2 hours for bushings up through 900 kV BIL and not more than 1°C in 4 hours for bushings above 900 kV BIL. The 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.

7.2.4 Tap withstand voltage

A rated frequency withstand test shall be applied to or induced at the tap for 1 minute 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 oil shall be immersed in oil. The temperature of the oil shall be maintained at 95°C ± 2°C and shall be measured by means of a thermocouple immersed in oil approximately 30 mm below the surface and about 300 mm away from the bushing.

— 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 or simulated by appropriate means.

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

— Voltage shall not be applied until thermal equilibrium between the oil 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.

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— The bushing has reached thermal stability when its power factor rises no more than 0.02 when measured in percent over a period of 5 hours.

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 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. 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 met provided the crest voltage attained during the test is equal to or more than the voltage determined by Equation (1) as follows:

$$Voltage = MCV * [1 + \{(T - 0.1) - T_1\} / (A * T_1)] \quad (1)$$

where

MCV = minimum crest voltage in kV from Table 5.
T = specific time to sparkover in μsec 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 Practices for Seismic Design of Substations.*

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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 tests in the following clauses 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.

Capacitance C_2 between the voltage tap and grounded flange shall be measured at 10 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.

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

7.4.3 Rated frequency dry withstand test 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 either RIV or apparent charge measurement.

General principles and circuits for RIV measurement 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. Refer to IEEE Std 454™ for general recommendations on both methods of partial discharge measurement.

General principles and circuit for apparent charge measurement are described in IEC Pub 60270 (2000-12), 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:

- Measure RIV or apparent charge at 1.5 times the rated maximum line-to-ground voltage specified by Table 1 in IEEE Std C57.19.01. Partial discharge limits are specified in Table 5 of IEEE Std C57.19.01.
- Perform a 1 minute dry withstand test at the voltage specified in Table 1 of IEEE Std C57.19.01. 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.

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— Repeat measurements of RIV or apparent charge at 1.5 times rated maximum line-to-ground voltage. Table 5 of IEEE Std C57.19.01 specifies partial discharge limits.

At the time this document was revised there were efforts underway in IEEE Std C57.12.90™, *Test Codes for Transformers,* to standardize in the use of apparent charge measurements (in picocoulombs) for transformers. If this requirement becomes a standard, users may require that apparent charge measurements (pC) be done on bushings in stead of RIV measurements.

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 Internal pressure and vacuum tests

An internal pressure test shall be applied at 140 kPa (gage) for a minimum of 1 hour and a full vacuum shall be applied for 1 hour without resultant leakage.

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

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