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(Revision and redesignation of
ANSI/IEEE Std 21-1976)

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

Sponsor

Transformers Committee
of the
IEEE Power Engineering Society

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Abstract: Service conditions, rating, general requirements, and test procedures for outdoor apparatus bushings are set forth. They apply to outdoor power apparatus bushings that have basic impulse insulation levels of 110 kV and above for use as components of oil-filled transformers, oil-filled reactors, and oil circuit breakers. The following are not covered: high-voltage-cable terminations (potheads), 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 reclosures and line sectionalizers, and bushings for oil-less and oil-poor apparatus.

Keywords: apparatus bushings, bushings, oil circuit breakers, oil-filled reactors, oil-filled transformers

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Foreword

(This foreword is not a part of IEEE C57.19.00-1991, IEEE Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings.)

This document is based on the standard practices in the United States for outdoor power apparatus bushings. It is the result of joint efforts of professional engineers, manufacturers, and users working together in an Accredited Standards Committee, C76, under the auspices of the American National Standards Institute (ANSI). The work was initially carried out under the auspices 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 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 AIEE.

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 AIEE proposal was subsequently reviewed by the West Coast Subcommittee of the AIEE Transformers Committee, which developed additional recommendations and submitted them to Committee C76 in November 1960. 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.

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. The latter is still under consideration. Other changes in this revision included

(1) Test procedure updating
(2) 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
(3) 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 latest revision 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 C57.19.00, which is indicative of its Sponsor Committee. Other major changes were made to improve the test sequence, to allow apparent charge measurements to be made instead of radio influence voltage measurements during the low-frequency dry withstand tests, and to provide for special tests, such as thermal stability tests.

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

1. Scope and Purpose

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

This standard does not apply to the following:

(1) High-voltage cable terminations (potheads)
(2) Bushings for instrument transformers
(3) Bushings for test transformers
(4) Bushings in which the internal insulation is provided by a gas
(5) Bushings applied with gaseous insulation (other than air at atmospheric pressure) external to the bushing
(6) Bushings for distribution-class circuit breakers and transformers
(7) Bushings for automatic circuit reclosures and line sectionalizers
(8) Bushings for oil-less and oil-poor apparatus

1.2 Purpose. This standard defines the special terms used, service conditions, rating, general requirements, and test procedure for outdoor apparatus bushings. See IEEE C57.19.01-1991 [5] for specific listings of values of electrical and mechanical characteristics, dimensions, and other related requirements that are defined or described in this standard.

2. References

The following standards form a part of this standard to the extent specified in this document:

[1] ANSI C63.2-1987, American National Standard for Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz Specifications.[1]

[2] ASTM D3487-88, Specification for Mineral Insulating Oil Used in Electric Apparatus.[2]

[3] IEC Pub 137 (1984), Bushings for alternating voltages above 1 000 V.[3]

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[1]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[2]ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

[3]IEC publications are available from IEC Sales Department, Case Postale 131, 3 rue de Varembé, CH 1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[4] IEC Pub 270 (1981), Partial discharge measurements.

[5] IEEE C57.19.01-1991, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.[4]

[6] IEEE C57.19.101-1989, IEEE Trial-Use Guide for Loading Power Apparatus Bushings.

[7] IEEE C57.113-1988, IEEE Trial-Use Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.

[8] IEEE Std 4-1978, IEEE Standard Techniques for High Voltage Testing.

[9] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms.

[10] IEEE Std 454-1973 (Reaff. 1979, W1988). IEEE Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Tests.[5]

[11] NEMA Publication 107-1987, Methods for Measurement for Radio Influence Voltage (RIV) of High-Voltage Apparatus.[6]

3. Definitions

For terms not specifically defined in this standard, see IEEE Std 100-1988 [9].

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.

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.

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 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.

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.

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[5]IEEE Std 454-1973 has been withdrawn; however, copies can be obtained from the IEEE Standards Department, IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[6]NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

capacitance (of bushing)

(1) The main capacitance, C_1, of a bushing is the capacitance between the high-voltage conductor and the voltage tap or the test tap.
(2) The tap capacitance, C_2, of a capacitance graded bushing is the capacitance between the voltage tap and mounting flange (ground).
(3) 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 in which the internal insulation consists of several coaxial layers of different insulation materials.

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 line voltage and the metal flange at the ground voltage.

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 hollow conductor of the bushing and connected to the top of the bushing.

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

interchangeable bushing. A bushing designed for use in oil-filled power transformers, reactors, and oil circuit breakers.

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

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

oil. As used in this standard, mineral oil as described in ASTM D3487-88 [2].

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.

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.

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.

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 voltamperes, when tested under a sinusoidal 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.

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 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.

solid bushing. A bushing in which the major insulation is provided by a ceramic or analogous material.

4. Service Conditions

4.1 Usual Service Conditions. Apparatus bushings conforming to this standard shall be suitable for operation at their ratings, provided

(1) The temperature of the ambient air is not above 40 °C or below -30 °C
(2) The altitude does not exceed 1000 m (3300 ft)
(3) The temperature of the transformer insulating oil in which the lower end of the bushing is immersed and the bushing mounting surface does not exceed 95 °C averaged over a 24 h period
(4) For bushings in oil circuit breakers, the temperature of the insulating oil in which the lower end is immersed does not exceed 80 °C
(5) The external terminal and bus connections, when operated alone at rated current, do not exceed a 30 °C rise
(6) The bushing is mounted at an angle of inclination to the vertical not exceeding 20°

4.2 Unusual Service Conditions. Bushings complying with this standard may be applied at higher or lower ambient temperatures or at higher altitudes than specified in 4.1, but their performance may be affected.[7]

4.2.1 Applications at Altitudes Greater Than 1000 m (3300 ft). 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 (3300 ft). The minimum insulation necessary at the required altitude can be obtained by dividing the standard insulation at 1000 m (3300 ft) by the appropriate correction factor from Table 1.)

Table 1
Dielectric-Strength Correction Factors for Altitudes Greater Than 1000 m (3300 ft)

Altitude		Altitude Correction Factor for Dielectric Strength
(ft)	(m)	
3 300	1000	1.00
4 000	1200	0.98
5 000	1500	0.95
6 000	1800	0.92
7 000	2100	0.89
8 000	2400	0.86
9 000	2700	0.83
10 000	3000	0.80
12 000	3600	0.75
14 000	4200	0.70
15 000	4500	0.67

NOTE: An altitude of 15000 ft (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 should be brought to the attention of those responsible for the design, testing, and application of the equipment. Examples of such conditions are:

(1) Damaging fumes or vapors, excessive abrasive or conducting dust, explosive mixtures of dust or gases, steam, salt spray, excessive moisture or dripping water, icing, etc.
(2) Tilting in excess of 20° from vertical
(3) Abnormal vibration or shocks
(4) Unusual transportation or storage conditions
(5) Unusual space limitations
(6) Unusual temperature applications
(7) Proximity of installation adapters and tank walls

[7]Details will be considered in the application guide, IEEE PC57.19.100, which is under development.

5. Rating

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

(1) Rated maximum line-to-ground voltage
(2) Rated frequency
(3) Rated dielectric strength
(4) Rated continuous current

5.1 Rated Maximum Line-to-Ground Voltage. The rated maximum line-to-ground voltage is the highest rms power 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 Tables 1 and 2 of IEEE C57.19.01-1991 [5]) and shall include the following:

5.3.1 Rated Low-Frequency Test Voltage

5.3.1.1 Dry Test. The test for a dry 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 test for a wet bushing is the test voltage that a new bushing shall be capable of withstanding for 10 s when tested under the conditions specified in 7.2.1.1.

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.

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 of the current-carrying parts in contact with temperature index 105 insulation shall not exceed 65 °C over ambient air, and the temperature of noncurrent-carrying metal parts in contact with temperature index 105 insulation shall not exceed 105 °C total temperature when bushings are operated under the following conditions:

(1) When the lower end of the bushing is immersed to the minimum oil level in oil having a rise of 55 °C over the ambient air and the bushing is carrying the rated current for transformer applications.
(2) When the lower end of the bushing is immersed to the minimum oil level in oil having a rise of 40 °C over ambient air and the bushing is carrying the rated current for circuit breaker applications.

NOTE: Bushings that pass the thermal basis of rating tests in oil according to (1) in 5.4.1 with a 55 °C temperature rise over ambient air are suitable for use in 65 °C rise oil-filled transformers. The oil temperature in these transformers is limited to 95 °C averaged over a 24 h period, which is equivalent to conditions used in the bushing thermal test.

For further clarification of basis of rating versus temperatures encountered in operation, see IEEE C57.19.101-1989 [6].

5.4.2 Draw-Lead Applications. During the draw-lead application, the central conductor of the bushing does not carry any current and, therefore, the current rating of the draw-lead is not associated with the bushing current rating. The current rating for this type of application is solely limited by the hottest-spot temperature of the draw-lead conductor used.

6. General Requirements

This standard includes a number of general requirements that are applicable to certain ratings of outdoor power apparatus bushings. Specific values for these requirements are listed elsewhere in this standard or in IEEE C57.19.01-1991 [5] under corresponding headings.

6.1 Electrical Requirements

(1) Voltage withstand tests
(2) Partial discharge
(3) Power factor
(4) Creep distance

6.2 Mechanical Requirements

(1) Dimensions
(2) Cantilever strength
(3) Internal pressure and vacuum
(4) Transformer or interchangeable bushings that have oil volumes separate from the transformer. These shall be designed to withstand full vacuum when mounted in the transformer tank.
(5) Draw lead bushing cap pressure
(6) Bushing voltage tap. All bushings 450 kV basic lightning-impulse insulation level (BIL) and above shall be provided with a bushing voltage tap. These taps shall be either normally grounded or normally ungrounded, as shown in Fig 1 of IEEE C57.19.01-1991 [5].
(7) Bushing test tap. All capacitance-graded bushings with BIL below 450 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 Nameplate Markings. The following information shall appear on all bushing nameplates, except on small 110 kV BIL bushings, which shall be marked in a conspicuous place with the specific identification of the manufacturer.

(1) Name of the manufacturer, identification number, type, year of manufacture, and serial number
(2) Rated maximum line-to-ground voltage
(3) Rated continuous current (see NOTE)

NOTE: Where bushings have a dual continuous current rating, the nameplate shall indicate the rating for

(1) Oil circuit breaker application
(2) Power transformer application

(4) Rated full-wave lightning-impulse withstand voltage (BIL)
(5) Capacitance C_1 and C_2, on all bushings equipped with voltage taps, and C_1 on all bushings equipped with test taps
(6) Power factor measured from conductor to tap, where applicable, at 10 kV or above and referred to 20 °C, by the Ungrounded Specimen Test (UST) method
(7) Length of bushing below mounting surface (L)

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, and specifies the tests that will demonstrate ratings in this standard. It does not preclude the use of other equivalent or more effective methods of demonstrating ratings. These tests are divided into the following classifications:

(1) Design tests
(2) Special tests
(3) Routine tests

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 sections of this standard. The following shall be in accordance with applicable sections in IEEE Std 4-1978 [8]:

(1) Definitions of tests
(2) General test procedures
(3) Characteristics and tolerance of waveshapes
(4) Method of measurement
(5) Standard atmospheric and precipitation conditions
(6) Rate and duration of voltage application for low-frequency tests

7.1.2 Test Specimen Requirements. The test specimen shall comply with the following requirements:

(1) 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.
(2) Bushings shall be completely assembled with all elements normally considered essential parts of the bushings.
(3) The bushing shall be dry (except for wet tests) and clean.
(4) Voltage withstand tests shall be made with the following provisions: The bushing shall be mounted on a relatively flat metallic grounded mounting plate that extends outward from the bushing flange at least 25% of the porcelain height to 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.

(5) For partial discharge tests, suitable external shielding may be applied to eliminate external corona on the air-end terminal.

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 (50 °F and 104 °F).

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 Fig 1.5 of IEEE Std 4-1978 [8] for determination of absolute humidity.

7.1.4 Correction Factors. When actual test conditions vary from standard test conditions as specified in IEEE Std 4-1978 [8], correction factors k_d for variation in relative air density and k_h 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 the rod-gap configuration of Table 1.3 of IEEE Std 4-1978 [8] and shall be applied as follows:

(1) Dry 1 min low-frequency withstand tests: No corrections
(2) Wet 10 s low-frequency withstand tests: Correction factor k_d may be applied
(3) Full-wave lightning-impulse withstand tests: Correction factors k_d and k_h may be applied at either positive or negative polarity, but not at both
(4) Chopped-wave lightning impulse test: No correction
(5) Wet switching-impulse withstand tests: Correction factor k_d 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 shall not be required as a result of minor changes in standard atmospheric conditions or correction factors now used in IEEE Std 4-1978 [8] (the revision of ANSI C68.1-1968).

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 stressed 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 are Tables 9 and 10 of IEEE C57.19.01-1991 [5].

Design tests shall include the following, plus all routine tests specified in 7.4, except that the low-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

(1) Low-frequency wet withstand voltage
(2) Full-wave lightning-impulse withstand voltage
(3) Chopped-wave lightning-impulse withstand voltage
(4) Wet switching-impulse withstand voltage (only for applications on maximum system voltage 362 kV and above)
(5) Low-frequency dry withstand test with partial discharge measurements

7.2.1.1 Low-Frequency Wet Withstand Voltage. Wet withstand tests shall apply only to bushings for use at maximum system voltages of 242 kV or less and shall be applied under wet conditions described in section 1.3.3.2 (Practice in USA in Table 1.2) of IEEE Std 4-1978 [8].

If the bushing withstands the specified test voltage for 10 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.

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 4-1978 [8] shall be used. Procedures shown under section 2.4.3.1.3 of IEEE Std 4-1978 [8] 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.

7.2.1.4 Wet Switching-Impulse Withstand Voltage. This test shall apply only to bushings intended for use at maximum system voltages of 362 kV and above. A positive polarity standard 250 x 2500 μs impulse, as described in IEEE Std 4-1978 [8], shall be applied under wet conditions described in section 1.3.3.2 (Practice in USA in Table 1.2). Procedures shown under section 2.4.3.1.3 shall be used.

7.2.1.5 Low-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 Step 3 shall be applied for 1 h. Partial discharge measurements, either apparent charge or RIV, shall be made at 5 min intervals.

7.2.2 Mechanical Tests

(1) Draw-lead bushing cap pressure test
(2) Cantilever strength tests

7.2.2.1 Draw-Lead Bushing Cap Pressure Test. The bushing cap assembly shall withstand an internal hydraulic pressure test of 138 kPa (20 lb/in^2 gauge) 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 internal pressure (gauge) shall be 69 kPa (10 lb/in^2). The temperature shall be approximately 25 °C. The specified load shall (see Table 8 in IEEE C57.19.01-1991 [5]) 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 0.76 mm (0.03 in). There shall be no leakage at either end at any time during the test or within 10 min after removal of the load.

7.2.3 Thermal Tests. Thermal tests shall apply to bottom-connected bushings only. The bushing shall be tested in the following manner:

(1) The connections to the bushings shall be made in such a manner that they will not appreciably affect the bushing temperature rise. The lower end of the bushing shall be immersed to the oil level required in 5.4.1 at test ambient temperature.
(2) Rated continuous current at rated frequency shall be applied continuously until thermal conditions become constant or until the measured temperatures do not increase by more than 1 °C for 2 h for bushings up thru 900 kV BIL and not more than 1 °C for 4 h for bushings 1050 kV BIL and above. Operating voltage need not be applied during the test.
(3) The temperatures during the test shall be measured with thermocouples in sufficient number to detect the hottest part. The temperature of the hottest point on the conductor of the bushing shall be determined by thermocouples soldered or suitably fixed along the length of the conductor or imbedded in the insulation.
(4) The ambient temperature shall be determined as that of the surrounding air by taking the average reading of three thermometers, placed at least 610 mm (2 ft) away from any part of the bushing on test. The thermometers shall be located at heights corresponding to the mounting flange, midpoint, and top end of the bushing. The temperature of the surrounding air shall not be less than 10 °C nor more than 40 °C. No corrections for variations of the ambient temperature within this range shall be applied.
(5) The temperature of the lower end (oil bath) shall be measured by a thermocouple immersed approximately 50 mm (2 in) below the oil surface and located approximately 150 mm (6 in) from the surface of the bushing.
(6) Requirements, as outlined in 5.4.1, shall be fulfilled or the bushing shall be considered to have failed.

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 user 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:

(1) 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 ± 2 °C and shall be measured by means of thermometers immersed in oil about 50 mm (2 in) below the surface and about 300 mm (12 in) from the bushing.
(2) Rated continuous current at rated frequency shall be applied throughout the test.
(3) The test voltage shall be equal to 1.2 times the rated maximum line-to-ground voltage as specified by Table 2 of IEEE C57.19.01-1991 [5].
(4) Voltage shall not be applied until thermal equilibrium between the oil and the bushing has been reached.
(5) During the test, the power factor shall be measured periodically and the ambient air temperature shall be recorded at each measurement.

(6) 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 h.
(7) 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.

7.4 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 subsections 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 and, where applicable, capacitance C_2 between the voltage tap and grounded flange shall be measured at 10 kV or above before and after their respective low-frequency withstand voltage tests. Tolerance of acceptable change is specified by Table 10 of IEEE C57.19.01-1991 [5].

7.4.2 Power Factor. The power factor between the bushing conductor and the bushing tap shall be measured at 10 kV or above by the UST method before and after the low-frequency withstand voltage test.

Solid bushings not equipped with taps shall be tested by the Grounded Specimen Test (GST) method after the low-frequency withstand voltage test.

Limits and tolerance of acceptable change are specified by Table 10 of IEEE C57.19.01-1991 [5].

7.4.3 Low-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 107-1987 [11]. A radio noise and field-strength meter conforming to ANSI C63.2-1987 [1] 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 454-1973 [10] for general recommendations on both methods of partial discharge measurement.

General principles and circuit for apparent charge measurement are described in IEC Pub 270 (1981) [4], and a particular type of wide-band measurement is described in IEEE C57.113-1988 [7].

Measurements may be made by using either the bushing voltage tap or the coupling capacitor method.

Transformer bushings shall be subjected to the following test procedures:

(1) Measure RIV or apparent charge at 1.5 times the rated maximum line-to-ground voltage specified by Tables 1 and 2 in IEEE C57.19.01-1991 [5]. Partial discharge limits are specified by Table 9 of IEEE C57.19.01-1991 [5].
(2) Perform a 1 min dry withstand test at the voltage specified by Tables 1 or 2 in IEEE C57.19.01-1991 [5]. 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.

(3) Repeat measurements of RIV or apparent charge at 1.5 times rated maximum line-to-ground voltage. Partial discharge limits are specified by Table 9 of IEEE C57.19.01-1991 [5].

Since power circuit breakers are not normally subjected to partial discharge measurements, an alternate test maybe applied for oil-impregnated paper-insulated bushings applied specifically to power circuit breakers. If partial discharge measurements are not made according to the above procedure, the power factor and capacitance of the C_1 component of the major insulation shall be measured at maximum line-to-ground voltage before and after the low frequency dry withstand voltage test. If partial discharge measurements have been made, then the power factor and capacitance measurements may be made at 10 kV or higher. The bushing shall comply with the limits of change shown in Table 10 of IEEE C57.19.01-1991 [5].

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

7.4.5 Mechanical Tests. An internal hydraulic pressure test shall be applied at 138 kPa (20 psi gauge) for a minimum of 1 h without resultant leakage.