IEEE432

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IEEE Std 432-1992
(Revision of
IEEE Std 432-1976)

IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp)

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IEEE Std 432-1992

Published by the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017, USA.

September 29, 1992 *SH15438*

IEEE
Std 432-1992
(Revision of IEEE Std 432-1976)

IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp)

Sponsor

Electric Machinery Committee
of the
IEEE Power Engineering Society

Approved June 18, 1992

IEEE Standards Board

Abstract: Information necessary to permit an effective evaluation of the insulation systems of medium and small rotating electric machines is presented. The guide is intended to apply in general to industrial air-cooled machines rated from 5 hp to 10 000 hp. However, the procedures may be found useful for other types of machines.

Keywords: industrial power system maintenance, power system maintenance, rotating-machine insulation

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

ISBN 1-56937-237-0

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Foreword

[This foreword is not a part of IEEE Std 432-1992, IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp.)]

The purpose of this guide is to present information necessary to permit an effective evaluation of the insulation systems of medium and small rotating electric machines. Such an evaluation should serve as a guide to the degree of maintenance or replacement that might be deemed necessary and also offer some indication of the future service reliability of the equipment under consideration.

To fulfill these functions, the following should be reviewed:

(1) Service conditions reducing insulation life
(2) Insulation systems in general use
(3) Visual inspection methods
(4) Insulation maintenance testing principles
(5) Electrical insulation tests
(6) Methods for cleaning insulation structures

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IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp)

1. Introduction

1.1 Scope. This insulation maintenance guide is applicable to industrial air-cooled rotating electric machines rated from 5 hp to 10 000 hp. The procedures detailed herein may also be useful for other types of machines.

1.2 References. This guide should be used in conjunction with the following publications. When the standards are superseded by an approved revision, the revision should apply.

[1] IEEE Std 4-1978, IEEE Standard Techniques for High Voltage Testing (ANSI).[1]

[2] IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery (ANSI).

[3] IEEE Std 56-1977 (Reaff 1991), IEEE Guide for Insulation Maintenance of Large AC Rotating Machinery (10 000 kVA and Larger) (ANSI).

[4] IEEE Std 62-1978, IEEE Guide for Field Testing Power Apparatus Insulation.

[5] IEEE Std 67-1990, IEEE Guide for Operation and Maintenance of Turbine Generators (ANSI).

[6] IEEE Std 95-1977 (Reaff 1991), IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage (ANSI).

[7] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms—4th ed. (ANSI).

[8] IEEE Std 433-1974 (Reaff 1991), IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency (ANSI).

9] IEEE Std 492-1974 (Reaff 1986), IEEE Guide for Operation and Maintenance of Hydro-Generators (ANSI).

[10] IEEE Std 522-1992, IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines.

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[1] 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.

2. The Significance of Maintenance

Rotating electric machines are complex structures that are subjected to mechanical, electrical, thermal, and environmental stresses of varying magnitude. Of the various components, the insulation systems are the most susceptible to aging or damage due to these stresses. The service life of an electric machine will, therefore, largely depend on the serviceability of the insulation systems.

Where reliability is of concern, adequate inspection and testing programs are advocated to assure that the equipment is maintained in satisfactory condition to minimize the possibility of in-service failure.

The experience and data obtained from regular maintenance inspection and testing programs can, in addition to providing an evaluation of the present condition of the equipment, give some indication of long-term trends and probable need for future repair or replacement.

The extent to which a maintenance program is pursued will depend largely on the operator's own experience and philosophy, but should also take into account the importance of service reliability for the equipment. Where high service reliability is required, a regular maintenance program involving periodic disassembly and knowledgeable visual examination of the equipment, together with the application of electrical tests of proven significance, is strongly recommended.

It should be recognized that overpotential tests can damage insulation that is contaminated or in marginal condition. Where there is uncertainty, consultation with the manufacturer is recommended. This is implicit in setting up an appropriate maintenance testing program.

3. Service Conditions Reducing Insulation Life

As has been stated, electric machines and their insulation systems are subjected to mechanical, electrical, thermal and environmental stresses that give rise to many deteriorating influences. The most significant of these are the following:

(1) *Thermal aging.* This is the normal service temperature deteriorating influence on insulation.
(2) *Overtemperature.* This is the unusually high temperature of operation caused by conditions such as overload, high ambient temperature, restricted ventilation, foreign materials deposited on windings, or winding faults.
(3) *Overvoltage.* This is an abnormal voltage higher than the service voltage such as caused by switching, lightning surges, or certain power supplies.
(4) *Contamination.* This deteriorates electrical insulation by conducting current over insulated surfaces, or by attacking the material reducing electrical insulating quality or physical strength, or by thermally insulating the material that causes the material to operate at higher than normal temperatures. Such contaminants include the following:
    (a) Water or extreme humidity
    (b) Oil or grease, including unstable antiwear and extreme pressure lubricants
    (c) Conducting dusts and particles
    (d) Nonconducting dusts and particles
    (e) Chemicals of industry
(5) *Physical damage.* This contributes to electrical insulation failure by opening leakage paths through the insulation. Physical damages includes the following:
    (a) Physical shock
    (b) Vibration
    (c) Overspeed
    (d) Short-circuit forces or line starting
    (e) Erosion by foreign matter

(f) Damage by foreign objects
(g) Thermal cycling

(6) *Ionization effects.* Ionization (corona), which may occur at higher operating voltages, is accompanied by several undesirable effects such as chemical action, heating, and erosion (see Appendix A).

4. Insulation Systems in General Use

4.1 Insulated Parts. Insulation is present in various machine components, but the complexity of the structures is such that no attempt will be made to describe such components in detail. However, such detailed information as well as knowledge of modes of insulation failure are important to permit more meaningful evaluation. Principal components are generally described as follows.

4.1.1 Armature Winding. For the purpose of this guide, the armature winding can be considered to be the main current-carrying winding, usually the stator in ac machines and the rotor in dc machines, including associated leads where applicable. The armature coils usually have wire, turn, and ground insulation. Band insulation is also required for wire-banded armatures (see 4.2.)

DC armatures have commutator insulation, while insulated wedges, blocks, and insulated mechanical supports are common to both ac and dc machines. Shrink rings on commutators require micaceous insulation between the rings and commutator.

4.1.2 Field Windings. The fields of ac machines are either salient pole or cylindrical type, while in dc machines they comprise stationary coils. In all cases, they have turn and ground insulation, insulated mechanical supports, and lead insulation. AC machines, in addition, may have collector ring insulation, retaining ring insulation, and banding insulation.

4.1.3 Brush Rigging. Both ac and dc machines typically have insulated brush riggings.

4.1.4 Core and Frame Assembly. The principal insulation components in this assembly are the insulation between laminations in the core and insulation on through bolts in some designs.

4.1.5 Other Parts. Insulation is sometimes used on bearings to eliminate shaft currents. Insulation is also used to isolate temperature-measuring devices such as thermocouples, resistance temperature detectors, thermistors, etc.

4.2 Armature Winding Insulation

4.2.1 Wire Insulation. The individual wires of armature coils are usually insulated with organic resin enamels, polymeric films or fibers, paper, cotton, glass or polyester-glass fiber, or mica in various forms. Asbestos was formerly in common use. (Note that the alternative term "strand" is described for these components in IEEE Std 56-1977 [3].[2])

4.2.2 Turn Insulation. Groups of wires forming a single conductor may be insulated and held together with insulating tapes including cotton, fiberglass, films, papers, and mica. Individual wire insulation, as described in 4.2.1, may also be used as turn insulation, including materials applied as liquid resin coatings or those applied by taping with materials such as cotton, fiberglass, films, papers, or mica.

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[2] The numbers in brackets correspond to those of the references in 1.2; when preceded by B, they correspond to those of the bibliography in Section 11.

4.2.3 Ground Insulation. Ground insulation is generally defined as that insulation intended to isolate the current-carrying components (such as the armature conductors, the commutator, the slip rings, and connections thereto) from the non-current-carrying components (such as the core iron, the shaft, and other structural members).

Ground insulation takes on many different forms depending on the type of machine, intended use, ambient conditions, design, temperature class, and manufacturer's standard practice.

Ground insulation is generally a dry-type multilayered system comprising various insulating materials bonded and filled by different processes. Two common bonding materials are polyester- and epoxy-based resins. Mica or micaceous products are generally preferred in high-voltage machines for at least a part of the ground insulation system. For low-voltage machines, many materials in addition to mica composites have proven acceptable in service.

4.2.4 Commutator Insulation. A commutator is a cylindrical assembly of wedge-shaped copper segments separated from each other and ground by insulation that is usually micaceous. This structure is mechanically locked together by various techniques including vee grooves, cones and support rings at commutator bar ends, steel shrink rings over ring insulation on the commutator surface, and high-tension fiberglass bands applied into grooves in the commutator surface. Small-size units are often compression molded with a high-strength molding compound.

4.2.5 Support Insulation. Support insulation, such as blocks, slot wedges, etc., are usually made from wood, compressed laminates of fibrous materials, polyester, or similar felt pads impregnated with various types of bonding agents.

4.3 Field Windings

4.3.1 AC Machines. The rotating field coils, whether of the salient pole or cylindrical type, usually have fabricated ground insulation formed to the required configuration. Many organic and inorganic materials are used.

4.3.2 DC Machines. The stationary field coils of dc machines are constructed in a similar fashion to ac rotating field coils, except that they need not be built to withstand the effect of centrifugal forces. DC field coils are usually a complex assembly of exciting and commutating coils, each fitted over and insulated from a pole piece. Some coils contain multiple windings.

4.3.3 Collector Lead and Ring Insulation. The insulation used on current collector rings must be adequate for mechanical support and must provide adequate creepage to the grounded shaft. A wide choice of materials is available.

4.4 Brush-Rigging Insulation. The insulated components on brush riggings are generally made from molding compounds, laminated boards, or tubes made from paper, cotton, or glass fibers suitably bonded and impregnated. Moisture-resistant surfaces are very important for these components.

4.5 Core and Frame Assembly

4.5.1 Stator Core Interlaminar Insulation. Stator cores are built up with thin laminations insulated from each other to reduce core losses. A variety of thin insulating coatings, such as core-plate varnish, water-glass, and other chemical deposits, are used. On very small machines or machines where the volts per turn in the stator winding is low, iron oxides produced by appropriate annealing processes are often used.

Failure of interlaminar insulation may occur and is usually precipitated by external causes. Among these causes are overexcitation, mechanical damage due to foreign objects, vibration, excessive heating due to power arcs created by winding failure, or excessive losses in the finger plates of large machines. Failure may also occur from re-wind processing when excessive heat, such as burnout, is applied for coil removal at the service shop to cores with laminations insulated with organic coatings.

Such damage can initiate winding insulation faults and equipment failure. Careful inspection of the core condition is, therefore, mandatory whenever the machine in question is out of service for maintenance purposes. If distress is observed, a loop test is recommended. The loop test is described in Appendix A.

5. Visual Inspection Methods

To achieve maximum effectiveness, a visual inspection program should be directed initially to those areas that have been shown by previous experience to be most prone to the forms of damage or degradation caused by the influences listed in Section 3 of this guide.

The most suspect areas for deterioration or damage to which inspection should be directed are discussed in the following paragraphs. A suggested condition appraisal, summarizing these suspect areas for deterioration or damage, is shown in Appendix B.

5.1 Armature Winding

5.1.1 Deterioration or Degradation of Insulation From Thermal Aging. Examination of coils may reveal general puffiness, swelling into ventilation ducts, or a lack of firmness of the insulation, suggesting a loss of bond with consequent separation of the insulation layers from themselves or from the winding conductors or turns. (They will have a hollow sound when tapped.) The insulation may also be embrittled.

Shrinkage of the insulation, with consequent loosening of the coil in the slot or at the bracing, may also occur and may result in vibration and ground wall wear-away, producing dusting plus loss of coil semiconducting outer covering and thinning of the ground-wall insulation.

5.1.2 Girth Cracking. Girth cracking or separation of the ground wall is likely to occur on coils or bar windings and on machines having bar-type stator coils greater than about 12 ft (4 m) in length. Particular attention should be paid to the areas immediately adjacent to the ends of the slots. Where considerable cracking is observed, it is recommended that the wedges at the ends of the slot be removed, if possible, for inspection, as dangerous cracks may also have occurred just within the slots.

5.1.3 Contamination. The contamination of coil and connection surfaces adversely affects insulation strength. The most common contaminants are carbon dust, oil, and moisture.

5.1.4 Abrasion. Coil and connection surfaces may be damaged by abrasion or contamination from other sources, such as chemicals, or abrasive or conducting substances. Such effects are aggravated in the case of motors used in adverse atmospheric industrial applications, such as chemical plants, rubber mills, and paper manufacturing facilities. Abrasion-resistant coatings are often used to extend the life of windings operating in abrasive environments.

5.1.5 Cracking. Cracking or abrasion of insulation may result from prolonged or abnormal mechanical stresses. In stator windings, looseness of the bracing structure is a certain guide to such phenomena, and can itself cause further mechanical or electrical damage if allowed to go unchecked.

5.1.6 Erosion. Erosion may be caused by foreign substances impinging against coil insulation surfaces. Particularly damaging are magnetic particles that vibrate with the effects of the magnetic field in the machine.

5.1.7 Corona. Insulation is deteriorated by corona discharges in the body of the machine or end windings in the higher-voltage ratings. These are evident by white, gray, or red deposits in areas where the insulation is subject to high electrical stresses. Some experience is required to distinguish these effects from powdering, which can occur as a result of movement between surfaces such as in loose end-winding structures.

5.1.8 Loose Slot Wedges or Slot Fillers. This condition, if allowed to go uncorrected, may result in mechanical damage or may reduce the effectiveness of coil retention against short circuit and other abnormal mechanical forces resulting in corona in the slots.

5.1.9 Overspeed. The effects of overspeed may be observed on dc armatures by distortion of the windings or commutator risers, looseness or cracking of the banding, or movement of slot wedges.

5.1.10 Commutator Condition. Commutators should be checked for uneven discoloration, which can result from short-circuiting due to breakdown of insulation between bars, and from pin holes and burrs caused by flashover.

5.1.11 Carbon Deposits. Carbon accumulation over surfaces that are insulated to isolate current-carrying members from each other or from ground potential can provide paths for damaging leakage currents. For example, the risers (the connection straps between commutator bars and coils) may collect carbon deposits that can cause electrical leakage and subsequent failure. The area immediately behind the commutator can also be a repository for carbon.

5.1.12 Commutator Glass Bands. Commutator groove bands should be carefully inspected for (1) dryness or darkening, which may be an indication of loss in strength due to overtemperature, and (2) circumferential cracks within the band or at the groove walls, which may admit conductive contaminants. Separation of the band at the groove wall may be indicative of internal damage.

Restraining bands ("string bands"), which secure the exposed surface of the commutator cones, should be inspected for separation from the segment surface. Separation at this point is an area for entry of contaminants.

5.2 Field Windings. In addition to insulation degradation from causes similar to those listed in 5.1, close attention should be directed to the following in field windings:

5.2.1 Coil Distortion. Distortion of coils may be caused by abnormal mechanical, electrical, or thermal forces. Such distortion may cause failure of turn or ground insulation.

5.2.2 Loose Coils. Shrinkage and looseness of field coil washers or supports permits coil movement during periods of acceleration and deceleration with the probability of abrading turn insulation and breaking or loosening of connections between coils.

5.2.3 Rotor Coil Tightness. In cylindrical rotors (defined as "round-rotor" in IEEE Std 100-1988 [7]), evidence of heating of wedges at their contact with the retaining ring body, and "half-mooning" or cracks on the retaining rings, can be caused by high circulating currents. These currents may be due to unbalanced operation, excessive loads, or sustained single-phase faults close to the generator, such as in the leads or generator bus.

The condition and tightness of end-winding blocking, signs of deterioration or movement of the retaining ring insulating liner due to the above effects, and any other looseness should be noted.

Powdered insulation in air ducts is evidence of coil movement. Red oxide at metallic joints is evidence of movement of metal parts.

The integrity of field lead connections and condition of collector and collector-lead insulation should be checked.

5.3 Brush Rigging. Insulation supporting the brush rigging should be checked for evidence of flashover or carbonized leakage paths.

5.4 Core and Frame Assembly. In the assembly previously grouped together in 4.5 as the core and frame assembly, the following items are considered to be the most significant.

5.4.1 Stator Core. A close examination should be made at the bore surface for evidence of damage due to rubbing between the stator and rotor by foreign objects or loose laminations in the bore, or by interlaminar shorts following coil failure.

Whenever several laminations have become short-circuited due to these effects, the possibility exists that excessive local heating might arise, aggravating the problem by affecting the interlaminar resistance in the environment of the original fault with danger of further overheating, leading eventually to coil insulation damage.

When core damage is widespread and there is concern about the adequacy of subsequent repairs, a loop test is recommended. This type of test, detailed in 9.1 and Appendix A, can identify local hot spots.

Loose or broken ventilation duct separators or fingers can cause difficulties either by increasing core looseness or by impacting coil insulation. The core laminations should be examined for evidence of looseness, waviness, buckling, or broken teeth.

Overheating of the end finger plates is evident by discoloration of the paint or components in the areas affected. Abnormal overheating can lead to thermal degradation of the insulation between laminations with consequent short-circuiting and damage to the adjacent coil insulation.

5.4.2 Stator Insulated Through Bolts. Where these are fitted, examination of the insulated washer and associated pieces is indicated together with verification of tightness and locking of the nuts. The insulation resistance of through bolts to the stator should also be checked.

5.4.3 Bearing Insulation. This can only be closely examined when the bearing is completely disassembled. An inspection should be made and insulation resistance measured at that time.

6. Insulation Maintenance Testing Principles

A list of electrical tests designed to detect particular areas of weakness is included in this maintenance guide. It should be noted that all tests are not applicable to all machines. Some electrical tests may be potentially damaging to the insulation. The risks with such tests should also be recognized. For example, when a winding is tested that has been providing good service, but has a fault near ground or neutral connections, the fault may be worsened to a potentially nonfunctional condition. Where there is uncertainty, it is recommended that the manufacturer be consulted.

The tests are given in synopsis form in this guide, but further details are provided in Appendix A and in the appropriate IEEE standards to which reference is made.

Insulation evaluation tests can be divided into the following two categories:

(1) Tests to discern existing weaknesses or faults
(2) Tests that give some indication of expected service reliability

The tests have been grouped accordingly in the following sections of this guide. Their classification in this manner is flexible and selection of maintenance tests will depend on the user's own philosophy, performance records, production, and economics. The user is encouraged to discuss findings with the manufacturer for interpretation and trends.

7. Tests to Discern Existing Weakness

7.1 Insulation Resistance Tests at Low Voltage. These tests are usually made on all or parts of an armature or field circuit to ground. They primarily indicate the degree of contamination of the insulating surfaces or solid insulation by moisture and other conducting influences and will not usually reveal complete or uncontaminated ruptures.

Insulation resistance tests are based on determining the current through the insulation and across the surface when a direct voltage is applied. The current is dependent on the voltage and time of application, the area and thickness of the insulation, and on temperature and humidity conditions during the test.

IEEE Std 43-1974 [2] outlines a recommended practice for insulation resistance testing and the corrections to be made for temperature and humidity conditions. Recommended values for minimum insulation resistance for safe operation are published in IEEE Std 43-1974.

The insulation resistance test is used to determine the insulation condition prior to application of an overvoltage test.

7.2 Dielectric Absorption Tests. Dielectric absorption testing involves the determination of insulation resistance as a function of time. This test is also made on all or parts of an armature or field circuit to ground.

IEEE Std 43-1974 [2] outlines test procedures and equipment for the standard method, which is usually made at a test potential of 500 to 5000 V dc. Tests at higher potentials are commonly made usually using the voltmeter-ammeter method of resistance determination.

During this test the potential is held until the insulation resistance stabilizes or for a period of 10 min. The slope of the time resistance characteristic gives information on the relative condition of the insulation with respect to moisture and other contaminants. The ratio of the 10 min value to the 1 min value of insulation resistance is termed the "polarization-index," or PI. This PI value is useful in comparing the results of previous tests on the same machine.

Further details of these tests and suggested acceptable polarization indices for certain insulation systems are contained in Appendix A.

7.3 Overvoltage Tests. Overvoltage tests, also referred to as high-potential or hi-pot tests, are used to assure minimum dielectric strength of the insulation. Such tests are made on all or parts of the circuit-to-ground insulation of the armature or field winding.

Many users of large rotating machines apply overvoltage tests periodically and generally at the beginning of a machine overhaul or the overhaul of related equipment. This allows the detection and possible repair of insulation weaknesses during the scheduled outage.

Overvoltage tests should be applied wherever possible to each phase in sequence, the remaining two phases not under test being solidly grounded. In this way, the insulation between phases (or lines) is also tested. This is only practical, however, where both ends of each phase are brought out to separate terminals, as is usually the case in generators. Except for the larger horsepower ratings, most motors have either three or four leads brought out, precluding a test between phases.

The level of overpotential that should be applied will depend to a very large extent on the type of machine involved, the degree of exposure to overvoltages, and the level of serviceability required from the machine in question. Such tests should, however, be sufficiently searching to discern any weakness or incipient weakness in the insulation structure that might lead to service failure.

Overvoltage tests may be performed either by alternating or direct voltage methods. The values of test voltages usually are selected as follows:

(1) For 60 Hz tests, the overvoltage may be related to the rated machine voltage, and tests in the range of 125 to 150% of the line-to-line voltage are normal. Overvoltage tests are typically conducted for 60 s. For test procedures, refer to IEEE Std 4-1978 [1].

Equipment for making overvoltage tests at very low frequency (0.1 Hz) has become commercially available. Such equipment is typically less in cost and weight and smaller in size than equivalent 60 Hz equipment. For additional information, see IEEE Std 433-1974 [8].

(2) For dc tests, the recommended test voltage is a function of the rated machine voltage multiplied by a factor to represent the ratio between direct (test) voltage and alternating (rms) voltage. The recommended value is from 125 to 150% of the rated line-to-line voltage × 1.7. For test procedures, refer to IEEE Std 95-1977 [6].

It should be recognized that if the windings are clean and dry, overvoltage tests may not detect defects that are in the end turns or in leads remote from the stator core.

7.4 Interturn Insulation Tests. Film insulation usually provides high dielectric strength but, in many cases, the interturn insulation on motor coils is fibrous in nature. Fibrous insulation effectively provides a physical separation of the turns of the order of 0.010 to 0.025 in (0.25–0.635 mm) for motors, and the electric strength between the turns is essentially provided by the insulating value of the gas (air, hydrogen, etc.) contained between these fibers. Micaceous insulations are commonly used in high-voltage machines.

To provide a useful service in checking the adequacy of the insulation between turns, the test level selected must be greater than the minimum sparking potential of the air at the minimum permissible spacing. The test potential will often, therefore, be several times normal operating volts per turn. A test of about 500 V rms per turn is considered average for a new machine, while for maintenance tests potentials of one-half to two-thirds of the new coil turn test, eight to ten times normal operating volts per turn, are usually considered adequate to provide insurance from the possibilities of marginal insulation and contains allowance for switching transients and for surges likely to be encountered in service.

The normal operating volts per turn are often up to about 30 V for motors, while turbine and water-wheel generators are substantially above that value.

The test methods used include forms of surge comparison tests. A steep-front surge is applied to all or part of a winding, or by induction to individual coils within a winding. The resultant waveforms are viewed on an oscilloscope screen and interpretation of the patterns or amplitudes permits detection of short-circuited turns.

The surge comparison test applied directly to the winding terminals is limited, in the case of windings consisting of many coils in series, by the magnitude of the voltage that can be applied to the ground insulation without exceeding its specified test voltage. This limitation can be overcome by placing a surge coil in the bore over the coil to be tested and by applying directly into it a voltage appropriate to the induced volts per turn required in the stator coil. For additional information on procedures and requirements for interturn insulation tests, see IEEE Std 522-1992 [10]. See [B14] for detailed information on surge comparison testing.

7.5 Slot Discharge and Corona Probe Tests. The slot discharge test is conducted for the purpose of checking the adequacy of the ground connection between the surfaces of the coil and the core. Should surface discharging exist, it is important that it be detected, since accelerated deterioration of the ground wall insulation may occur. This test is usually applicable to machines with operating voltages in excess of 6000 V.

The corona probe test is intended to be an indicator and locator of unusual ionization within the insulation structure. The ability of this test to discriminate between harmful and acceptable levels of general ionization phenomena, such as occur in high-voltage windings, has not yet been demonstrated but is under study.

Further details of these tests are given in Appendix A, and in [B9] and [B12].

7.6 Rotor Winding Impedance Tests. Measurement and comparison of the impedance of rotor windings and individual coils provide a useful way of detecting and locating turn-to-turn faults. This test, commonly known as a "voltage drop" test, is sometimes made in the factory and can also be used as a maintenance test. The field winding is energized with low-potential alternating voltage (such as 120 V) at conventional frequency. Current and voltage are measured across various coils. With the field coils connected in series, similar coils should have a comparable voltage drop. Test periods longer than 10 min should be avoided on salient pole rotors with springs since an ac test will overheat the springs.

Comparison of the voltage drops across similar field coils will detect coils with shorted turns. A fault between turns not only reduces the total effective turns, but a short-circuited turn also produces a reduction in impedance. The test is suitable for cylindrical rotors of turbine generators and for multiple fields of other machines.

An impedance test can be made on the entire field winding, across the collector rings, with the generator driven at rated speed.

There are times when continued operation of a machine in a fault mode may be critical to prevent outage. Shorted turns of a minor nature, unlike shorted turns in the stator, may not necessarily require immediate reinsulation. Although not recommended, rotors have been known to operate for years with a few random short circuits between successive turns in the rotor winding. However, should subsequent periodic impedance testing show the shorting to be progressive in nature, reinsulation will likely be necessary to assure reliable operation. Continued operation of large salient pole motors known to have shorted turns is not recommended, since further damage can occur due to high currents in the shorted turns, particularly during start operations.

If the rotor has brushless excitation, the manufacturer's instructions should be reviewed carefully before making impedance tests.

8. Tests to Give Indication of Expected Service Reliability

8.1 Insulation Power-Factor Tests. These tests are mainly useful on the larger high-voltage machines (6000 V or higher).

The power factor of the insulation from the winding to core may be measured by special bridge circuits or by the volt-ampere-watt method. Equipment that is especially designed for such tests is available.

The power factor of the stator insulation will be affected by the test voltage, the type of insulation, temperature of the insulation and moisture, and voids in the insulation. Results are also affected by conditions external to the main insulation, such as the condition of the outer wrapper or slot liner, and the type of corona control used.

Increasing power factor on the same machine over a period of time is believed to denote a general deterioration of the insulation. Generally, power-factor increase with age is usually small for machines having corona control treatment on the slot portion, whereas the increase is usually much greater on machines having coils with slot liners constructed of organic materials.

Power-factor values on complete windings are an average of the insulation of all coils. When the coils in a machine can be individually tested, power factor can be used to compare the amount of deterioration among coils that have been operating at different voltages; e.g., between line coils and neutral coils.

The change in power factor of the stator insulation as the test voltage is raised from some low value to operating voltage may be indicative of the amount of ionization loss in or adjacent to the insulation. It is believed that an increase in ionization loss over a period of years indicates an increase in the size and number of voids and, hence, is an indication of deterioration within the insulation.

8.2 Controlled Overvoltage Test (DC). A controlled overvoltage test is one in which the increase of applied direct voltage is controlled, and measured currents are continuously observed for abnormalities, with the intention of stopping the test before breakdown occurs. This test is often referred to as a "direct-current leakage test" or a "step voltage test."

Methods of conducting the test and interpretation of the results are detailed in IEEE Std 95-1977 [6]. The methods described have been found applicable to equipment of smaller size and lower voltage rating.

IEEE Std 95-1977 was developed to provide uniform procedures for the following:

(1) Performing high direct-voltage acceptance tests and routine maintenance tests on the main ground insulation.
(2) Analyzing the variations in measured current so that any possible relationship of the components of these variations to the condition of the insulation can be more effectively studied.

Many operators have found this test to be a useful maintenance tool, although there is some controversy on the interpretation of the test results, and breakdown sometimes occurs without prior indication. The operator is urged to study IEEE Std 95-1977 to derive significant benefit from controlled overvoltage testing.

8.2.1 Alternative Method of Controlled Overvoltage Test. An alternative test method that has been adopted by some users is the "graded time test," detailed in the Appendix of IEEE Std 95-1977 [6].

In this test, an attempt is made to provide a linear relationship of the time-dependent absorption current with the total leakage current and therefore obtain a more significant impression of the behavior of the insulation when subjected to increased voltage steps. This phenomenon is discussed in [B7].

An alternate analysis of the graphical solution is presented in [B17] by the use of a set of templates for proportioning magnitude of leakage current and determining time schedule for the test.

8.2.2 Other Methods. Other specialized procedures for controlled dc overvoltage testing have been developed for certain applications. The requirements of the application and the specific information desired from the test will dictate whether these methods should be considered.

9. Other Special Tests

In addition to the tests outlined above, there are a number of other special tests that may be useful. Some of the more frequently used tests and a summary of their performance follow.

9.1 Stator Core Interlaminar Insulation Test. In cases where several core laminations have been short-circuited by the causes referred to in 5.4, repairs will usually be required to restore the interlaminar insulation.

An effective test can be made by inducing in the stator core a flux at rated frequency at approximately the flux density in the core corresponding to 105% of rated voltage. This test is known as the loop test.

This can be done by passing a temporary coil through the stator bore and then around one side of the frame. This coil should be insulated from the core and frame and be braced securely in position. A single-turn test coil is similarly wrapped around the core and connected to a voltmeter.

Methods of calculating the test-coil voltage and ampere-turn requirement are given in Appendix A.

A recently developed technique, an electromagnetic core imperfection detector, appears to offer a simpler procedure with lower kVA requirement for core-fault detection.[3]

9.2 Interturn Short Circuits on Cylindrical Rotors. In addition to the impedance measurements referred to in 7.6 of this guide, several other tests are available by which short circuits between turns of cylindrical rotors can often be detected. Among these are the following:

(1) The flux distribution over the rotor body surface, when a potential of 120 V at 60 Hz is applied to the collector rings, is observed by a test coil connected to a galvanometer, as described in [B5]. The test coil is arranged to span adjacent rotor teeth and is usually placed on the part of the rotor body close to the coil retaining rings. The magnitude and sign of the voltage induced in the coil for each pair of teeth is plotted. The flux pattern shows a significant change in magnitude and sign whenever a short circuit exists in the slot being tested.
(2) In another test method, an ac voltage is applied to the collector rings and the induced voltage in the test coil is read on a voltmeter. An iron-cored coil is used on the rotor body or an air-cored coil can be used in the end windings.

9.3 Coil-to-Core Contact Resistance. It is essential that the corona suppression coatings applied to the surface of coils in high-voltage windings be adequately grounded. A low-resistance grounding path is usually provided by direct-contact resistance with the stator core. Measurement of the coil-to-core contact resistance may provide a useful indication of the condition of the corona suppression system.

10. Cleaning Instructions

Proper maintenance of electrical equipment requires periodic visual examination of the machine and windings and appropriate electrical and thermal checks. Insulation surfaces should be examined for cracks and accumulations of dirt and dust to determine required action. Lower than normal insulation resistance can be an indication that conductive contaminant is present. The contaminant may be carbon, salts, metal dusts, or virtually any dirt saturated with moisture. These contaminants develop a conductive path to produce shorts or grounds with subsequent failure. Cleaning is also advisable if heavy accumulations of dirt and dust can be seen, or are suspected to be restricting ventilation as manifested by excessive heating.

With no visual, electrical, or thermal evidence that dirt is present, cleaning should not be initiated since more harm than good may result.

If harmful dirt accumulations are present, a variety of cleaning techniques are available. The one selected will depend on

(1) The extent of the cleaning operation to be undertaken
(2) The type, rating, and insulation structure of the machine involved
(3) The type of dirt to be removed

10.1 Field Service Cleaning—Assembled Machines. Where cleaning is required at the installation, and complete disassembly of the machine is unnecessary or not feasible, dry dirt, dust, or carbon should first be picked up by a vacuum cleaner to prevent the redistribution of the contaminant. A small nonconductive nozzle or tube connected to the vacuum cleaner may be required to reach dusty surfaces or to enter into narrow openings such as between commu-

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[3] An electromagnetic core imperfection detector is a device for detection of current flow between core laminations with excitation.

tator risers. After most of the dust has been removed, a small brush can be affixed to the vacuum nozzle to loosen and allow removal of dirt more firmly attached.

Suction should be used to remove dust produced within a machine, such as in the stoning of commutators, collector rings, or the seating of brushes.

After the initial cleaning with vacuum, compressed air (not to exceed 30 lb/in^2 [207 kPA]) may be used to remove the remaining dust and dirt. An exhaust must be provided so that dirt will be removed from the machine. Indiscriminate blowing may produce mechanical unbalance of an armature or rotating field by redistribution of dirt.

Compressed air used for cleaning should be clean and free of moisture or oil. Air pressure or velocity should be adequately controlled to prevent mechanical damage to the insulation.

Disassembly of the machine and more effective cleaning by a qualified service shop may be required if the previously described field service cleaning procedures do not yield effective results.

10.2 Service Shop—Disassembled Machines. An initial insulation-resistance reading should be taken on the machine to check electrical integrity. A reading of not less than 1 MΩ/kV of machine rated voltage but not less than 1 MΩ would be expected with severely contaminated machines. A zero reading may indicate an insulation breakdown requiring repair, not just cleaning.

The "steam-jenny" method of cleaning, which sprays a high-velocity jet of hot water and water containing a mild detergent, is normally effective in cleaning windings including those subjected to flooding or salt contamination. The detergent spray is followed by multiple sprays with clean water to remove or dilute the detergent. Water immersion with multiple rinses and changes of water may also be used to remove contamination. The machine should then be dried (low-temperature oven may be used) until normal insulation resistance values are obtained at room temperature. Other cleaning methods may be used, such as abrasive blasting at light pressures using ground corncobs or nutshells.

Solvents are effective for removing oil or grease and may be required if water or detergent is not adequate. However, solvents may carry contamination, such as conductive dusts, metals, salts and carbon, into cracks, crevices, and interstices by direct flow or by capillary action. Removal of contamination from such inaccessible areas is virtually impossible. A solvent dampened cloth is the preferred cleaning method rather than direct application of liquids. Extreme care should be taken when using solvents both with respect to the equipment and the personnel. Environmental concerns, the disposal of waste products, the possibility of damage to the insulation, and health and safety hazards for the worker should be considered when selecting a solvent. Adequate ventilation and protective gear, such as a dust mask, glasses and gloves, should be used during equipment cleaning. Of course, equipment should not be cleaned when energized.

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Appendixes

[These Appendixes are not a part of IEEE Std 432-1992, IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp), but are included for information only.]

Appendix A
Discussion of Tests Described in the Guide

A1. Nature of the Deterioration Due to Voltage Stress

Electrical insulation that operates in a high-stress field is subject to deteriorating influences not present at lower stress levels. Partial discharge (corona) can cause degradation of insulation in two ways—by chemical effects and by ion bombardment. This occurs when the voltage gradient on gas molecules in void spaces in the insulation exceeds a certain value, depending on the nature of the gas and its pressure and temperature. Ozone and nitrogen oxides that can attack organic materials in the insulation may be formed. The symptoms of this kind of degradation are reddish or white deposits. The effect of corona is not present to a noticeable degree in hydrogen-cooled machines since the oxygen content is small.

The other deteriorating effect of corona is present when alternating voltage stress is high enough to ionize the gas molecules in the void spaces, thereby converting them to charged particles. During the positive half cycle of voltage they are impelled in one direction, some of them crashing into molecules of solid insulation in the void wall. During the negative half cycle, these projectiles are driven in the opposite direction, so each cycle of ac subjects the insulation to two volleys of ionization. In certain organic insulations, the oxygen and hydrogen atoms may be split from the carbon atoms, leaving the familiar dendrites or tree formations, called tracking, which are actually conducting paths of carbon.

The rate at which deterioration from corona occurs in certain insulations can vary from negligible to rapid, depending on the amount of energy present in the discharges, and where the discharges are located. The total energy being fed into a volume of insulation can be measured, but there is no simple method to determine whether it is being expended in many relatively harmless low-energy discharges, or in a few localized ones that may be injurious. Because of the uncertainty associated with internal ionization, it is desirable to keep this effect to a minimum.

Corona existing on the outside surface of insulation does not damage insulation as rapidly as internal corona; furthermore, such external corona effects can be monitored by visual inspections.

Ionization is accompanied by several undesirable effects, such as chemical action, generation of heat, and ionic bombardment. Continued ionization can cause charring or decomposition of the organic insulating material in the vicinity of the ionization. Severe localized ionization can lead to early breakdown of the insulation. The presence of oxygen in the area of ionization may increase the damaging effect, particularly in the presence of moisture, so that it is particularly important to locate severe ionization in insulation that operates in air or that is exposed to moisture. Inorganic insulation components such as mica and ceramics are more resistant to the effects of corona.

A2. Dielectric Absorption Test

Dielectric absorption testing involves a determination of insulation resistance as a function of time (usually up to 10 min or until insulation resistance stabilizes). This test is also used on all, or parts of, circuit-to-ground insulation of either armature or field. IEEE Std 43-1974 [2] outlines test procedures and equipment for the standard method, which is usually made at a test potential of 500 to 5000 V dc or at a value appropriate to the voltage rating of the winding or the basic insulation condition.

Insulation resistance versus time curves, particularly on higher-voltage stator-winding ground insulation, are sometimes made at test potentials higher than the value specified in IEEE Std 43-1974. Test voltages used vary from 500 V dc up to potentials above normal operating levels. High-voltage direct-current (HVDC) test sets utilizing the voltmeter-ammeter method of resistance determination are usually employed.

Dielectric absorption tests are considered to be more significant than the 1 min insulation resistance tests, particularly on the higher voltage windings, because the slope of the time-resistance characteristic gives further information concerning the relative condition of the insulation with respect to moisture and other contaminants. The ratio of the ten-to-one minute insulation resistance is called the "polarization index," or PI. In terms of measured current at some fixed voltage, PI is the ratio of the one-to-ten minute values. These ratios are nondimensional in character and aid in making comparisons between insulation on machines of different physical size and between tests performed at different times on the same machine.

The voltage for making polarization index checks is usually 500 V dc. The suggested polarization index values for clean, dry windings (according to IEEE Std 43-1974) are as follows:

(1) *Class A Insulation*—1.5 or more
(2) *Class B Insulation*—2.0 or more
(3) *Class F Insulation*—2.0 or more

These values are considered satisfactory for varnish- or asphalt-impregnated windings. Polyester- or epoxy-impregnated windings may have different PI values, but such values have not been established. The values of PI given above are for machine windings only. Windings must be isolated for meaningful results. If the insulation resistance measurements are made with leads, cables, or surge-protective capacitors connected to the machine, the values obtained do not necessarily apply to the winding alone.

A polarization index of less than 1.0 indicates a conduction current increasing with time. This normally would be an unsatisfactory condition and might be due to a leakage path that has not been dried out. If the index is still less than 1.0 after cleaning and drying the insulation, the apparatus manufacturer should be consulted.

An abnormally high polarization index from an older winding; i.e., a PI in the order of 5 or more for a winding in the 20-year age bracket, could indicate intact, but lifeless, dried-out insulation. An "in-service" failure could result from a sudden fracture of the brittle insulation caused by mechanical shock, such as introduced from a short circuit on the system.

Frequently, the insulation resistance is found to be higher than the basic minimum requirements, but the polarization index is below the recommended values. This condition occasionally occurs when testing field windings or dc armatures. Generally, a machine that has been idle for some time could be returned to service if the PI value is 1.0 or above and the insulation resistance is above the minimum requirement. The insulation resistance of a reliable winding structure should be well above the basic requirements and the PI value at least equal to or above the suggested minimum.

A3. Slot Discharge and Corona Probe Tests

Two common ways of determining the presence of ionization or corona are (1) by measuring the power factor of the insulation at two voltages and noting the increase, and (2) by the use of a cathode-ray oscilloscope. The first method gives a measure of the total ionization if readings are made at two voltages, one at or slightly above the operating level and one below any practical corona level (2 kV is commonly used). Some specifications set a limit on the power-factor difference (called tip-up) obtained in this way. If the oscilloscope is connected to an exploring coil, the signal can detect the location of the corona, but will not relate whether the corona is internal or external and gives only a very rough idea of the intensity.

The slot discharge test is made for the purpose of checking the adequacy of the ground connection between the conducting coil surfaces and the core. If such surface discharging exists in a winding, it is important that it be detected. Greatly accelerated deterioration of the major ground insulation is produced by slot discharges. These tests are usually applicable to machines with operating voltages in excess of 6000 V.

Tests with a slot discharge analyzer check the adequacy of the electric contact between the core and the stator coils for those machines having low-resistance conducting surfaces in the slot portions. This test is effective in detecting and locating the presence of surface discharge, which is injurious to the coil insulation. Detection is accomplished by a simple test from the machine terminals. Discharge is located by the probe test described below.

Tests are made with the winding energized at the maximum normal operating stress to ground. When a discharge exists, high-frequency reflections are readily observable at the machine terminals on a cathode-ray oscilloscope connected to the slot discharge analyzer.

The corona probe test is intended to be an indicator and locator of unusual ionization about the insulation structure. Such a test is sensitive in varying degrees to surface corona and unusual internal ionization. The ability of this test to discriminate between harmful and acceptable levels of general ionization phenomena, such as occur in high-voltage windings, has not been demonstrated but is under study.

The corona probe test equipment consists of three basic units: an antenna, an amplifier, and an indicator. A typical antenna is about 1 in (2.5 cm) long, surrounded by an insulating housing, and mounted on the end of a long insulating handle. The antenna is connected to the amplifier by a length of shielded lead. The amplifier is one of the usual type for radio frequencies, and must reject 60 Hz. The indicator may be earphones, an output meter, or preferably a cathode-ray oscilloscope. The corona probe is used to explore the insulation for areas of ionization while the winding is energized from a source of test voltage. The probe is particularly useful for determining the effect of the dielectric-stress gradients in the end-turn insulation.

Partial discharge probe techniques are now well established for more precisely determining the location and intensity of slot discharges.

A4. Stator Core Interlaminar Insulation Test (Loop Test)

A test coil may be wound around the stator core and excited to evaluate the quality of the interlaminar insulation. To induce flux in the stator core, equivalent to the operating flux at 105% of rated voltage and rated hertz, the following data may be used:

(1) The ampere-turns required may be approximated from Table A1.

(2) The test-coil voltage, however, is a more significant criterion, as it will enable the actual volts per turn in the stator winding to be simulated.

The test-coil voltage per turn is calculated as follows:

$$\text{Voltage per turn of test coil} = \frac{1.05 \times \text{phase voltage}}{2 \times K_d \times K_p \times N}$$

where

Phase voltage = Line-to-line voltage for delta connection and $\sqrt{3}$ × line-to-line voltage for wye connection
K_d = Distribution factor = 0.955 for a three-phase wye or delta-connected stator winding
K_p = Chord factor of the stator winding
N = Number of turns/phase in series of the stator winding

The number of turns for the test coil is determined by the above equation and the available voltage. The current capability of the cable to be used for the test is determined by dividing the required ampere-turns by the number of turns to be used.

When the coil is energized, hot spots due to short-circuited laminations will be apparent within a few minutes. Hot spots may be detected by feel with the hand or by infrared detectors. Care should be exercised in entering the core of a large machine with the coil energized because of the hazard from voltage induced between laminations.

Table A1
Induction Requirements

Induction		Magnetization Force	
Kilolines per Square Inch	Tesla	Ampere Turns, per Inch of Core Mean Periphery	Oersteds, per Centimeter of Core Mean Periphery
85	13.2	9	1.7
90	13.9	18	3.5
95	14.7	37	7.2
106	16.4	145	28.2

Appendix B
Rotating Electric Machinery Insulation Condition Appraisal From Visual Inspection

Table B1
Visual Inspection Checklist

Component	Deterioration or Damage	Condition NONE/ SLIGHT/ MAJOR
Armature windings (stationary ac, rotating dc)	(a) Puffy coils	
	(b) Soft insulations	
	(c) Girth cracking	
	(d) Separation in ground wall	
	(e) Bond cracks at slot ends	
	(f) Bond cracks into slots (wedge removed for inspection)	
	(g) Contamination of coil or connection surfaces (carbon dust, dirt, oil)	
	(h) Abrasion damage from chemicals, abrasives, or foreign materials	
	(i) Cracks/abrasion from mechanical forces, coil movement	
	(j) Loose bracing structure	
	(k) Corona damage (white, gray, or red deposits)	
	(l) Loose wedges or slot fillers	
	(m) Distorted windings, coils, or commutator risers	
	(n) Loose restraint bands	
	(o) Cracked restraint bands	
	(p) Uneven color commutator bars	
	(q) Evidence or occurrence of flashover	
	(r) Evidence of bar faults or band burning at walls of glass-band grooves	

Table B1 (*Continued*)
Visual Inspection Checklist

Component	Deterioration or Damage	Condition NONE/ SLIGHT/ MAJOR
Field windings (rotating ac, stationary dc)	(a) Puffy coils	
	(b) Soft insulations	
	(c) Contamination of coil, collector, banding, or connection surfaces (carbon dust, dirt, oil)	
	(d) Abrasion damage from chemicals, abrasives, or foreign materials	
	(e) Cracks/abrasion from mechanical forces, coil movement	
	(f) Loose wedges	
	(g) Distortion of coils	
	(h) Shrinkage or looseness of coils, washers, or pads from poles	
	(i) Loose connections	
	(j) Heating of wedges	
	(k) Cracks in retaining rings	
	(l) Loose end-winding blocking	
	(m) Powdered insulations in air ducts	
	(n) Red oxide at metallic joints	
	(o) Loose collector or collector leads	
Brush rigging	(a) Evidence or occurrence of flashover	
	(b) Carbonized leakage paths	
	(c) Loose parts	
	(d) Carbon dust accumulation	
Cores	(a) Evidence or occurrence of rub or impact damage (rotor rub or objects in air gap)	
	(b) Burned punchings at bore surface	
	(c) Heating of adjacent punchings	
	(d) Loose or broken vent duct separators	
	(e) Core looseness	
	(f) Heating of end-finger plates	
	(g) Loose or broken laminations at clamping flanges	
Insulated through bolts	(a) Contamination	
	(b) Looseness	
Bearing insulation	(a) Cracks	
	(b) Distortion, evidence of excessive heating	
	(c) Oxidized or corroded conductors/strands	
	(d) Loose connections	

ISBN 1-55937-237-0