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IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage

Sponsor
**Rotating Machinery Committee
of the
IEEE Power Engineering Society**

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Foreword

(This foreword is not a part of IEEE Std 95-1977, Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.)

Traditionally, the insulation of rotating machines has been tested for dielectric strength with alternating voltage. In 1952 attention was directed to testing with direct voltage. Since then, high direct voltage has been widely used. Many reports of procedure and results are found in the *IEEE Transactions* with expressions of widely differing opinion.

In 1957 the Insulation Subcommittee of the IEEE Rotating Machinery Committee appointed a working group to review the existing literature and to prepare a guide for the conduct and interpretation of high direct voltage insulation tests. It was found that many methods of making the tests have been used and that there was no uniform opinion of their relative merits.

In 1971 the Insulation Subcommittee of the IEEE Rotating Machinery Committee appointed a working group to revise the existing guide to a recommended practice.

At present there is wide usage of high direct voltage for insulation testing, but there are still areas of disagreement regarding the utility of such tests. In this recommended practice every effort has been made to state facts and to indicate what is doubtful. This document gives the present opinion and evaluation of high direct voltage insulation testing of a large number of investigators with experience in a wide area of test activities.

Many of those who have used the methods described in this recommended practice have found them to be satisfactory and a valuable addition to other test procedures. It is hoped that the use of this recommended practice will achieve more uniform results and will result in a factual appraisal of the high direct voltage dielectric test.

A general discussion of test procedures and a comparison between alternating and direct voltage testing may be found in the appendix. For background information on overvoltage testing see IEEE Std 56-1977, Guide for Insulation Maintenance for Large AC Rotating Machinery, Section 5.

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WARNING

Due to High Voltage Used, Dielectric Tests Should Be Conducted Only by Experienced Personnel, and Adequate Safety Precautions Should Be Taken to Avoid Injury to Personnel and Damage to Property.

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IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage

1. Scope

This recommended practice presents uniform methods for testing insulation with direct voltages higher than 5000 V.¹ It applies to large ac rotating machines rated at 10000 kVA or greater and rated at 6000 V or higher.² It covers acceptance testing of new equipment in the factory or in the field after erection, and routine maintenance testing of machines that have been in service.

2. Purpose

The purpose of this recommended practice is:

- 1) To provide uniform procedures for performing high direct voltage acceptance tests and routine maintenance tests on the main ground insulation of windings of large ac machines
- 2) To provide uniform procedures for 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
- 3) To define terms which have a specific meaning as used in this document

3. Definitions

The following definitions are based on those in common use which have been modified to be more specific for the purpose of this recommended practice.

absorption current (or component): A reversible component of the measured current, which changes with time of voltage application, resulting from the phenomenon of “dielectric absorption” within the insulation when stressed by direct voltage. See IEEE Std 62-1958, Guide for Making Dielectric Measurements in the Field, Section 6.

acceptance proof test: A test applied to new insulated winding before commercial use. It may be performed at the factory or after installation, or both. See American National Standard General Requirements for Synchronous Machines, ANSI C50.10-1977.

¹For insulation resistance measurements at direct voltages below 5000 V, see IEEE Std 43-1974. Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

²These methods have been found applicable to equipment of smaller size and lower voltage.

breakdown voltage: The voltage at which a disruptive discharge takes place through or over the surface of the insulation.

capacitive current (or component): A reversible component of the measured current on charge or discharge of the winding which is due to the geometrical capacitance, that is, the capacitance as measured with alternating current of power or higher frequencies. With high direct voltage this current has a very short time constant and so does not affect the usual measurements. See IEEE Std 62-1958, Section 6.

controlled overvoltage test (dc leakage, measured current, or step voltage test): A test 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. See Section 6.2.

electric strength (dielectric strength): The maximum potential gradient that the material can withstand without rupture.

high direct voltage: A direct voltage above 5000 V supplied by portable test equipment of limited capacity.

leakage (conduction) current: The non-reversible constant current component of the measured current which remains after the capacitive current and absorption current have disappeared. Leakage current passes through the insulation volume, through any defects in the insulation, and across the insulation surface.

maintenance proof test: A test applied to an armature winding after being in service to determine that it is suitable for continued service. It is usually made at a lower voltage than the acceptance proof test.

measured current: The total direct current resulting from the application of direct voltage to insulation and including the leakage current, the absorption current, and, theoretically, the capacitive current. Measured current is the value read on the microammeter during a direct high voltage test of insulation.

overvoltage (overpotential): A voltage above the normal rated voltage or the maximum operating voltage of a device or circuit. A direct test overvoltage is a voltage above the peak of the alternating line voltage.

polarization index: The ratio of the insulation resistance of a machine winding measured at 1 min after voltage has been applied divided into the measurement at 10 min. See IEEE Std 43-1974.

proof test (withstand test): A “fail” or “no fail” test of the insulation system of a rotating machine made to demonstrate whether the electrical strength of the insulation is above a predetermined minimum value.

4. Preparations for Test: Test Connections

4.1 Proof Test Preparations

The preparations required for proof tests are simpler than when current measurements are made in conducting controlled overvoltage tests. If proof tests are to be made without current measurement, only those sections marked by an asterisk need to be consulted.

4.2 Air-Cooled Machines

4.2.1 *Temperature of the Winding*

4.2.1.1

A direct voltage test should be made at winding temperatures not in excess of 40°C unless otherwise agreed upon between the user and the manufacturer.

4.2.1.2

Temperature is important when making leakage measurements at high direct voltages because it influences humidity and moisture condensation on the surface of the insulation. Insulation resistance and dielectric absorption vary with temperature, so that constant temperature is required for accurate and comparable measurements. Hence, temperatures near ambient are preferred; otherwise, resistance values must be corrected to a common base temperature. See IEEE Std 43-1974, Section 4.

4.2.2 Humidity.

The insulation resistance and the polarization index should be at or above the minimum value recommended in IEEE Std 43-1974 before making a high direct voltage test. Surface leakages on end windings, etc, are increased if moisture is allowed to settle on them, particularly if any dirt is present. It is difficult to attain a standard degree of humidification for close correlation of measurements on successive tests. For these reasons, some users prefer to keep windings dry until tested by maintaining their temperature *slightly above* ambient. When machines are idle for long periods, they may be heated to prevent absorption of moisture. See IEEE Std 43-1974, Appendix. Overvoltage tests will be most significant when made under humidity conditions approaching those under which the machine will operate. The usual procedure when proof tests are made is to keep the winding dry both prior to the test and when in service.

4.2.3 Dirt on the Winding

4.2.3.1

When dirt is present, the effect of moisture on the surface is to increase the amount of leakage current. It is usually desirable to reduce such currents by avoiding moisture condensation. Accumulation of dirt on the winding may increase test voltage stresses in end windings, especially if moisture is present.

4.2.3.2

If dirt that is oil soaked or otherwise flammable appears to present a fire hazard, in view of the possibility of a flashover during the test, the winding should be cleaned before testing.

4.2.3.3

The winding may be cleaned before testing if it is considered that the clean condition is a standard upon which measurements from successive tests can confidently be compared.

4.2.3.4

The winding should be cleaned if dirt is found responsible for insulation resistance below the minimum value recommended in IEEE Std 43-1974. Consideration may be given to testing both before cleaning, for easiest detection of incipient faults and indication of repairs required during the time out of service, and testing again after cleaning and drying and any other work for final assurance of fitness for service.

4.2.4 Varnish and Other Coatings.

The presence on the windings of certain varnishes, etc, in the uncured state, causes high leakage currents. Such coatings should be allowed to dry and cure thoroughly before tests are made.

4.2.5 Disposition of Rotor.

The machine may be tested with or without the rotor in place. However, if the rotor is to be removed during an overhaul for other reasons, it is preferable to test the stator winding after the rotor has been removed. The winding can then be better inspected and observed, and it is possible to use fire-fighting equipment more effectively, although fire has very seldom occurred during high direct voltage tests.

4.3 Hydrogen-Cooled Machines

Hydrogen-cooled machines may be tested in hydrogen, in carbon dioxide, or in air. Hydrogen or carbon dioxide of suitable pressure should be applied for tests to maintain effectiveness of the striking distances. The procedures for air-cooled machines listed in Section 4.2 should be observed.

4.4 Liquid-Cooled Armature Windings

The procedures listed in Section 4.2.6 should be observed when the machine is tested. For water-cooled windings the normal procedure is to have the insulating hoses dried internally prior to the test. If water of acceptable conductivity is flowing through the insulating hoses during the test, equipment rated for approximately 100 mA is required.

4.5 Isolation of the Winding from Cables and Auxiliary Equipment

4.5.1

It is preferable to exclude from the test any items that can readily be disconnected in the time available and to apply separate tests appropriate to them. The sensitivity of current measurements to any weakness in the winding will be reduced by the inclusion of external elements. Pothead and busbar insulators and other creepage surfaces must be dry and carefully cleaned, and may be guarded as indicated in IEEE Std 62-1958. Porcelain surfaces may be coated with silicone compound to reduce leakage currents due to condensed moisture on the surface. If auxiliary equipment is included in the test and weakness is detected, the weakness should be located by sectionalizing. If isolation is difficult and the leakages of the connected item and of the windings are of the same order (one not more than twice the other), they may be tested individually to provide reference data and tested together thereafter until deviation from normal is detected.

4.5.2

Oil-filled apparatus should not be included in the test when current measurements are made because current readings may be erratic and may not provide significant results.

4.5.3

If it is impractical to isolate an oil-filled transformer, the maximum test voltage should not exceed the transformer test voltage specification given in IEEE Std 262-1973 (ANSI C57.12.90-1973), Test Code for Distribution, Power, and Regulating Transformers.

4.5.4

It is important to record all cables and auxiliary equipment included in each test for comparison with tests at other times.

4.6 Sectionalizing the Winding

The sensitivity of fault detection becomes greater as the winding portion upon which current measurement is made becomes smaller.

4.6.1

It is recommended that on large machines each phase be isolated and tested separately. The neutral end of each phase winding should be disconnected whenever practical. Testing one phase at a time gives a comparison between phases which is useful in evaluating the condition of the winding and for historical records.

4.6.2

Tests may be made on the entire winding at one time under certain conditions, although this procedure is not the preferred method. One objection to testing all phases at a time is that only ground insulation is tested and no test is made of the phase-to-phase insulation as is made when one phase is tested at a time with other phases grounded. Testing all phases at a time is applicable for small machines and for machines that have inaccessible neutral connections. In this case the three line leads of the winding should be connected together to avoid surges at an open end in the event of failure or flashover.

4.6.2.1

If separation of phases is unusually difficult, it may be done once to establish a reference and all phases tested together thereafter until some deviation from the normal is found.

4.6.2.2

A comparison of the leakage current in the three phases may be obtained when all phases are tested at the same time if special connections are made as shown in Fig 1 and if the direct current is measured on each phase. This method reduces test time. It requires special instrumentation technique and does not provide a phase-to-phase test.

4.7 Discharge of the Winding

4.7.1

Following a high direct voltage test, the winding should be grounded for a minimum time period equal to or greater than 4 times the accumulated test period, but in no case less than 1 h to ensure that no significant energy remains stored in the winding.

4.7.2

Unless the winding is grounded, the energy stored in the winding which has been tested will be dangerous for periods of several hours. Opening the test source will not remove voltage from the winding because of the stored energy in it. The winding will not be safe to personnel without grounding until completely discharged.

4.7.3

If the ground is removed too soon, a voltage will build up in the winding and may reach a high value. Such voltage would be dangerous to personnel who might touch the winding and could damage the winding if under such condition it were placed in service or given other tests.

4.8 Test Equipment

General information on high direct voltage insulation test equipment is given in IEEE Std 62-1958, Section 6.

4.8.1 *Power Source to DC Test Equipment*

4.8.1.1

The ac circuit should be free from intermittent loads and transients.

4.8.1.2

The ac supply to the direct voltage test equipment must have constant non-fluctuating voltage if accurate dc measurements are to be made. Regulating transformers, electronic regulators, motor generators, or combinations of these may be used. Commercially available regulators perform best when their apparent power capacity matches the capacity of the load.

4.8.1.3

Normal system frequency is preferable to a nonsynchronized source, such as a separately driven house generator, because of the effect of variable frequency upon voltage regulators and electronic test equipment.

4.8.1.4

A low-ampere 115 V 60 Hz power source will supply the usual equipment for high direct voltage tests on rotating machine insulation.

4.8.2 *High Direct Test Voltage*

4.8.2.1

A source of adjustable direct voltage is required. Usually a variable auto-transformer is provided in the ac supply circuit.

4.8.2.2

If it is desired to raise voltage continuously rather than in steps, some means of smooth variation is necessary. A geared drive is advantageous. A motor-driven variable autotransformer will raise voltage in a uniform series of small steps. Stepless voltage increases, in linear or other functions of time, can be arranged with certain direct voltage supplies, electrostatic generators in particular.

4.8.2.3

The voltage control should be arranged for a small voltage change between steps, for example, a variable autotransformer of many turns. Such equipment of the required current rating and designed for 240 V usually has more turns and will give smaller steps than when using autotransformers designed for 120 V.

4.8.2.4

The high-voltage polarity of the test set may be either positive or negative. If test results are to be compared, the test should be made with the same polarity. The test report should indicate the polarity used.

4.8.3 *Direct Voltage Measurement*

4.8.3.1

The dc test set should be provided with a high voltage measurement unit calibrated in kilovolts on the voltmeter. Voltage instrumentation should be capable of measuring kilovolts with several ranges available.

4.8.3.2

It is occasionally desirable to check kilovoltmeter calibration. This may be done by means of a sphere-gap. See IEEE Std 4-1969 (ANSI C68.1-1968), Techniques for Dielectric Tests. The calibration sphere-gap may serve as an overvoltage limiter during the test if the gap is increased 20 percent above the calculated gap for the maximum voltage.