

62.2™

IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus— Electrical Machinery

IEEE Instrumentation and Measurement Society

Sponsored by the
Electric Machinery Committee



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IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus— Electrical Machinery

Sponsor
Electric Machinery Committee
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Abstract: This is a guide for determining applicable tests and inspection techniques for various types of large rotating electric machines. It provides short discussions relating to the capabilities and limitations of each test, typical test procedures and in some cases, how to interpret the expected range of results. This is to be a companion document to P62 Part 1-1995.

Keywords: brushless machine, commutator, damper winding, partial discharge, stator core, stator winding, thermocouple

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Introduction

This introduction is not part of IEEE Std 62.2-2004, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Electrical Machinery.

The condition of power apparatus is of prime importance for the successful operation of a power system. During transportation, installation and service operation, the apparatus may be exposed to conditions which adversely affect its reliability and useful life. One of the principal aims of the maintenance engineer is to detect defects at an early stage and take appropriate corrective measures. The detection is usually achieved by means of diagnostic evaluation in the field which is performed at regular intervals (for example annually or more frequently as necessary). This guide describes most of the off-line diagnostic tests and measurements which are common practice and provides additional information in the case of more specialized procedures. Each test has an interpretation subclause which is provided not to establish a standard but merely to provide a guide to the user. There is not necessarily any direct relationship between these field tests and factory tests. For tests performed within the warranty period, the measurements should agree with the manufacturer's data when performed under similar conditions. When measurements are performed on service-aged equipment, there may be some deviation between field and factory data. Interpretation of measured results is usually based on a comparison with data obtained previously on the same unit or by comparison with similar units. Many of the levels specified in this document are not standardized; however, the values quoted have been found to be practical and are widely used by the industry. The frequency of the tests will vary depending upon the type, size, age and operating history of the unit. It is recommended that the user of the power apparatus establish a maintenance schedule based on these conditions and on original equipment manufacturer (OEM) recommendations. The test results obtained during the periodic checks should be systematically filed in order to provide a diagnostic data base.

This guide was first published in April 1958 as AIEE Std 62, Recommended Guide for Making Dielectric Measurements in the Field. It was revised and republished as IEEE Std 62 - 1978, Guide for Field Testing Power Apparatus Insulation. This present revision contains more detailed descriptions of test procedures than the previous editions and also includes guidance covering visual inspection. It will therefore be published in different parts with each part covering a specific type of power apparatus.

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IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Electrical Machinery

1. Overview

Throughout this guide the term “machine” has been used when the subject matter pertains to both generators and motors. Many of the diagnostic tests are also appropriate for motors, exciters and synchronous condensers. The diagnostic charts in clause 4 should be consulted. The diagnostic charts identify the subsystems and how the diagnostic tests apply to the various types of rotating equipment. For each procedure there is a description of how it relates to evaluating the condition of the listed pieces of equipment.

Interpretive discussions are also included in several areas to provide additional insight on the particular test, or to provide guidance on acceptance criteria. These discussions are based on the authors’ judgment of accepted practice. It should be noted that sometimes the results of several types of tests need to be interpreted together to diagnose a problem. Acceptance criteria provided by the original equipment manufacturer should also be consulted, as they may take precedence over the criteria in this document.

It should also be noted that the terms “bar” and “coil” are used throughout the guide, but are not interchangeable. A bar is usually considered to be half of a coil, and is most often applied to single-turn coils.

1.1 Scope

This guide describes off-line inspections and diagnostic tests which are performed in the field on rotating electrical equipment with voltage ratings of 4000 V or greater. The guide is intended to address large industrial and utility sized machinery. These evaluation procedures, which are in common use on large rotating machines, have been found prudent in assuring high equipment reliability at low overall maintenance cost. The procedures are presented in categories depending on the subsystem of the machine being examined.

1.2 Purpose

This guide is intended to assist maintenance personnel in determining what diagnostic tests should be planned for their rotating electrical machines, what should be expected of the tests, and in general, how to perform the tests. This guide brings together, into one document, many commonly-performed appropriate tests for electrical machines, and references other individual standards so more detailed information may be obtained.

2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/EIA-282-A, Standard for Silicon Rectifier Diodes.¹

ANSI C50.10-1990, American National Standard for Rotating Electrical Machinery—Synchronous Machines. (Presently being replaced by C50-12 and C50-13).

ASTM D 1868-81, Standard Test Method for Detections and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems.²

ASTM F855-97e1, Standard Specifications for Temporary Protective Grounds to Be Used on De-energized Electric Power Lines and Equipment.

IEC 60894, Guide for Test Procedures for the Measurement of Loss Tangent on Coils and Bars for Machine Windings.³

IEEE Std 4TM-1995, IEEE Standard Techniques for High Voltage Testing (ANSI).^{4,5}

IEEE Std 43TM-2000, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery (ANSI).

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

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²ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

³IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

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⁵IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

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

IEEE Std 95™-2002, Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct-Voltage.

IEEE Std 112™-1996, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators (ANSI).

IEEE Std 115™-2002, IEEE Guide: Test Procedures for Synchronous Machines Part I-Acceptance and Performance Testing Part II-Test Procedures and Parameter Determination for Dynamic Analysis.

IEEE Std 118™-1978, (Reaff 1992) IEEE Standard Test Code for Resistance Measurements.

IEEE Std 286™-2000, IEEE Recommended Practice for the Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation.

IEEE Std 393™-1991, (Reaff 1998) IEEE Standard for Test Procedures for Magnetic Cores.

IEEE Std 433™-1974, (Reaff 1991)(Presently under revision), IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency.

IEEE Std 492™-1999, IEEE Guide for Operation and Maintenance of Hydro-Generators.

IEEE Std 510™-1983, (Reaff 1992) IEEE Recommended Practices for Safety in High-Voltage and High Power Testing.

IEEE Std 522™-1992 (Reaff 1998) IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines.

IEEE Std 1434™-2000 IEEE Guide to the Measurement of Partial Discharges in Rotating Machinery.

3. Definitions

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

3.1 apparent charge (terminal charge): That charge that, if it could be injected instantaneously between the terminals of the test object, would momentarily change the voltage between its terminals by the same amount as the partial discharge itself. The apparent charge should not be confused with the charge transferred across the discharging cavity in the dielectric medium. Apparent charge within the terms of this document, is expressed in coulombs, abbreviated C. One picocoulomb (pC) is equal to 10⁻¹² coulombs.

3.2 diagnostic field tests and measurements (power apparatus): Procedures which are performed on site on the complete apparatus or parts thereof in order to determine its suitability for service.

NOTE—The parameters measured differ from apparatus to apparatus and may include electrical, mechanical, chemical, thermal, environmental, etc., quantities. Interpretation of the results is usually based on a change in the measured characteristics and/or by comparison with pre-established criteria. The tests are normally carried out at regular intervals based on users experience and or manufacturers recommendations. These tests may also be performed on defective apparatus in order to determine the location and/or cause of failure.⁶

3.3 dissipation factor (dielectric): The cotangent of the phase angle between a sinusoidal voltage applied across a dielectric or combinations of dielectrics, and the resulting current through the dielectric system.

3.4 partial discharge (PD): Electric discharge that only partially bridges the insulation between conductors

3.5 power factor (dielectric): The cosine of the phase angle between a sinusoidal voltage applied across a dielectric or combinations of dielectrics and the resulting current through the dielectric system.

3.6 OEM: Original Equipment Manufacturer

3.7 coil: A unit of a winding consisting of one or more insulated conductors connected in series and surrounded by common insulation, and arranged to link or produce magnetic flux.

3.8 bar: Usually considered to be half of a coil and is most often applied to single-turn coils.

4. Diagnostic charts

The diagnostic charts contained in this clause are intended to provide the user with a means of identifying applicable diagnostic procedures for each type of rotating machinery based on the machinery subsystems. Where there is a blank box located at the intersection of a given machinery type and a given procedure, that procedure is not applicable to the subsystem of that particular piece of machinery. For those procedures which do apply to a listed machine type and subsystem, a reference to the appropriate clause is shown.

Not all the tests are necessarily performed by any single user. In addition, the specific tests carried out vary according to the regular practice of the user and may depend on the history of the apparatus.

The establishment of benchmark values on a new piece of electrical equipment is very important when considering evaluation of future test results. Benchmark values are the first measurements taken on a piece of equipment, new or used. Subsequent test results, when compared to these initial values and similar tests on similar equipment, may indicate a trend.

⁶Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the standard.

DIAGNOSTIC CHART
AC Rotating Machinery**A** = Synchronous - Cylindrical Rotor**B** = Synchronous – Salient Pole Rotor**C** = Induction - Squirrel Cage**D** = Induction – Wound Rotor

* = Commonly Not Applicable

		A	B	C	D
Stator	Winding	Visual Inspection	7.1.1	7.1.1	7.1.1
		Wedge Tightness	7.1.2	7.1.2	7.1.2
		Winding Insulation Resistance	7.1.3	7.1.3	7.1.3
		Controlled Direct Overvoltage Tests	7.1.4	7.1.4	7.1.4
		Overvoltage Proof Test (AC, DC, 0.1 Hertz)	7.1.5	7.1.5	7.1.5
		Dissipation Factor and Tip-Up	7.1.6	7.1.6	7.1.6
		Turn to Turn	7.1.7*	7.1.7	7.1.7
		Partial Discharge	7.1.8	7.1.8	7.1.8
		Corona Probe Test	7.1.9	7.1.9	7.1.9
		Winding Conductor Resistance	7.1.10	7.1.10	7.1.10
		Detector (RTD/TC) Insulation Test	7.1.11	7.1.11	7.1.11
		Detector (RTD/TC) Continuity/Calibration	7.1.12	7.1.12	7.1.12
		Tube to Tube Insulation	7.1.13	-	-
		Tube to Copper Insulation	7.1.14	-	-
		Group Transpositions	7.1.15	7.1.15*	7.1.15*
		Modal Analysis (Bump Test)	7.1.16	7.1.16*	7.1.16*
		Bushing/Dielectric Loss	7.1.17	-	-
Rotor	Core	Visual Inspection	7.2.1	7.2.1	7.2.1
		Low Energy Core Test	7.2.2	7.2.2*	7.2.2
		High Energy Core Test	7.2.3	7.2.3	7.2.3
		Core Tightness	7.2.4	7.2.4	7.2.4
		Through Bolt Insulation Resistance	7.2.5	-	-
		Flux Shield Insulation Resistance	7.2.6	-	-
		Visual Inspection	7.3.1	7.3.1	7.3.1
	Coolant Passage	Gas Cooling Passage Pressure Drop and Flow	7.3.2	-	-
		Water Cooling Passage Leak and Flow Tests	7.3.3	7.3.3	-
		Water Flow Verification	7.3.4	7.7.4	-
	Winding	Visual Inspection	8.1.1	8.1.1	8.1.1
		Conductor Resistance	8.1.2	8.1.2	-
		Salient Pole Interconnection Test	-	8.1.3	-
		Groundwall Insulation Resistance	8.1.4	8.1.4	-
		Locating Winding Grounds	8.1.5	8.1.5	-
		Turn Insulation Testing (Pole Drop & Impedance)	8.1.6	8.1.6	-
		Turn Short Location (Turn Drop)	8.1.7	8.1.7	-
	Mechanical Components	Visual Inspection	8.2.1	8.2.1	8.2.1
		Ultrasonic	8.2.2	8.2.2*	8.2.2*
		Eddy Current	8.2.3	-	8.2.3*
		Dye Penetrant	8.2.4	8.2.4	8.2.4
	Damper	Bore Leak Test	8.2.5	-	-
		Visual Inspection	-	8.3.1	8.3.1
		Winding Integrity	-	8.3.2	8.3.2
Assembly	General	Visual Inspection	9.1.1	9.1.1	9.1.1
		Air Gap Measurement Visual	9.1.2	9.1.2	9.1.2
		Cooler Leak Test	9.1.3	9.1.3	9.1.3*
		Air Leak Test	9.1.4	-	-
	Bearing	Visual Inspection	9.2.1	9.2.1	9.2.1
		Bearing Insulation	9.2.2	9.2.2	9.2.2
		Bearing Mechanical	9.2.3	9.2.3	9.2.3
		Visual Inspection	9.3.1	9.3.1	-
	Brush Rigging	Brush Rigging Insulation	9.3.2	9.3.2	-
		Brush Rigging Mechanical	9.3.3	9.3.3	-

DIAGNOSTIC CHART DC and Brushless Rotating Machines

1E = DC Exciters Machines
F = Brushless Machines

			E	F
Stator	Field Windings	Visual Inspection	10.1.1	10.1.1
		Conductor Resistance	10.1.2	10.1.2
		Insulation Resistance	10.1.3	10.1.3
		Turn Insulation Testing (Pole Drop)	10.1.4	10.1.4
Rotor	Winding Connections	Visual Inspection	10.2.1	10.2.1
		Resistance	10.2.2	10.2.2
	Armature Windings	Visual Inspection	11.1.1	11.1.1
		Conductor Resistance	11.1.2	11.1.2
		Insulation Resistance	11.1.3	11.1.3
Assembly	Diode Wheel	Visual Inspection	--	11.2.1
		Insulation Resistance	-	11.2.2
		Fuse Resistance	-	11.2.3
		Contact Resistance	-	11.2.4
		Diode Integrity Check	-	11.2.5
		Capacitor	-	11.2.6
	Commutator	Visual Inspection	11.3.1	-
		Run Out Measurement	11.3.2	-
	Brush Rigging	Visual Inspection	12.1.1	-
		Physical Spacing	12.1.2	-
		Insulation Resistance	12.1.3	-
		Kick Neutral	12.1.4	-
Bearing		Visual	12.2.1	12.2.1
		Insulation Resistance	12.2.2	12.2.2

DIAGNOSTIC CHART Permanent Magnet Generators

G = Permanent Magnet Generator

			G
Permanent Magnet Generator	Stator	Visual Inspection	13.1.1
		Conductor Resistance	13.1.2
		Winding Insulation Resistance	13.1.3
	Rotor	Visual Inspection	13.2

5. Safety

5.1 General

Personnel safety is of paramount importance. In addition, considerations of safety in electrical testing apply to the test equipment and apparatus under test. The following guidelines cover many of the fundamentally important procedures which have been found to be practical. However, it is not possible to cover all aspects in this document and the test personnel should also consult IEEE Std 510-1983⁷, ASTM F855-97, manufacturers' instruction manuals, union, company or government regulations.

Prior to performing any test of power apparatus, there should be a meeting of all people who will be involved or affected by the test. The test procedure should be discussed so there is a clear understanding of all aspects of the work to be performed. Particular emphasis should be placed on personnel hazards and the safety precautions associated with these hazards. In addition, procedures and precautions should be discussed which will assure the production of meaningful test results without subjecting the test specimen to unnecessary risks. In those situations where the tests are not being conducted by owner personnel, concurrence of the owner should be obtained on test magnitudes before the tests are performed. Responsibilities for the various duties involved in performing the test should be assigned.

5.2 Personnel considerations

5.2.1 Responsibility (qualifications)

Personnel assigned to performing the procedures described in this document should be well trained for the particular task to be performed. In particular, they should be aware of the safety hazards that may be created if proper procedures are not followed. Many of the test evaluations call for a high degree of judgment on the part of the evaluator and that can only be obtained by experience. Experience on one type of machine does not necessarily qualify a person to conduct and evaluate tests on another type of machine.

It is the responsibility of the tester to ensure the safety of all personnel including plant personnel and those directly working on the test. The tester should also consider the safety of the apparatus being tested and the test equipment.

5.2.2 Hazards

Insulation tests in the field present a hazard to personnel unless suitable precautions are taken. Apparatus or circuits to be tested shall be disconnected from the power system. Typical safety procedures call for a visual check of the disconnection or, when this is not possible, a check with a voltage indicator. Solid grounds are then applied. Personnel should be instructed to treat all ungrounded apparatus as energized.

5.2.3 Ground connection

Use of working grounds should comply with established company guidelines. For further information see ASTM F 855-97. The test equipment, as well as windings, nearby components, and associated equipment not under test, should be solidly grounded for the duration of the test, and after the test if dc is used.

5.2.4 Precautions

When testing, precautions shall be taken, including warning signs and barriers as listed in 5.2.5, to prevent any personnel from contacting energized circuits. An observer should be stationed to warn approaching

⁷Information on references can be found in Clause 2.

personnel and may be supplied with means to de-energize the circuit. The means may include a switch to shut off the power source and ground the circuit until all stored charges are dissipated.

5.2.5 Warning signs and barriers

The test area shall be marked off with signs and easily visible tape. Warning signs shall conform to the requirements of governing bodies such as the Occupational Safety and Health Administration (OSHA) in the United States.

5.2.6 Hazardous materials

On some rotating machines hazardous materials such as asbestos and lead carbonate may be present. In such cases, work, cleaning, and disposal of hazardous materials shall be performed according to appropriate government regulations.

5.2.7 Machine rotation

Some test procedures are performed with the machine rotating slowly and with cover plates, guards, and end-shields removed. Hydro machines may be operated for test purposes with covers removed at rated speed or at runaway speed. These tests present mechanical hazards in addition to electrical ones. Appropriate procedures should therefore be developed to prevent injury to personnel present.

5.2.8 Documentation

It is recommended that the following documentation be available before commencing any diagnostic tests:

- nameplate data of machine
- relevant standards
- written test procedure
- machine instruction manual
- instruction manual for test equipment
- manufacturer's information indicating expected test values
- previous inspection and test results (if available)
- operational and maintenance history

5.3 Equipment considerations

5.3.1 Consequences of failure

Some type of tests, particularly overvoltage, may result in failure of deteriorated insulation which otherwise might have operated safely for an additional period of time. Failure can substantially expand the magnitude and length of the outage.

5.3.2 Overvoltage

To prevent an unintended overvoltage, a sphere gap, adjusted to spark over at a voltage slightly above the desired maximum, should be connected across the voltage source, (e.g. IEEE Std 4-1995). By selecting the proper value of series resistor, the gap may be used to provide a warning signal, to inhibit further rise in the test voltage, or to activate an overcurrent circuit breaker in the power supply circuit.

5.3.3 Surge arresters

If the test voltage is expected to approach or exceed the maximum continuous voltage of any equipment mounted metal-oxide surge arrestors, or the duty-cycle voltage rating of any equipment mounted silicon-carbide surge arresters, then they should be disconnected before energizing the windings in order to avoid arrester damage and limitation of the test voltage due to arrester operation. It may be necessary to disconnect surge arresters even when using lower test voltages in order to obtain meaningful insulation resistance measurements.

6. Guide to maintenance inspections

Of all evaluation techniques used to determine the condition of rotating electrical machinery, none is more revealing than a thorough visual inspection performed by knowledgeable maintenance personnel. Physical inspection in conjunction with various applicable tests described in this document will make the best possible determination of the condition of the rotating machinery.

6.1 General

This guide will provide basic techniques and methods for making inspections of all categories of rotating electrical machinery. Depending on the machine being inspected, various levels of accessibility can be provided. This is determined by the design of the machine and the degree of disassembly allowed for the inspection. In general, the greater the degree of disassembly, the more accurate the inspection results. Still, interim crawl through inspections can be of great value between major disassemblies.

Every inspection should begin with a consultation with the operating personnel to discuss their operating experience prior to the current machine outage. Any unusual operating experiences or conditions reported may indicate the need to focus particular attention to a specific area of the machine. They may also indicate the need for special tests not ordinarily applied during maintenance inspection. Unusual operating conditions may include excitation disturbances, excessive vibration or noise, synchronizing out-of-phase, generator motoring, voltage or power surges, overloads, loss of cooling water, temperature abnormalities, or hydrogen leakage. (Hydrogen leakage refers to leakage from the machine or, in the case of liquid cooled stator windings, into the stator cooling system.) Previous inspection reports and operating records should be consulted.

Inspection check lists are helpful to itemize equipment components that require specific attention. Inspection of a component often involves only a visual check for evidence of overheating, mechanical damage, dusting, fretting, corrosion, proper peening or locking of hardware, etc. In some cases, the visual inspection should be accompanied by nondestructive examinations and other mechanical checks.

It is imperative that the visual inspection occur prior to the cleaning of any machine components. An exception would be if a hazardous material, such as lead carbonate, is present; it should be properly removed before inspecting. Many signs of deterioration could be missed if the machine is cleaned before inspection.

In many cases, it is advisable to solicit the manufacturer's assistance in planning for and executing inspection and test programs.

Before beginning the inspection of a machine, necessary tools and equipment should be available. Minimum tools required would include: small and large mirrors, lights, small hammer, borescopes, small magnet, and video, digital or 35 mm camera. Additional tools which may be needed include flexible borescope and robotic devices with accessories.

Typically, the evidence of looseness and vibration produces visual deposits in the form of dust or a grease-like substance. The components can be tightly adhering at one interface of the structure and still show indications of a broken bond surface at another interface. This may indicate relative motion at this interface. If the component remains affixed at its other interfaces, wear generally does not progress to an extreme situation. However, if a component becomes “hand loose”, the wear into insulation may become extreme.

Tapping components with a small hammer is effective in determining tightness. A feel of relative motion when tapped or non-solid sounds are indicators of looseness. The skilled inspector can discern qualitatively a tight component from a loose one.

6.2 Related documents

In designing a test and inspection program for specific machines or classes of machines, reference should be made to the manufacturer's machine-specific recommendations and general technical information letters, maintenance history of the specific machine and similar machines in service with other users. In addition, the operating duty, maloperation, and application of the specific unit should be taken into consideration, such as: load cycling, number of start-stop cycles, output demands, high cooling medium temperatures, closed versus open ventilation, instrumentation, overload, over temperature, asynchronous operation, synchronizing difficulties, overspeed, cooling water leaks, oil leaks, hydrogen leakage rate and location, contamination history, flux probe data, field ground detection, vibration history and test history.

6.3 Accessibility

The machine should be disassembled in order to make as complete an inspection as possible. However, with the use of robotic devices and/or with video equipment, it should be possible to make visual inspections in partially disassembled equipment. Some mechanical tests can also be performed with these robotic devices. Interim crawl through inspections can be of great value between major disassemblies when specific components of the machine are thought to be in questionable condition. It should be understood that such a crawl through inspection will not provide access to some of the most critical and vulnerable parts of a machine. A crawl through inspection is a valuable process when used as a final inspection for foreign material and tools left in a machine just prior to closing the machine.

Accessibility not only determines the extent of an inspection, it determines whether a machine is considered a confined space. Confined spaces may require atmospheric tests, breathing apparatus, and an observer. Entry into a confined space will be governed by local, state or federal regulations. Regardless of the degree of machine disassembly, an atmospheric test for the presents of normal oxygen levels needs to be performed. Both heavy and light gasses may have occupied the machine before disassembly and quantities of these gasses may be trapped in the lower and upper cavities of the machine frame. Once such tests have been performed, the confined space rules relate to the degree of disassembly. In most cases, when the field is removed from a cylindrical rotor machine and both ends of the machine are left open, it is no longer considered a confined space.

6.4 Inspection procedures

A thorough inspection will include comprehensive visual evaluation, touching, and smelling, accompanied by electrical and mechanical tests. The inspection procedures vary with components, but should focus on detecting and evaluating tightness, motion, wear, discoloration, deposit, amount and type of contamination, displacement, migration, distortion, puffing, softening, cracking, and any other possible abnormalities. Any abnormal condition discovered during an inspection should be compared to previous inspection reports. If change has occurred, perform a comprehensive examination (including appropriate tests) of components that may have been affected by the observed condition or that may have contributed to the condition. Detailed inspection procedures for each system are outlined in its subclause.

6.5 Reporting

The inspection results should be reported in such a manner that at future inspections previously identified problems and concerns can be reviewed and reevaluated in relation to present results and recommendations. Early corrective action is essential in elimination of major problems. Cleaning and re-painting is a good means of eliminating the old progressions so that the future inspections will be confined to the new evidence, but good records should be kept in order to prevent loss of important maintenance information.

6.6 Evaluation

A proper evaluation of inspection results includes more than just a report of findings. It should put these findings in a discussion related to fitness for the intended future service and maintenance of the equipment.

6.7 Frequency of inspection

Inspection frequency should be determined for each specific unit based upon a number of criteria. Some of these include:

- the mode of operation
- the operating history (including system faults and observations of operating parameters out of the ordinary range)
- operating history of the class of machine
- machine size including the ability to make complete crawl-through inspections
- the future expected service of the machine
- significance of the machine in the system

Inspections historically have been made on a three to five year basis with some variations, including rotor-in and rotor-out inspections at alternating intervals. Recent trends are longer intervals which are chosen based on equipment condition, economics, projected plant life, and risk analyses.

7. Inspection and test techniques—AC machine stators

This clause covers tests used in evaluating the condition and serviceability of rotating electrical machinery. There may be tests used on a very selective basis which are not included in this clause, but most tests in general use are included.

The stator is the major stationary element of a rotating machine, and includes the frame (assembly), core, and windings.

Windings and circuits not under test which are internal to the machine or closely associated with it should be both shorted and grounded during testing and inspection. At a minimum, this includes stator windings, field windings, internal excitation coils, RTDs, thermocouples, arrestors and internal monitor circuits. External to the machine, the CTs should be shorted and grounded and the PTs isolated and grounded. Power leads/isophase bus should be disconnected and solidly grounded.

7.1 Stator winding

The winding being considered in this subclause is the stator winding existing between the neutral leads/bushings and the main leads/bushings of the machine stator.

7.1.1 Stator winding visual inspection

7.1.1.1 Discussion

Normal operating electromagnetic forces on the slot portion of a stator bar are high. On larger machines these forces are typically of the order of 5 to 25 times the combined top and bottom bar weights. Thus if the bar restraint systems are not fully functioning, vibration will occur. This movement can cause bar groundwall insulation to be damaged by impact or by abrasive wear. Detecting evidence of this vibration may be difficult, if the vibration is small and still in its early stages. If vibration is occurring, dust will be generated as the insulation components wear. On a clean dry machine, the dust deposits will normally be thin but easily detectable. If the machine is contaminated by oil, the dust and oil will combine to form a heavy “grease”, which is often a darker, near-black color. In either case, exact location of the wear source may be difficult to determine, and magnitude of wear difficult to assess. If bar slot vibration is suspected, it is particularly important to consider doing an overvoltage test of the winding.

7.1.1.2 Slot portion

Bar slot vibration: Inspect for dust or grease-like accumulation on the wedges and core iron. With borescope or small light, view accessible ventilation passages of the core for buildup of wear products.

Bar slot discharge: If the semi-conductive slot coating materials are not adequate, or if bars are free to vibrate in the slot, severe degradation of the groundwall insulation, slot wedges, and slot fillers can occur. Careful inspection of the bars through the ventilation ducts may allow detection of wear and wear products.

Wedge and filler vibration and movement: Individual loose wedges will vibrate due to core deflection which results from the magnetic forces caused by the field flux. This core deflection (vibration peak to peak) is typically in the range of 50 to 80 micrometers (several mils) in magnitude. Bar vibration, if occurring, will also cause wedge vibration and may cause filler migration. Because the dust generation from vibrating wedges and vibrating bars may be similar in nature, distinguishing between bar vibration and wedge vibration may not be easily accomplished. Isolated vibrating wedges are ordinarily not a cause for concern as long as they are not end wedges. Vibration can usually be stopped by painting the wedge dovetails. Bar vibration is always a serious cause for concern and generally should be corrected by rewedging or other means. Migrating filler may reach into the end winding and cut into bar groundwall insulation, thus this condition should be detected and corrected.

Checklist For Slot Portion Of Stator Winding

- Evidence of corona (partial discharge)
- Degree of cleanliness, including dust generation from vibrating armature bars
- Evidence of outward migration of slot side filler, filler from under wedges or filler between top and bottom coil sides
- Blockage of ventilating passages due to axial wedge movement (on units with cut-back or air flow type slot wedges.)
- Looseness of slot wedges as evidenced by dusting, axial movement, vibration when tapped, or mechanical measurements
- Mechanical damage to coil insulation, such as from coil vibration, foreign objects, short circuit forces, starved cooling circuit, or loose blocking
- Tape separation or softness in stator groundwall insulation under end wedge (if significant tape migration is found close to core in end winding)
- Charring or overheating evidence on wedges, slot fillers, or coil surfaces which might be associated with iron overheating or slot discharge
- Evidence of air gap baffle distress
- Winding over-temperature as evidenced by puffed bars or flowed asphalt or fillers

7.1.1.3 Stator bar insulation tape migration

Many large asphalt windings and a few thermoset windings have experienced this problem, usually on the top bars and at the collector end of the winding. The classic manifestation of tape migration is the “girth crack”, or separation of the surface layer of tape at the end of the slot. Two information sources relate to amount of damage done to a specific bar:

- a) Total amount of tape migration, and
- b) Physical appearance of the bar in the area of the separation

The separations occur in the area from about 100 mm (4 in) inside the core to 300 mm (12 in) beyond the end of the core, but most commonly in the 150 mm (6 in) area of the bar just beyond the core. If separations are suspected inside the core, the end wedges may be removed.

7.1.1.4 Stator end winding assembly

End windings and connection rings: While the electromagnetic forces on these components are less than on the bars in the slot, the tie and support systems are also less effective. Also, the end windings are the most vulnerable location for foreign material entrapment and damage. In addition, electrical gradients on the individual bars at the ends of the slot, and gradients at the phase breaks, may result in corona activity. If vibration is occurring between the various components, dust or grease will be generated similar to that described under slot inspection. Inspection should be thorough and observed deterioration may be serious or minor, depending on the specific conditions observed.

Electrical connections are usually covered by insulation; therefore, problems may be difficult to detect by inspection unless in advanced stages. Common forms of deterioration are cracking of components or increase in contact resistance. Deterioration is usually manifested by discoloration and/or dust generation.

Checklist For End Winding Portion Of Stator Winding

- Cleanliness, looking for accumulation of atmospheric dust, foreign objects, or evidence of oil contamination
- Evidence of dusting, erosion or cutting due to movement and vibration of bracing components, bar vibration, and loose blocking
- Evidence of frayed, displaced or broken lashings or banding
- Evidence of softness or insulation disturbance in connection taping
- Evidence of loose hardware
- Evidence of coil, bracing, or circuit ring distortion due to differential thermal expansion or faults. Minor evidence may consist of paint cracks at mating surfaces between winding and bracing components.
- Evidence of overheating at the overlap of the stress control coating and semiconductive slot coating
- Evidence of partial discharge activity as displayed by tightly adhering deposits on winding surfaces between phase coils near coil crossovers, and between connections in areas where voltage differences (in operation) are high. Deposits vary from a white-gray color in air-cooled machines to red, brown and black in hydrogen cooled machines.
- Tape separation in coil groundwall insulation for several centimeters outward from the end of the core. If significant tape separation evidence is noted, all end wedges should be removed to permit an inspection of coil surfaces near the ends of each stator slot.
- Breakage of bonds between connection components in windings with bare connections. Evidence of solder/braze joint overheating, broken strands, or dusting.
- Evidence of overheating or mechanical damage

- Evidence of water leakage in liquid cooled machines. No visual evidence does not necessarily mean that no leaks exist.

7.1.2 Stator slot wedge tightness

There are many types of slot wedging systems, and each has its own means of testing. The following tests apply to the evaluation of slot wedge tightness and the general implications of various results.

7.1.2.1 Discussion

Stator coil slot wedges fit into grooves near the tops of the stator core teeth. These wedges, along with various filler strips hold stator coils securely in their respective slots. The traditional filler strip is made of a flat sheet of insulating material and is used as a shim between the top of the coil and the underside of the wedge. Depending on the gap between the top of the coil and the bottom of the wedges, several such filler strips of various thicknesses may be used to provide a positive downward clamping action on the top of the coil by the wedges.

A second type of wedging system in general use is designed to apply a downward spring loading force on the tops of the coils. The intent is to provide downward pressure on a coil even after it has settled to some extent in its slot. The key component of this wedging system is the ripple spring filler strip which is placed directly beneath the wedge. This filler is made of fiberglass shaped into a corrugated strip similar to the cross section of a corrugated metal roof. The ripple spring filler is compressed into a near flat condition as the slot wedges are installed over them.

A third type of wedging system in common use is the “piggy-back” process. This system uses a wedge with under-side taper and corresponding slide to allow positive downward pressure on the bars during assembly in the slot. This type wedge can be combined with top and/or side pressure springs the full length of each top and bottom bar. The side ripple springs act as a damper to restrain the bars against electromagnetic forces on the bars. Since the major electromagnetic forces on the stator bars are always downward in the slot, the side springs need only contain mechanical rebound in order to be effective, thus greatly reducing duty on the slot wedging system. These side springs are also used by some manufacturers with conventional top-wedge systems.

A wedging system tends to relax its restraining force on the coils as the machine accrues service time. This is due to shrinkage and creep of all of the various insulation components in the stator slot: strand, turn, groundwall, armor. Also, shrinkage and deformation may occur on the wedges and on the top and side fillers and springs. It is for these reasons that wedging systems need to be periodically tested for tightness.

The electromagnetic force which a stator coil exerts on all restraining components is proportional to the square of the current carried by the coil. For this reason, the acceptable looseness of a stator coil wedging system is determined partially by the armature current rating of the machine.

7.1.2.2 References

- Past inspection reports for the particular machine to be tested.
- The nameplate rating of the machine.
- Documents providing details of the wedging system used in the machine.

7.1.2.3 Test intervals

In general, a test for stator slot wedge tightness is typically performed at five year intervals. However, these intervals may be longer or shorter depending on the type and history of the machine. Other factors could have an overriding influence on this general rule. Air cooled machines frequently operate over a wider

temperature range; therefore, they may need more frequent testing. Machines that are speed and load cycled should also be inspected on a more frequent basis. New machines, regardless of size, do most of their loosening in the stator slot area during their first year of service. Significant advantages can be realized by inspecting the machine early in its life. Further, no machine should operate more than five years after initial start-up without a thorough inspection of the slot wedging system.

7.1.2.4 Procedure

The most common type of slot wedge tightness test is performed using a small hand held hammer to tap each wedge and thereby determine its tightness by how it responds to the impact of the hammer. This technique might appear to be crude and likely to produce a wide range of results when testing any given wedge. However, this has proven not to be the case on this time-tested technique. An experienced inspector can easily identify wedges that are very loose, slightly loose, tight or very tight. This type of test is actually an impact test and produces meaningful results on all wedging systems except relatively tight radial ripple spring wedging systems.

This same type of impact test can be accomplished with an electrically actuated hammer by itself or attached to a robotic device which travels down each row of slot wedges and impacts each wedge with the electrically actuated hammer. An accelerometer measures the impact force of the hammer and an eddy current sensor detects the amount of wedge deflection. A similar test technique uses a hand-held acoustic device. These test methods have several advantages over the manual hammer method. First, it impacts each wedge with a calibrated force, thereby producing a repeatable response for each wedge. Second, the response is compared to the same standard each time. Finally, the computer which controls the process makes a permanent record of each wedge response.

Another method can be used when testing wedges that are installed over a ripple spring type of filler. Some of these wedges have a series of holes drilled through them in a row down the center of the wedge. These wedges are commonly known as checking wedges. These holes are spaced such that at least one of them is over a crest of the ripple and one is aligned with the valley of a ripple. When the wedges are first installed, they almost completely flatten the strip which provides very little difference between the depth of a valley and the depth of a crest when measured with a depth gauge from the top of the wedge. Such depth measurements are made through the series of holes drilled in each checking wedge. Checking wedges are installed at intervals along the length of each stator slot.

As the wedged coil shrinks and settles in its slot over a period of time, the ripple spring filler relaxes and the crest-to-valley measurement increases. This increase in crest-to-valley measurement is inversely related to the pressure securing the coil by the slot wedges. Such measurements of ripple spring relaxation can be measured by either a manually operated dial depth micrometer or a robotic device similar to that which automates the impact test. A computer controls the robotic process and records the results. There are some robotically operated wedge checking devices that can operate in the air gap area with the machine field in place.

7.1.2.5 Interpretation

Once a chart is made indicating the location of loose wedges, a determination of corrective action can be made. In general, large machines can tolerate a fewer percentage of loose wedges than smaller machines. Several loose wedges adjacent to each other are a more serious condition than if randomly scattered through the bore or slot. Loose wedges, which are near or at the end of a slot, create a more serious condition than if located near the center of the core. Wedges that are loose enough to allow filler strips to migrate out from under them indicates a serious condition and should be corrected in all cases.

7.1.3 Stator winding insulation resistance tests

These tests stress electrical insulation systems to values which are relatively low, but which are sufficiently searching to detect certain major problems. Two types of tests are described which are usually performed concurrently with the same instrument: insulation resistance, and polarization index. See IEEE Std 43-2000 for specific information on performing the insulation resistance tests.

7.1.3.1 Discussion

Frequently, it is desired to know if a particular insulation system meets the minimum requirements for service or is suitable for application of overvoltage type tests as described in 7.1.4 and 7.1.5. Insulation resistance tests and polarization index tests are used to determine if the insulation system meets these minimum requirements. These tests provide a source of valuable information, but it should be understood that they would only detect some of the more severe problems that are encountered with insulation systems. Typically, they will detect major points of physical damage to the insulation, the presence of absorbed moisture, the presence of surface contamination or a water cooled stator winding which is not completely internally dried. Any of these insulation conditions should be corrected before the equipment under test is returned to service or tested at voltage levels above the rated line-to-neutral voltage of the machine.

The current that results from the applied direct voltage consists of four parts:

- a) *Geometric capacitance current*: A reversible current of comparatively high magnitude and short duration, which decays exponentially with time of application, and which depends on the internal resistance of the measuring instrument and the geometric capacitance of the winding.
- b) *Absorption (polarization) current*: A current resulting from molecular polarizing and electron drift, which decays with time of voltage application at a decreasing rate from a comparatively high initial value to nearly zero, and depends on the type and condition of the bonding material used in the insulation system.
- c) *Surface leakage current*: A current that is constant with time, and which usually exists over the surface of the end-turns of the stator winding or between exposed conductors and the rotor body in insulated rotor windings. The magnitude of the surface leakage current is dependent upon temperature and the amount of conductive material, i.e., moisture or contamination on the surface of the insulation.
- d) *Conduction current*: A current that is constant with time, that passes through the bulk insulation from the grounded surface to the high-voltage conductor, and that depends on the type of bonding material used in the insulation system.

In order to have meaningful results from the insulation resistance test, it is necessary that the readings of conduction and surface leakage currents not be taken until capacitive charging current has become negligible and absorption current has become relatively insignificant.

It is important that the temperature of the insulation system be known when performing the insulation resistance test. Insulation resistance is very sensitive to insulation temperature and varies inversely with temperature, on an exponential basis. Insulation resistance measurements are generally corrected to a standard temperature (usually 40 °C) using formulas, nomographs or tables which have been prepared for this purpose. Refer to IEEE Std 43-2000 for correction information.

7.1.3.2 Test intervals

The insulation resistance and polarization index tests should be performed whenever electrical equipment has been out of service for a period of time and is about to be returned to service, during installation of new equipment, prior to any overvoltage test or when the condition of an insulation system is in question.

7.1.3.3 Procedure

Both the insulation resistance test and the polarization index test are performed using a relatively small test instrument capable of producing a constant level of voltage for each of several selectable set points. In testing rotors and other low voltage windings, normally a 250 or 500 volt range should be used. The selectable voltage levels are typically 250, 500, 1000, 2500, or 5000 V dc. The instrument is equipped with a meter which can either indicate current flow through the insulation under test or the actual resistance of the insulation when subjected to the selected voltage.

In order to perform the insulation resistance test, the test instrument leads are connected such that one lead is firmly attached to the grounded frame of the equipment under test. The other lead is firmly connected to the conductor which the insulation system under test is intended to isolate above ground potential. All surrounding equipment and adjacent circuits should be grounded and personnel safety shall be assured.

A test voltage level is selected which is less than the peak voltage to ground to which the insulation is subjected while in service. The test instrument is turned on for a period of one minute and the insulation resistance is read or calculated from the reading on the test instrument meter. Should the test instrument consist of a hand cranked generator, it is important to maintain a relatively constant cranking speed for the one minute period as indicated in the instrument's instruction manual. If only the insulation resistance is desired and no polarization index is desired, the test is complete at the end of one minute and the test specimen shall be safely grounded. Typical values of insulation resistance for rotating machinery are read in megohms.

Should a polarization index be desired, the procedure is the same as that described for insulation resistance testing except the test specimen remains with the test voltage applied across it for a total of ten minutes. Resistance readings are read from the test meter at an elapsed time of one minute and at the elapsed time of ten minutes. (It may be of interest to read and record the value at each minute). Care should be taken to maintain a constant applied voltage for the entire ten minute duration. The polarization index is a dimensionless number equal to the quotient of the ten minute resistance reading divided by the one minute resistance reading.

7.1.3.4 Interpretation of test results

Interpreting the results of the insulation resistance test: The insulation resistance test can be conducted as either a spot test or as a comparison test. The spot test is a single isolated reading of insulation resistance with no previous history. The comparison test compares the present reading to a history of temperature corrected readings on the apparatus, with all of the insulation resistance readings taken at the same voltage.

Interpreting the results of the spot test: The results of the insulation resistance spot test may be interpreted using Table 1. If each phase is tested separately, with the other two phases grounded, the resistance is approximately twice that of the entire winding. Therefore, the observed insulation resistance should be divided by two to obtain a value which, after correction for temperature, may be compared with the recommended minimum values in Table 1.

Table 1—Recommended Minimum Insulation Resistance Values at 40 °C

Insulation Resistance	Description
$R_{(1 \text{ min})} = V + 1$	for most windings made before about 1970, all field windings, and others not described below
$R_{(1 \text{ min})} = 100$	for most dc armature and ac stator windings built after about 1970 (form wound coils)
$R_{(1 \text{ min})} = 5$	for most machines with random-wound coils and form-wound coils rated below 1kV

Where:

$R_{(1 \text{ min})}$ = recommended minimum insulation resistance in megohms at 40 °C of the entire machine winding.

V = rated machine terminal to terminal rms voltage, kV.

It should be noted that quick, large deviations of the test meter reading while test voltage is applied is usually an indicator of moisture within the insulation, surface contamination or both. Cleaning the surface and drying the insulation system should allow for more meaningful test results. Such cleaning and drying will also be necessary if the equipment is to be returned to service or tested as described in 7.1.4 or 7.1.5.

Interpreting the results of the comparison test: The results of the insulation resistance comparison test may reveal a great deal of information about the insulation system. This interpretation relies on the accumulation of insulation resistance data over an extended period of time during the life of the equipment. The time period may be months or years and is dependent on the type of apparatus and reliability required. When data are graphed, trends may be clearly indicated and maintenance may be scheduled before failure.

Interpreting the results of the polarization index test: The polarization index (or PI) is the ratio of the ten minute insulation resistance value and the one minute value. For a large rotating machine, the charging time may be quite long and the polarization index test allows meaningful data to be recorded while the insulation is still charging.

For small stators the polarization index will typically be equal to one or slightly higher. Larger machines may exhibit a polarization index of 1.5 to 2 or more. If the one minute Insulation Resistance is above 5000 megohms, the calculated PI may not be meaningful for reasons of test equipment sensitivity and other effects described in IEEE Std 43-2000. In such cases, the PI may be disregarded as a measure of winding condition. Table 2 shows typical values of polarization index for different thermal classes of insulating materials.

Table 2—Minimum polarization index values

Insulation Class	Minimum P. I.	Comments:
105 °C	1.5	—
130 °C 155 °C 180 °C	2.0	Water cooled windings will typically be 1.0 until fully dried internally. Air cooled machines if contaminated will often be near or at 1.0 until cleaned and dried. If an over-potential test is to be performed, it is advisable that the polarization index be at least 2.0 or higher on stator windings.

In general, a high value of polarization index suggests but does not confirm that the insulation system is in good condition. A polarization index near 1.0 for stator windings indicates that immediate corrective action may be required. The polarization index can be dependent on the materials of the insulation system. Consult the manufacturer if polarization index values are consistently encountered outside the above guidelines. For older insulation systems, such as asphaltic-mica or shellac mica-folium, PI values above 5.0 may indicate that the insulation system has deteriorated, and the insulation system condition may need to be addressed.

7.1.4 Controlled direct overvoltage tests

7.1.4.1 Discussion

It is important to note that the dc overvoltage test will identify both general coil deterioration and localized incipient failures. If inspection of the stator reveals no unusual deterioration mechanisms (i.e. water leaks, mechanical looseness or slot movement) the probability is high that a successful test of the stator will assure successful operation until the next major outage. On the other hand, localized damage can severely alter the remaining life of the insulation system. In these cases, finding the damage through overvoltage testing may negate the remaining life in the system and force a repair. The significant point is that if there is a test failure the timing will allow the work to be done in a less critical time as well as prevent a more damaging failure. In reaching the basic decisions relative to performance of stator overvoltage tests, the owner is faced with divergent and conflicting alternatives:

- Perform a suitability-for-service overvoltage test such as described in IEEE Std 95-2002 and risk a winding failure during the test, or
- Conduct an overvoltage test at a reduced value and with a reduced risk of winding failure during the test, or
- Omit overvoltage test altogether and accept increased risk of service failure, forced outage, and possible severe machine damage.

In the final analysis this is a risk assessment decision. Depending on the importance of a particular machine to the system and other business and economic factors, judgment should be made among the options to overvoltage test at a reduced voltage value, or perform a dc controlled overvoltage test, or omit the overvoltage test altogether.

These tests apply to the insulation testing of machine stator windings using dc controlled overvoltage tests. It does not cover low voltage insulation tests, or ac and dc proof tests.

The dc controlled overvoltage tests are valuable diagnostic tools for several reasons. They provide a leakage current/applied voltage relationship that is not provided with either the ac or dc type of proof tests. The observed current at the end of a test level time period is representative of leakage current since charging and absorption currents are reduced and nearly stabilized. The test results can also be compared with previous test results in a way that can aid in detecting changes in the insulation system. If the winding under test is not clean and dry, the time graded dc test may also provide the operator with the opportunity to detect an impending flashover or insulation puncture and abort the test. As with other dc tests, there is no destructive corona developed at the higher test voltages.

The three dc controlled overvoltage tests described in this document are intended to allow the operator the chance to observe non-linear increases in leakage current as a function of voltage separate from the absorption and charging currents. The least complicated of the three variations is the stepped overvoltage test. This test allows most of the charging and absorption current to drop to negligible levels by using fixed time and voltage steps. The time-graded overvoltage test is designed to linearize the absorption current as a function of voltage thus making changes in leakage current readily discernible. This is done by varying the time steps using measured winding conditions to select appropriate time intervals for each voltage step. The ramped voltage test is an automated test that ramps the applied dc voltage to the desired maximum level at a constant rate (e.g., 1 kV/min) and thus automatically linearizes the geometric capacitive and absorption components of the current so that small, meaningful variations in the measured current are easily observed.

7.1.4.2 Test intervals

Controlled overvoltage tests are frequently used as an alternative to an ac or dc overvoltage proof test. They are used to qualify new windings, service aged windings during normal scheduled maintenance outages and to test repairs made on high voltage coils.

7.1.4.3 Safety

The capacitance charging current and absorption current generated by application of the test voltage are reversible. Upon removal of the test voltage source the test specimen will remain charged and will be a hazard.

Warning: The energy stored within the test specimen may be lethal and shall be dissipated safely.

Capacitive test objects which have a solid dielectric require special precautions. These objects should be discharged using a resistive discharge device and then short-circuited and grounded after dc testing. It is recommended that the test specimen and test equipment be discharged to ground by short circuiting for a period of at least four times as long as the test voltage was applied, but for not less than one hour. Before bare hand contact is made, the absence of voltage shall be confirmed with the test specimen ungrounded after a period of 10 min, or the specimen should remain solidly grounded. Failure to observe this precaution may result in a buildup of voltage on the object due to residual dielectric absorption in the insulation. The external ground should remain on the winding until the dielectric absorption currents have dissipated or until the winding has been reconnected to a solidly grounded circuit. This requires that the ground be left in place, in accordance with normal safe work practice.

7.1.4.4 Precautions

Moisture and surface condition: Moisture within the insulation and surface contamination of the insulation may reduce the insulation resistance significantly. Should the measured insulation resistance be unsatisfactorily low, the machine should be dried or cleaned before proceeding. Insulation resistance and polarization index should be at or above the minimum values specified in 7.1.3.4 (Table 1).

Test atmosphere: It is well known that as the atmospheric pressure decreases, the disruptive flashover voltage is reduced (Paschen's Law). It is further known that the disruptive discharge voltage for positive, negative, and alternating voltages are not identical. When testing at high altitude with high voltages, precautions may be required to ensure disruptive discharge does not occur. When testing in a hydrogen atmosphere, gauge pressure should be at rated machine pressure or 200 kPa (30 PSIG), whichever is lower, in order to compensate for the lower dielectric flashover properties of hydrogen in comparison with air.

For gas inner-cooled machines consult the manufacturer for precautions regarding connecting vent tube potential to the winding potential.

Fire hazard: High voltage tests should never be conducted on a closed machine with an air atmosphere, due to the possibility that fire ignition may occur during test. The operators may not become aware of the fire; and even if it is detected, may not be able to access for extinction.

Application of test voltage: It is important that the test voltage be raised gradually to avoid surges or transients being developed which may exceed the insulation stress rating. The test voltage should be applied such that the desired value is not exceeded. Further, the test voltage should be applied to the apparatus long enough to allow full charging of the insulation system.

Discharge of test apparatus and specimen: Proper discharge of the test apparatus is important from the standpoint of operator safety as was discussed in 7.1.4.3. Improper discharge of the apparatus under test may cause damage to that apparatus by creation of large transient overvoltages and traveling waves. These traveling waves may cause voltage multiplication by factors of as much as four times the applied voltage. To avoid damage created by discharge transients it is recommended that the test specimen be discharged through a suitable resistive load prior to the application of the direct short circuit to ground. In this way, charge is removed from the specimen slowly without generation of surge voltages.

7.1.4.5 Procedure

A. Stepped overvoltage test

This test is performed only on stator windings of rotating machines. The applied voltage is usually applied to one phase of the stator winding and both ends of that winding should be shorted together during the test. The other phases are grounded. Each of the two phases that are grounded should have their ends shorted together. This will test insulation between phases as well as phase-to-ground. If phase-to-ground test information is all that is desired all three phases could be tied together and tested to the frame of the stator. The machine under test should be isolated from all other equipment not intended for testing. This generally includes power cables for motors, isophase bus and transformers for generators. All stator winding RTDs should be shorted and grounded. The CTs should be shorted and grounded; and if the field is installed, the collector rings should be shorted and grounded.

The upper limit of the applied test voltage varies depending upon the known condition of the winding, previous test results and equipment history. With these factors considered, IEEE Std 95-2002 should be used as a guide in determining the test level.

The controlled overvoltage test for rotating machines should be performed only after the winding has been found to have a polarization index greater than 2 at an applied dc voltage level approximately equal to the rated line to ground ac voltage of the machine. This initial test level which is used to determine the polarization index is considered to be the first step in the series of voltage steps. Succeeding steps should not exceed 3% of the final test level rounded up to the nearest kilovolt and should be held for a period of one minute before proceeding to the next step. The minimum recommended voltage step is 1 kV. Current readings should be made at the end of each one-minute interval. Steps are made in succession until reaching the final level.

A plot of current vs. voltage should be recorded on a log log scale and should be nearly linear. Any significant deviation from linearity should be cause for concern and termination of the test.

B. Graded-time overvoltage test

This is a dc leakage current test that allows for gathering quantitative information relating to the condition of the insulation. IEEE Std 95-2002 should be used to select a maximum test voltage. This maximum test level may be adjusted downward depending on the known condition of the insulation system. It is generally assumed that the applied voltage should exceed the stator normal operating voltage. The winding connections for this test are the same as those for the fixed incremental step test described above. The controlled overvoltage test for rotating machines should be performed only after the winding has been found to have a polarization index greater than 2 at an applied dc voltage level approximately equal to the rated line to ground ac voltage of the machine.

The results of a time graded leakage current test are usually compared with results of previous test on the same winding to determine the condition of the insulation system. Comparative studies of this type can help in the detection of a failing insulation system because of physical distress or the aging process. Winding maintenance as well as complete rewinds are often based partially on the results of this test.

The time graded overvoltage test is a special type of controlled overvoltage test. This test is designed to linearize the charging and absorption currents as a function of voltage thus making changes in leakage current readily discernible.

The ten minute period during which the PI is obtained is also used to plot voltage vs. current on a log log scale graph. Points to be plotted are taken at elapsed times of 0.5, 0.75, 1.0, 1.5, 2 min and each minute thereafter up to 10.

Near the end of the 10 min period, several current levels need to be identified on the plotted curve and these values have to be entered in the formula for determining the time schedule of applied voltage (IEEE Std 95-2002). The resulting calculation produces a number “N” which is dimensionless and corresponds to a prescribed time schedule for making voltage steps up to the maximum desired test level. These voltage steps are usually calculated to be 20% of the initial applied voltage that was held for 10 min. A chart containing the prescribed time schedule is included in Annex A.2 of IEEE Std 95-2002.

Although this test is more difficult to perform than a controlled overvoltage test conducted at even time intervals, it does result in changes in leakage current being easier to detect.

C. Ramped overvoltage test

This test requires automated test equipment and enables various ramping rates of the test voltage to be selected. The same procedure is used as in making the stepped overvoltage test except that the ramp in voltage starts at the voltage level where the ten minute PI test is performed and is actually a continuation of that test. This means that the applied voltage for measuring the PI is not removed before starting the ramp. The winding connections for this test are the same as those for the stepped overvoltage test described above. This test provides a method whereby the effects of geometric capacitive and dielectric absorption currents are linearized as a function of voltage so that small, meaningful variations in the measured current are more easily observed.

The dc ramped voltage test provides similar information to the above described controlled overvoltage tests, but without the requirement of plotting and calculating while the test is in progress. By applying a dc ramp with a fixed rate of rise, the absorption current is made a linear function of applied voltage, thus allowing variations in insulation leakage currents to be revealed. Any variation in the rate of rise of the applied voltage will, however, create a nonlinear absorption current, thus reducing the validity of the test.

The suggested rate of rise of test voltage is 1 kV/min.

7.1.4.6 Interpretation of results

Interpreting the results of the three dc controlled overvoltage tests is the same. If the leakage current increases in a linear manner up to the maximum test voltage, the winding is generally considered suitable for service. Typical resistance values of healthy insulation systems measured at maximum test voltages may range from 500 to 5000 megohms.

Any deviation from a linear log current/voltage relationship should be cause for concern. If the current starts to rise faster than the voltage, the insulation system may be reaching the point of breakdown and the test should be immediately aborted. If the current increase starts to lag the voltage increase, there is usually a problem with the test setup or the operation of the test. Failure of the insulation can not necessarily be anticipated and prevented with this type of test.

7.1.5 Overvoltage proof test (AC, DC, 0.1 Hz)

7.1.5.1 Discussion

It is important to note that the overvoltage test will identify both general coil deterioration and localized incipient failures. If inspection of the stator reveals no unusual deterioration mechanisms (i.e. water leaks, mechanical looseness, slot contents movement) the probability is very high that a test of the stator will result in successful operation until the next major outage. On the other hand, localized damage can severely alter the remaining life curve of the insulation system. In these cases, finding the damage through overvoltage testing, will negate the remaining life in the system and force a repair. The significant point is that the timing will allow the work to be done in a less critical time as well as prevent a more damaging failure.

In reaching the basic decisions relative to performance of stator overvoltage tests, the owner is faced with divergent and conflicting alternatives:

- a) Perform a suitability-for-service overvoltage test such as a 1.5 times line to line voltage test level and risk a winding failure during the test, or
- b) Conduct an overvoltage test at a reduced value and with a reduced risk of winding failure during the test, or
- c) Omit overvoltage test altogether and accept increased risk of service failure, forced outage, and possible severe machine damage.

In the final analysis this is a risk assessment decision. Depending on the importance of a particular machine to the system and other business and economic factors, judgment should be made among the options to overvoltage test at a reduced voltage value, or perform a dc controlled overvoltage test, or omit the overvoltage test altogether.

These tests cover the overvoltage proof testing of rotating machinery stator windings using dc, power frequency and 0.1 Hz ac testing methods. These proof tests produce pass/fail results and are not intended to produce quantitative results.

Overvoltage tests may be used on a scheduled basis (usually to coincide with scheduled outages of the equipment being tested) to determine the condition of conductor insulation. These tests are also conducted on machines that have been subjected to severe electrical, mechanical, or thermal stress as well as machines that have just been subjected to a winding repair.

Most types of diagnostic tests performed on power apparatus have advantages and disadvantages relative to their ability to detect weaknesses without damaging the test specimen in the process. Overvoltage testing of power equipment can be done using several techniques, each with its own advantages and disadvantages.