SECTION 5

DIAGNOSTIC TESTS AND INSPECTION TECHNIQUES

5.0 INTRODUCTION

The insulation systems in rotating machines are exposed to a variety of aging factors in service, as indicated in sections 2 and 3. High temperature, environment, a number of mechanical effects (including thermal expansion and contraction), vibration, electromagnetic bar forces, motor start-up forces in the end turns, and voltage stresses both at operating levels and due to severe transients, contribute to irreversible changes and loss of insulation integrity and reliability.

Frequently, these aging factors interact to reinforce the effects of each other. For example, high-temperature operation could result in shrinkage or deterioration of the insulation in a stator winding and shrinkage and loosening of the winding bracing system; this increases vibration and erosion, and leads to still greater vibration. At some point, loss of contact of the semiconductive paint to the slot wall or delamination within the groundwall could occur, leading to slot discharge and internal discharge, respectively, and a progressively accelerating rate of electrical aging. The increased erosion associated with this partial discharge condition, in turn, worsens the initial looseness, and the machine may be on the road to a runaway winding failure.

Station maintenance engineers have at their disposal a variety of nondestructive diagnostic tests which may be used as tools to track the condition of the insulation in the machines and, perhaps more significantly, the rate at which aging is taking place (*13*). This information is essential for the allocation of sometimes scarce resources for the most efficient and cost-effective programs to schedule maintenance, make repairs, and otherwise contribute to trouble-free operation. Experience has shown that the more sensitive the test, the sooner a developing deterioration process can be detected and the less costly will be the repair.

This section contains a listing and brief description of available diagnostic tests for rotating machine insulation, the conditions they are best suited to detect, some opinions of their relevance and relative usefulness, as well as guidance on how to interpret test results. Only reasonably well-proven tests are included. Some new tests, which still may be very useful, have not been included because of uncertainties in interpreting them.

This section has been organized somewhat arbitrarily into electrical, mechanical, and visual tests and inspections. Temperature monitoring of rotating machines by means of thermocouples or resistance temperature detectors is not described in this section but is discussed in detail in section 6.

An overview of the tests discussed in this section, together with information of where they are used, is found in tables 5-1, 5-2, and 5-3 for the stator, rotor, and core lamination insulation systems, respectively. Table 5-4 contains a summary of tests which can be used to detect open circuits in squirrel cage rotor windings. Before using any of the tests, the reader is advised to consult the respective test specifications or papers which are referenced. These references contain detailed instructions for conducting the tests, a listing of the required test equipment, and safety precautions as needed. The tests and inspections described in this section should be carried out by skilled, experienced people to assure the safety of those involved and to obtain the fullest benefit from the work.

As described in section 6, any assessment of insulation system condition requires a thorough visual inspection by an experienced observer (see section 5.3) as well as knowledge of the insulation system design, operating environment, and past maintenance. Many of the test methods detailed below are used primarily to establish when the cost of dismantling a machine (for inspection purposes) is justified.

Section 5.1 applies primarily to tests on the stator insulation of large rotating machines, although insulation resistance and hipot tests may be done on any insulated rotor winding and other components. Special tests for rotor or field winding systems are described in section 5.1.3.

5.1 ELECTRICAL TECHNIQUES

The condition of electrical insulating materials is often best assessed through an electrical test (*14,15,16*). Such tests on insulation systems in

Table 5-1-1 Stator Insulation System Tests

Test Name	Section No.	Applicability	Purpose	Effectiveness*	Ease of Testing**	Advantages	Disadvantages
Insulation Resistance (IR)	5.1.1.1	All machines	Detect serious flaws, moisture, and cleanliness	Low to moderate	Easy	Little skill required, equipment inexpensive, detects wet windings	Not sensitive to all bulk insulation conditions; less effective for epoxy-mica windings
Polarization Index (PI)	5.1.1.1	All machines	Detect serious flaws, moisture absorption, and cleanliness	Moderate	Easy	As above; better than insulation resistance alone	As above
DC Hipot	5.1.1.2	All machines	Detect serious flaws such as cracks, punctures, and shorts	Low to moderate	Easy	Little skill required, equipment inexpensive, well-known	May cause insulation failure; not a diagnostic test
High Voltage dc Step or Ramp	5.1.1.3	All machines	Detect serious flaws such as cracks, punctures, and shorts	Partly effective	Moderate	May prevent failure during dc hipot	Not widely used; requires experience to judge when to abort test
Off-Line Partial Discharge (PD) Test	5.1.2.2(a)	6.6-kV machines and above	Assess delamination and stress control layers	Partly effective	Difficult	Non-destructive; pd easily measured since little interference	Requires large ac power supply and specialized equipment; experience necessary to interpret data; may be misleading with respect to slot discharge; outage required
Tennessee Valley Authority (TVA) Probe	5.1.2.5(a)	6.6-kV machines and above	Locate partial discharge sites in winding	Moderate	Difficult	Locate most deteriorated parts of winding	Need external ac supply; safety hazard; experience required to interpret readout; requires outage; could be misleading
Ultrasonic Probe	5.1.2.5(b)	6.6-kV machines and above	Locate partial discharge sites in winding	Moderate	Difficult	Locate surface discharge	As above
On-Line Conventional Partial Discharge (PD) Test	5.1.2.2(b)	6.6-kV machines and above	Assess delamination, stress control layers, and slot support tightness	Moderate	Difficult	Sensitive to all pd occurring during normal operation; no external ac supply needed	Great skill required to separate pd signal from interference
Partial Discharge Analyzer (PDA) Test	5.1.2.2(c)	Hydrogenerators	Assess delamination, stress control layers, and slot support tightness	Effective	Easy	Little skill to do test and interpret data; no outage required; very sensitive to pd since interference eliminated	Installation of sensors required on high voltage part of winding; currently only valid for hydro generators; moderately expensive to install test
Radio Frequency (RF) Monitor	5.1.2.2(d)	6.6-kV machines and above with Y winding	Assess delamination, stress control layers, and slot support tightness, strand short arcing	Low	Easy	Little skill to install and do test; no outage required; no high voltage connection	Significant experience required to interpret data due to presence of interference
Tip-Up Test	5.1.2.3(a)	All machines	Assess delamination and semi-conductive coating	Moderate	Difficult	Well known	Measures average deterioration only. Requires sectionalizing; only sensitive for tests on individual bars/coils, unless entire winding deteriorated; separate ac power supply and special equipment needed
Dielectric Loss Analyzer (DLA) Test	5.1.2.3(b)	All machines	Assess delamination and semi-conductive coating	Moderate	Moderate	More sensitive than tip-up test	As for tip-up test; not used in North America
AC Hipot	5.1.2.1	All machines	Detect serious flaws	Effective	Difficult	May be more sensitive than dc hipot test	Can be destructive; may age the insulation; large power supply required; not sensitive to aging

* an opinion on how well the test accomplishes the stated purpose
** an opinion on how easily generating station staff can carry out the test

Table 5-1-2 Stator Insulation System Tests

Test Name	Section No.	Applicability	Purpose	Effectiveness*	Ease of Testing**	Advantages	Disadvantages
Generator Condition Monitor (GCM)	5.1.5.2	Hydrogen-cooled machines	Detect burning insulation	Effective	Easy	Detects all locations of overheating in generator	Only for large turbines; interpretation can be difficult
Ozone Monitoring	5.1.2.6	Air-cooled machines	Detect slot and endwinding discharge	Effective	Easy	Easy to install; no interference to generator	Relatively poor sensitivity
Very Low Frequency (VLF) Hipot Test	5.1.2.4	All machines	Detect serious flaws, may be used in conjunction with pd, tip-up tests	Moderate	Moderate	Requires smaller ac power supply; electric stress within coil/bar the same as for 60 Hz	Test set expensive; not widely used
Turn Insulation Surge Test	5.1.2.7	All machines with multi-turn coils	Detect serious flaws in the turn insulation in complete windings	Low	Moderate to difficult	Only test for turn insulation	Will not detect aging or minor flaws; experience necessary to interpret data; not effective if test windings have large number of series coils; may damage good coils
Wedge Tightness Hammer Test	5.2.1	All non post-VPI machines. Some coils for large machines VPI'd prior to winding.	Determine wedge tightness	Effective	Moderate	Effective; no special test equipment required	Some experience necessary to do test; requires outage with rotor removed
Vintek Wedge Tightness Test	5.2.1.	Hydrogenerators	Determine wedge tightness	Effective	Easy	Objective; less skill required	Only applicable to machines without ripple springs; requires outage with rotor removed
Semicon Resistance Test	5.2.2	All machines with semicon coating	Determine how well grounded stator coils are	Moderate	Easy	Direct method to ensure good grounding	Not easily applied to bottom coils in slot
Side Clearance Test	5.2.2	All non post-VPI machines	Determine effectiveness of side packing and/or side ripple springs	Effective	Easy	Effective; no exotic test equipment required	Can only be done during major outage with rotor removed
Endwinding Mechanical Response	5.2.3	All machines	Determine slackness of end-winding bracing and blocking	Moderate	Difficult	Objective; can be trended over time	Requires outage, expensive equipment, and interpretation experience; should have prior test results
Visual (with disassembly)	5.3.1	All machines	Determine condition, e.g. overheating, abrasion, cleanliness; needed to estimate required maintenance or repair	Effective	Difficult	Obtain greatest assurance of condition	Requires extensive outage and experience
Visual (without disassembly)	5.3.1	All machines	Determine condition, e.g. overheating, abrasion, cleanliness; needed to estimate required maintenance or repair	Moderate	Moderate	Simple, shorter outage than when completely disassembled	Requires outage, experience; may miss important signs of deterioration

* an opinion on how well the test accomplishes the stated purpose
** an opinion on how easily generating station staff can carry out the test

Table 5-2 Rotor Insulation System Tests

Test Name	Section No.	Applicability	Purpose	Effectiveness*	Ease of Testing**	Advantages	Disadvantages
Insulation Resistance (IR)	5.1.1.1	All machines	Detect serious flaws, moisture, and cleanliness in groundwall	Low to moderate	Easy	Little skill; equipment inexpensive; detects wet windings	Not sensitive to all bulk insulation conditions
Polarization Index (PI)	5.1.1.1	All machines	Detect serious flaws, moisture, and cleanliness in groundwall	Low to moderate	Easy	As above; better than insulation resistance alone	As above
DC Hipot	5.1.1.2	All machines	Detect serious flaws such as cracks and punctures in groundwall	Moderate	Easy	Little skill; equipment inexpensive; well-known	May cause insulation failure; not a diagnostic test
AC Hipot	5.1.2.1	All machines	Detect serious flaws in groundwall	Effective	Easy	May be more effective than dc hipot test	Can be destructive; may age the insulation
Open Circuit Test	5.1.3.1	Synchronous machines	Detect shorted turns	Low	Moderate	Relatively simple; test with rotor in place	Requires outage; need to drive rotor; interpretation requires experience; requires test when rotor OK
Air Gap Search Coil Test	5.1.3.2	Synchronous machines	Detect shorted turns	Effective	Moderate	Test with rotor in place	Need to install sensor; some interpretation necessary
Rotor Impedance Test	5.1.3.3	Synchronous machines	Detect shorted turns	Moderate	Moderate	Turn shorts can be detected during normal operation; test with rotor in place; simple test equipment	Require slip rings; interpretation may be difficult
Shorted Turn Test — Rotor Removed	5.1.3.4.	Synchronous machines	Detect shorted turns	Moderate	Difficult	Can measure individual coils	Rotor must be removed; difficult if damper winding; cannot detect shorts that only occur in operation
Surge Test	5.1.3.6	Synchronous machines	Detect shorted turns	Moderate	Moderate	Locates site of short	Requires specialized equipment and expertise; may not find some types of shorts
Visual Inspection (with disassembly)	5.3.2	All machines	Determine condition of turn and ground insulation	Moderate	Difficult	Confirm results of testing; assess extent of deterioration	Requires major outage and major disassembly; still may not locate most severely aged insulation
Visual Inspection (without disassembly)	5.3.2	All machines	Determine condition of turn and ground insulation	Low	Moderate	Requires shorter outage than when completely disassembled	Outage and rotor removal, limited inspection possible

* an opinion on how well the test accomplishes the stated purpose
** an opinion on how easily generating station staff can carry out the test

Table 5-3 Core Lamination Insulation Tests

Test Name	Section No.	Applicability	Purpose	Effectiveness*	Ease of Testing**	Advantages	Disadvantages
Rated Core Flux Test	5.1.5.1	All machines	Locate sites of defective core insulation, if any	Effective	Difficult	Well proven; straightforward; effective with infrared monitoring	Requires major outage, some experience, and some special equipment; may further damage a weak core
EL-CID Test	5.1.5.2	All machines	Locate sites of defective core insulation, if any	Effective	Moderate	Requires less power than Rated Flux Test; easier to set up; can monitor repairs; safe	May be less sensitive to deep-seated faults; requires experience to analyze data and an extensive outage
Condition Monitor	5.1.5.3	Hydrogen-cooled generators	Determine if core insulation is overheating	Moderate	Easy	Continuous monitor during service; can give significant warning prior to core failure; may detect overheating in other insulation systems	Some instruments prone to "false" alarms caused by oil mist; experience required to interpret output; instrument is expensive and dedicated to one machine
Mechanical Resonance Test	5.2.4	All machines	Determine if core insulation is prone to failure due to abrasion or lamination breakage	Moderate	Difficult	Confirmation of visual inspection	Requires outage; expensive test equipment and data analysis expertise
Core Lamination Tightness	5.2.5	All machines	Determine if laminations are loose	Moderate to good	Easy	Simple	Requires outage; may not reach all areas; may damage insulation
Visual Inspection	5.3.3	All machines	Determine condition (overheating, looseness, abrasion)	Good	Moderate	Simple	Requires major outage, experience

* an opinion on how well the test accomplishes the stated purpose
** an opinion on how easily generating station staff can carry out the test

Table 5-4 Tests For Open Circuits In Squirrel Cage Rotor Windings

Test Name	Section No.	Applicability	Purpose	Effectiveness*	Ease of Testing**	Advantages	Disadvantages
Stator Current Fluctuation	5.1.4.1	Squirrel Cage Induction motors	Determine if winding is open-circuited	Moderate	Easy	Can be done on-line with readily available equipment	Requires experience to interpret results
Rotor Speed Fluctuation	5.1.4	Squirrel Cage Induction motors	Determine if winding is open-circuited	Effective	Moderate	Can be done on-line	Requires special test equipment. No North American experience
Manual Rotation	5.1.4.2	Squirrel Cage Induction motors	Determine if winding is open-circuited	Moderate	Easy	Can be done with readily available equipment	May not detect breaks that open when motor is running. Motor has to be taken out of service

* an opinion on how well the test accomplishes the stated purpose
** an opinion on how easily generating station staff can carry out the test