

## CHAPTER – 12

### HYDRO GENERATOR AND EXCITATION SYSTEM TESTS

#### 12.1 Introduction

A series of tests are performed on hydro electric synchronous generators so as to ensure.

- a) Quality control of components
- b) Factory assembly and test at manufacturers works for quality assurance and acceptable manufacture assemblies to meet specifications.
- c) Field assembly and tests for quality control check of field assemblies
- d) Performance tests to ensure units meet contractual performance guarantees.
- e) To provide bench mark of as built condition serving as an aid in future maintenance and repair activities.

Type tests are performed on one unit of the serial purchase e.g. tests for ensuring conformity with contractual guarantees. Routine tests are performed on every generator in a multi unit plant.

#### 12.2 Quality Assurance Plan at Manufacturing Works

Quality assurance plan gives details of inspection, tests and customer witness/hold points for each major component of each functional assembly. The tests include material composition and its properties, Non destructive (NDT) e.g. X-ray, hydraulic tests, leakage tests, insulation, high voltage tests and functional tests etc. along with applicable standards and acceptance criteria. The approved quality plan forms the basis for inspection and acceptance of equipment.

#### 12.3 Test Specification

The generator specifications should contain very complete and clearly phrased factory and field test sections. The tests required should be explicitly listed, with specific tests values identified when they are different from the IS standards. Specific test procedures, if required or preferred, should be identified. All factory and field tests should be witnessed by the engineer (purchaser).

Test specification depends upon the generator rating. Small hydro generator up to say 5 MW capacity may be shipped assembled from the factory.

A large generator may be shipped from the factory in its component parts and require complete assembly in the field.

For all generators that are assembled or partially assembled in the factory, the field tests should exactly repeat the required factory tests to confirm that no problem has occurred during installation of the generator. For generators that must be completely assembled in the field, the field tests should be as comprehensive as possible to provide greater assurance that the machine will function properly throughout its lifetime.

#### 12.4 Micro Hydro Generators

These are category 1 generators which are supplied as completely assembled by manufacturers. Type and routine tests as per IS: 4722-2001 carried out at manufacturers works may be accepted as per manufacturers' certificate.

### 12.4.1 Type Tests

The following constitute the type tests:

- (a) Measurement of winding resistance;
- (b) Phase sequence test;
- (c) Regulation test
- (d) Measurement of leakage reactances and potier reactance
- (e) Measurement of open-circuit characteristic
- (f) Measurement of short-circuit characteristic
- (g) Efficiency test;
- (h) Temperature-rise test;
- (i) Over speed test;
- (j) Insulation resistance test (both before and after Dielectric test);
- (k) Dielectric test;
- (l) Determination of deviation of voltage wave form from sinusoidal

### 12.4.2 Routine tests

- (a) Measurement of winding resistance;
- (b) Insulation resistance test;
- (c) Phase sequence test;
- (d) Regulation test
- (e) Measurement of open-circuit characteristic

### 12.5 Testing of generators up to 5 MW unit size. These are usually category 1 or 2 of the generators as defined below.

- a. **Category –1** Factory assembled generators supplied to site completely assembled. These are generally up to 1 MW unit size.
- b. **Category – 2** Factory assembled generators supplied at site as two integral component parts, rotor and stator. These are generally between 0.5 MW and 5 MW unit size.

These categories of generators should meet test requirements as per IS: 4722.

#### 12.5.1 Factory Assembly Test

Following factory and final acceptance tests conducted as per IS: 4722 are recommended to ensure proper performance and guarantees for category 1 & 2 types of generators.

- a. Resistance test of stator and rotor windings.
- b. Dielectric test of armature and field windings.
- c. Insulation resistance of armature and field windings.
- d. Polarisation Index

This should include the polarization index (PI) values for both armature and field windings. As per IS: 4722 AC machines rated above 3.3 kV having output more than 1000 kW may be tested for polarization index (PI) of insulated windings in accordance with IS: 7816. Minimum values of PI (insulation resistance 10 min./IR 1 min.) is 1.75 for class E insulation and 2.0 for class B insulation. Minimum value of PI (R 60 sec./IR 15 sec.) is 1.3 for all classes of insulation.

- e. Stator core loop test at rated flux for one hour.
- f. Phase rotation check
- g. No load saturation test
- h. Short circuit saturation test
- i. Mechanical balance of rotor

- j. Dynamic balancing of rotor at 125% rated speed
- k. Efficiency test
- l. Non Destructive Test (N.D.) of rotor shaft and shaft coupling bolts
- m. Material test certificates of various component parts.
- n. Temperature rise test

### 12.5.2 Field Acceptance Test

Field acceptance tests (all units). These tests consist of:

- a. Stator dielectric tests. These tests consist of: Insulation resistance and polarization index, Test voltage for dielectric tests should be as per IS: 4722.
- b. Rotor dielectric tests.
- c. Stator and rotor resistance tests.

### 12.5.3 Performance test

Special field test (one unit of series). These tests consist of:

- a. Efficiency tests.
- b. Heat run tests.
- c. Machine parameter tests.
- d. Excitation test.
- e. Over speed tests

Full overspeed test should be performed for all units up to 3 MW

## 12.6 Testing of generators above 5 MW unit size

**These generator may be category 2 (Para 12.5) or following categories.**

**Category 3:** Generators that require field assembly of the stator, but can have the rotor shipped to the site as an integral component part. Category 3 generators are usually up to 25 MW.

**Category 4:** Generators that require complete assembly of the stator and rotor at the site. These are usually greater than 25 MW.

**Note:** General practice in India is to have stator sections wound in factory and joints made in the field.

### 12.6.1 Factory Assembly and Tests

#### a) Resistance of stator and rotor winding

For generators not completely wound in the factory this test is carried out only on the portion of winding assembled in factory.

#### b) Dielectric Tests of Stator and Rotor Winding

Units not completely wound in the factory, the tests be carried out only on the portion of winding assembled in the factory.

#### c) Insulation resistance of stator and rotor windings

### 12.6.2 Field Assembly and Tests

- a) Resistance of stator and rotor windings
- b) Dielectric tests of stator and rotor windings
- c) Voltage balance

- d) Phase sequence
- e) Mechanical balance

A filed check of mechanical balance of all machines should be carried out.

- f) Measurement of insulation resistance of stator and rotor winding including polarization index test.
- g) Measurement of bearing insulation resistance
- h) Open circuit saturation curves
- i) Short circuit saturation curves
- j) Short circuit saturation curves

### 12.6.3 Performance tests on generators above 5 MW

- a) Current balance
- b) No load/open circuit saturation curves
- c) Short circuit saturation curves (synchronous impedance curves).  
Generator with brushless exciters, reading of exciter rotor current instead of generator rotor current may be taken
- d) Over speed
- e) Impedance of rotor coils
- f) Temperature rise tests
- g) Harmonic analysis and measurement of THF
- h) Short circuit withstand tests and measurements of reactances and time constants
- i) Efficiency tests by measurement of segregated losses.
- j) Bearing current (shaft voltage)

## 12.7 Test Procedure

### 12.7.1 Dielectric Tests of Stator and Rotor Winding

#### 12.7.1.1 Test Voltages

Standard test voltages of power frequency as near as possible to sine wave for generator as per IS: 4722 are as follows. This test ensures that the insulation is capable of enduring temporary over voltages.

**Stator Winding** of Generators – 1000 Volts + twice the rated voltage

High voltage test is performed phase by phase. Two phases and core not under test are connected to frame.

**Rotor Winding** up to and including 500 V DC – Ten times the rated field voltage with minimum of 150 V

#### 12.7.1.2 Duration of Application of test Voltages

Full test voltage slowly increased is maintained for 1 minute.

For mass produced (standard) generators up to 200 kW and rated voltage up to 660 volts, the test voltage be applied for 5 second.

#### 12.7.1.3 Additional tests After Installation

High voltage test at full voltage made on the windings on acceptance may not be repeated. If however, a second test is made the test voltage may not exceed 80 %.

#### 12.7.1.4 Rewound Machine

Complete Rewound Machine are tested at full test voltage. Partially rewound machines are tested at 75% of test voltage.

Overall machines after cleaning and drying are subjected to a test voltage of 1.5 times the rated voltage.

#### **12.7.1.5 Stator Winding Turn Insulation test**

Stator Winding Turn Insulation test to turn insulation of multi turn coils may be tested as per IEEE std. 522 by special agreement.

#### **12.7.2 Insulation resistance tests and Other Diagnostic Tests**

DC voltage insulation resistance tests be carried out as per procedure given in IS: 7816. Polarization index test is an important diagnostic technique and provide trend data for electrical insulation system.

Other available techniques for the purpose are as follows and may be specifically provided.

- a) Power factor and power factor tip up tests (IEEE std. 286)
- b) DC high voltage tests (IEEE std. 95)
- c) Various partial discharge (Crona tests) IEEE std. 1434
- d) Partial discharge tests performed on individual coils and bars or on complete windings.

The acceptable value depends upon type of insulation. Ionization probe tests are useful for assessing condition of individual coils.

#### **12.7.3 Testing High Voltage Terminal Bushings**

High voltages terminal bushings (when used) may be tested independently of the machine winding. They should withstand 1.5 times the 1 minute AC test voltage of the machine winding (IEEE std. C50-12).

#### **12.7.4 Over speed test – As per clause 17 of IS: 4722**

#### **12.7.5 Short Circuit withstand test – As pr clause 19 and 20 of IS: 4722**

#### **12.7.6 Vibration – As per IS: 12075**

#### **12.7.7 Noise test – As per ISO: 3746**

### **12.8 Excitation System tests**

#### **12.8.1 Equipment Tests**

Complete factory assembly of the excitation system is generally not required. Routine, type and special tests may be carried out as per IEEE std. 421.4-2004. In addition factory tests and type tests for the excitation system recommended are given below:

- **Static Excitation (potential source rectifier exciter) system**

- a) **Excitation transformer - factory tests**

Factory tests may be carried out as per IS: 11171/IEC 35413 Routine tests should include measurement of following.

- i) Winding resistance
- ii) Ratio
- iii) Polarity and phase relationships
- iv) No-load loss (if capable)
- v) Magnetizing current at rated voltage
- vi) High potential test in accordance with IEEE std. 421.3-1997
- vii) Induced potential

b) **Type Tests (certified test report if type test is performed)**

- i) Impedance, load loss, and regulation
- ii) Temperature rise, i.e., heat run
- iii) Impulse test (s)

• **Rectifier Assembly**

a) **Excitation transformer - factory tests**

Factory tests may be carried out as per relevant IS: std. Or IEEE std. C57.12.91-2001 Routine tests should include measurement of following.

- i) Continuity of rectifier fuses
- ii) Polarity and phase relationships
- iii) Range and stability of rectifier phase control
- iv) High potential test in accordance with IEEE std. 421.3 - 1997

b) **Type Tests (certified test report if type test is performed)**

- i) Rated current, watt losses
- ii) Temperature rise, i.e. heat run
- iii) Burn in, 48 hours unless otherwise specified (designate if current or voltage burn in is required)
- iv) Verify current balance between parallel bridge

**12.8.2 Brushless Excitation System**

a) **Factory tests**

- i) Insulation resistance
- ii) Resistance of all windings at a specified temperature
- iii) Resistance of all external current limiting resistors and field rheostats, where applicable
- iv) Air gap
- v) No-load saturation curve, from residual voltage to exciter ceiling voltage
- vi) Phase rotation
- vii) Continuity of rectifier fuses
- viii) Rectifier leakage
- ix) Range and stability of rectifier phase control, where applicable
- x) High potential test
- xi) Operation at anticipated over speed

b) **Type tests**

- i) Audible noise
- ii) Load saturation curve, up to 110% of nominal ceiling voltage
- iii) Main exciter regulation
- iv) Heat run
- v) Exciter time constant
- vi) Excitation system voltage response time and response
- vii) Operation at anticipated over speed, at the anticipated maximum head

## 12.9 Testing of Large Generators

Any generator that must be assembled in the powerhouse will require field testing after installation to measure values of efficiency and reactances, particularly when efficiency guarantees are included in the purchase specification. Normally this requires a second generator in the powerhouse with special switching equipment and “back-fed” excitation system to permit performing retardation tests used to determine generator efficiency. In addition, special arrangements are required to use one of the generator voltage class breakers as a shorting breaker during sudden short circuit tests.

Calibration of test instruments and shipping of necessary switchgear and excitation equipment requires considerable time. If the associated turbine is to be given a field efficiency test, it may be desirable to coordinate the turbine and generator tests so that the electrical testing instruments will be available to measure generator output during the turbine test. The heat run requires a load on the generator. Normally, the generator is loaded by connecting the generator output to the system load. If system load isn't sufficient to load the generator, IEEE 115 outlines alternative techniques to simulate load conditions.

Generator erectors usually apply dielectric tests on the armature (stator) and field windings before the rotor is put into the machine. If the stator is wound in the field, a high potential test is usually done once each day on all of the coils installed during that day. This facilitates repairs if the winding fails under test and may preclude missing scheduled “on-line” dates. The test voltages for these intermediate tests must be planned so that each one has a lower value than the previous test, but greater than the test voltage specified for the final high potential test.

IS: 7816 describes the polarization index test. This index is the ratio of the insulation resistance obtained with a 10-min application of test voltage to that obtained with a similar application for a 1-minute period. Recommended indices and recommended insulation resistance value are also given in the referenced standard.

Because of the relatively small amount of insulation on the field windings, simple insulation (Megger) tests are adequate to determine their readiness for the high voltage tests. The dielectric test to be made with the field winding connected to the collector rings and hence the test cannot be made until after the generator is assembled with the DC leads of the static excitation system connected.

**Fire Protection Systems:** Generators with closed air recirculation systems are provided with automatic carbon dioxide extinguishing systems. On larger open ventilated generators, water spray installations with suitable detection systems to prevent false tripping should be considered.

## 12.10 Typical specifications for testing of large generator and static potential source type excitation system

### 12.10.1 Factory Assembly and Tests

#### Generators

Following factory assembly and tests should be performed. In accordance with relevant IEC/IEEE/IS specification latest edition and will include following. The test to be performed shall be listed in the tender.

- (a) The insulation between turns of the stator coils shall be tested at the factory by impressing an alternating potential of suitable frequency across each coil so as to produce a voltage of not less than 10 times normal operating voltage between adjacent turns. Factory tests of individual stator coils shall include suitable tests to demonstrate that an essentially void-free structure exists in the insulation system of each individual coil. The Contractor shall submit for approval, an outline and description of the test methods to be employed in factory testing the stator coils. The insulation between turns of the field coils of the generator should be similarly tested so as to produce a voltage of 40 volts between adjacent turns.
- (b) Resistance test of armature and field windings.
- (c) Dielectric test of armature and field windings.
- (d) Insulation resistance of armature and field windings.

This should include the polarization index values for both armature and field windings.

- (e) Stator core loop test at rated flux for one hour.
- (f) Phase rotation check.
- (g) No-load saturation test.
- (h) Short circuit saturation test.
- (i) Mechanical balance of rotor.
- (j) Dynamic balancing of rotor at 125 percent rated speed.
- (k) Current transformer test
- (l) Efficiency test
- (m) ND (non destructive) tests of rotor shaft and shaft coupling bolts.
- (n) Material test certificates of various component parts.
- (o) Temperature rise test
- (p) Hydrostatic test of each oil/air cooler
- (q) Power factor tip-up of stator coil insulation

The air coolers should be subjected to a static water pressure of 5.25 kg/cm<sup>2</sup> respectively, for a period of not less than one hour without showing leaks.

### **Excitation System**

Each excitation system should be subjected to routine tests, including but not restricted to the following:

- (a) Dielectric tests per IEC/I.S./ANSI C34.2 "Practices and Requirements for Power Rectifiers".
- (b) Complete operational check of sequencing and regulator sections. Regulator to be set to simulate actual operating conditions.
- (c) Complete operational check of all protective relays
- (d) Energize all power circuits for operational checks
- (e) Rated voltage test
- (f) Test of excitation system potential transformer in accordance with IS:11171/IEC: 35415/ANSI C57.12.00 "Distribution, Power, and Regulating Transformers"

### **Excitation System - Special Factory Tests**

In addition to the above mentioned tests, the Supplier should make, the following special factory tests on the excitation system for one generator:

- (a) Rated current test at 115% rated current and reduced voltage as outlined in IS/IEC/ANSI C34.2 "Semiconductor Power Rectifiers", may be substituted.
- (b) Heat run to determine maximum temperature rise. This test shall include a heat run at exciter rated output. Subject to the approval of the Contracting Officer a heat run at 115% rated current and reduced voltage as outlined in IS/IEC/ANSI C34.2 may be substituted in lieu of the heat run at rated output.
- (c) Phase control range.
- (d) Tests to determine the transient performance. These tests shall include a test to determine the excitation system voltage response and excitation system ceiling voltage. Excitation system voltage response and excitation system ceiling voltage should be determined with the excitation system at rated load field voltage and loaded with a resistance equal to generator's field resistance at 75 degrees C. Excitation system voltage response shall be determined for various step error signals as errors of up to 20% are introduced into the excitation system sensing circuits to produce increases in excitation system voltage.
- (e) Tests to demonstrate performance at extremes of input voltage to the exciter.
- (f) Tests to determine excitation system losses and efficiency. Losses measured should include as applicable those losses listed in IS/IEC. Excitation losses shall- also include I<sup>2</sup>R losses in the AC leads from the generator tap to the power potential source transformer in the AC leads. From the

power potential transformer to the stationary rectifier assembly, and in the DC leads from the excitation cubicle to the generator collector rings.

The test on the excitation system should be conducted in accordance with ANSI C34.2. Tests to determine excitation system transient performance should be conducted as specified in 5.29.3(d). The Contractor should notify the Purchaser as far in advance as practicable when each excitation system will be ready for test so that the test may be witnessed by Purchaser's Inspector. The Contractor should furnish the Purchaser with certified copies of a test report of the factory test including the characteristic curves. The test report should include descriptions of the tests performed, sample calculations and the formulas used in determining the results of the tests.

The following curves and data should be included in the test report showing the characteristics of the excitation system as determined by the factory tests:

- (a) Efficiency and power factor plotted against amperes output through a fixed resistance equal to the calculated resistance of the generator field winding at 75 degrees C.
- (b) Segregated and total losses, plotted against amperes out-put through a fixed resistance equal to the calculated resistance of the generator field winding at 75 degrees C.
- (c) Excitation system – voltage response plotted against percent excitation system error signal.
- (d) Computation of excitation system ripples voltage.

All other electrical parts, such as manual voltage adjusters and similar devices, should be tested individually in accordance with applicable ANSI or IEEE or IEC Standards, except that where the parts quantity production and routine tests are made and are of such routine tests are in accordance with the above noted standards, individual tests of such parts will not be required; however, in either event, the Contractor should submit certified test data covering each part.

#### **12.10.2 Field Tests**

After the generator and auxiliary equipment has been installed in the power plant ready for operation each generator should be tested by the erection supervisor in the presence of the Engineer in charge to determine, whether, the manufacturers guarantees and the requirements of the specifications have been fulfilled. The test should be made in accordance with the latest applicable requirements of I.E.C. standards, British standards, A.S. A. standards, N.E.M.A. and the IEEE-115. test code for synchronous machines, dated June, 1995 and the A.S.M.E. Test code for hydraulic prime Movers, dated May, 1999 or the latest revisions thereof, except as herein definitely stated . The waving of any test should not relieve the company of his responsibility to meet fully the requirements of the specifications. All test instruments and instrument transformers etc, should be furnished by the company. At the time the hydraulic turbine is tested, the company should furnish necessary calibrated electrical test instrument and instrument transformer for measuring the output of the generator and exciters using indicting watt-meters, ammeters, and voltmeters as recommended for the three wattmeter method as per Test code for hydraulic prime movers, published by the American Society of Mechanical Engineers. The supplier should cooperate with the engineer and with the other Supplier involved to establish a mutually satisfactory date for testing, so that the generator test may be started immediately after completion of the turbine tests.

After the thrust bearing cooling pipe line has been completely assembled, it should be subjected to a static water pressure of 5.25 kg/cm<sup>2</sup> for a period of not less than one hour, without showing any leaks or any drop in pressure.

After complete erection, the generator should be subjected to the following tests.

1. Alignment of turbine and generator shafts by mechanical rotation of the units.
2. Megger test for insulation resistance.
3. Dielectric tests of armature and field windings at not less than 80<sup>0</sup>C. The armature winding should be given a dielectric test in accordance with the latest approved standards, one phase at a time with

other windings grounded. The field windings should be given a dielectric test for one minute when connected to the interpoles through field leads the generator collector rings.

4. Resistance test of armature and field winding.
5. Operation test and adjustment of the entire excitation system to show compliance with all operating requirements of the specifications specially with regard to sensitivity and response.
6. Test for the determination of the time for brakes to stop the machine safely from speed to zero speed with the turbine gates fully closed and with exciter field open.
7. Phase sequence test should be carried out.

### 12.10.3 Performance Tests

In addition to the above field tests the following special tests should be made on one generator:

1. Conventional efficiency test. This test should include the determination of
  - a. Exciting circuit losses.
  - b. Fixed losses.
  - c. Direct load losses.
  - d. Stray load losses.

The exciting circuit losses should be included as a part of the generator losses in determination of the generator overall efficiency by summation of losses method, as laid down in British Standard No. 269/IEC standard.

2. Test to determine the maximum temperature rises of the various parts of the generator, when operating continuously at maximum rated output with the water supply to the surface air coolers regulated so that the temperature of the air leaving the cooler is approximately 40<sup>0</sup>C. Load will be provided by the Purchaser. Coolers capacity should also be tested.
3. Machine parameters tests.
4. Three-phase, short circuit test, to demonstrate that the generator is capable of withstanding short-circuit stresses without injury when the machine is operating under load. This test should be made by abruptly short-circuiting the generator when operating at no load, rated frequency, and rated voltage, for a period of not more than 10 seconds. One of the current waves, when taken on oscillograph should be particularly completely offset. If the first short-circuit does not produce this, additional short-circuits should be applied until such is obtained. The supplier should be responsible for any and all damage caused by the short-circuit test to the equipment.
5. In addition to the above listed tests, the erection supervisor of the Supplier should perform other tests, required to establish conformance of the equipment with the guarantees and the specifications, and to obtain data needed in testing the turbine with the generator used as a dynamometer. The waiving of any test by the Engineer should not constitute relinquishment of the suppliers responsibility to fully meet the requirements which were to have been demonstrated by that test.
6. The supplier should furnish a complete list of all testing equipment to perform above field tests and should also quote unit bid and loan prices. The supplier should also furnish a complete list of special testing instruments and quote unit bid and loan prices.
7. Load acceptance and rejection tests- The generator should be tested at selected loads from no load to full load for load acceptance and rejections. All the parameters of the machine should be recorded and should be within permissible limits.
8. Subsequent over speed Test:- Within one year after operation has begun, and at such time as directed by the purchase Engineer, the supplier should operate such generator at the specified over speed, or at the highest speed obtainable with the available head, whichever is the lower, for a period of not more than 5 minutes after the full speed has been attained. This test is to demonstrate that all parts of the generator will successfully withstand stresses incident to specified runaway speed.
9. Auxiliary equipment- All other auxiliary equipment should be checked, tested and commissioned before the main plant for their satisfactory performance.

10. Synchronization- The generator should be synchronized with the available system for best performance.
11. Tolerances: Tolerance limits for efficiency, total losses and power factor should be in accordance with the International Electro-technical Commission Standards for Electrical Machinery latest edition.

## **12.11 Maintenance Tests of Hydro Generator Stator Insulation**

### **12.11.1 Introduction**

Stator insulation deterioration due to electrical stresses is not uniform. The coils subjected to a voltage of 5 kV and above, i.e. line end coils, suffer a greater degree of deterioration than the rest leading to insulation failure and causing large expenses in repair and loss of generating capacity.

Evaluation of in-service stator insulation of large hydro generator during commercial use is required to restrict forced outages and study the general trend of insulation deterioration and distinguish the coils which are in advanced state of deterioration so that a decision for rewinding or replacement of individual coils can be taken.

### **12.11.2 Causes of Insulation Damages**

The causes of failure of stator insulation can be attributed to:-

- a) Partial discharge that occur inside the voids in the insulation which are inadvertently left during the manufacture leading to erosion in soft materials, microscopic cracks in brittle parts and formation of chemicals corroding the organic insulation.
- b) Surface discharges that occur when the semiconducting paint of the insulating portion in the slot portion or the anticorona varnish on the overhang portion of the coil gets electrically disconnected from the core iron.
- c) Weak strand insulation leading to breakdown of main insulation
- d) Defective turn to turn insulation on multiturn coils.
- e) Magnetic terminations which once lodged on the insulation surface holes into by the action of the alternating flux subsequently leading to corona discharge and ultimate failure of the ground wall insulation.
- f) Relaxation of the ground wall insulation in case of thermoplastic insulating systems leading to swelling of insulation thereby reducing ionization inception voltage.
- g) Differential expansion between the copper, insulation and the slot iron due to the thermal effects of load cycling leading to tape separation or girth cracking particularly in case of turbo generators for thermo plastic insulating systems. Most of the tape separation occurs just outside the end of the slot or under the end wedge.
- h) Vibration caused by electro-magnetic forces leading to tape separation and girth-cracks especially in hydro generators in case of thermoplastic insulation system.
- i) Mechanical damage caused by break away tooth pieces from the core striking against the insulation.

### **12.11.3 Insulation Tests**

Analyzing the causes of the failure, the maintenance test schedule comprise of such tests which can indicate:

- a) The dielectric strength of the ground will insulation
- b) The integrity of inter-strand insulation
- c) The integrity of turn-to-turn insulation
- d) The rigidity of core laminations
- e) The presence of voids in the insulation to assess the extent of its damaging effect on insulation.
- f) Physical displacement of slot wedges, presence of magnetic termites, evidence of tape separation.

The condition of the inter-strand insulation can be adjudged by observing for any hot spots in the winding during normal run or by conducting a short circuit of the winding surface through visual inspection of the winding surface can indicate presence of magnetic termites, displacement of slot wedges, and swelling and tape separation. The various tests that have been developed can be broadly classified as high voltage tests and non-destructive tests. Non-destructive tests are those in which the applied test voltage does not exceed the rated line to line voltage.

The high voltage tests are aimed at indicating that the insulation has sufficient dielectric strength to withstand over-voltages expected in the winding during operation. However the high-voltage tests can not detect faults in the end-turns or the leads remote from the stator core, if the windings are clean and dry. These tests can be further classified as tests for dielectric strength of the ground wall insulation and tests for turn-to-turn insulation in multi turn coils. Non destructive tests are based on measurement of the two well known properties of a dielectric which are known to be dependent on the condition of the insulation namely resistance partial discharge. The various tests developed for this purpose are given below and discussed as diagnostic tests in Para 12.7.2.

**Table 1: Classification of Insulation Maintenance Tests**

	<b>Non destructive tests Based on measurement of</b>		<b>High voltage tests</b>
	<b>Insulation resistance</b>	<b>Partial discharge</b>	
Ground wall insulation	<ul style="list-style-type: none"> <li>• 60 sec. insulation resistance tests</li> <li>• Two volt tests</li> <li>• Dielectric absorption test</li> <li>• Polarization index test</li> </ul>	<ul style="list-style-type: none"> <li>• Measurement of partial discharge</li> <li>• Slot-discharge test</li> <li>• Dissipation factor and dissipation</li> <li>• Ionization probe measurement</li> <li>• Sonic probe</li> </ul>	<ul style="list-style-type: none"> <li>• Ac power frequency test</li> <li>• DC HV test</li> <li>• DC step voltage test</li> <li>• AC 0.1 Hz test half sine wave HV test</li> <li>• Ac power frequency resource HV test</li> </ul>
Turn to turn insulation on multiturn coils			<ul style="list-style-type: none"> <li>• Surge comparison test</li> <li>• Surge induction test</li> </ul>

For a complete discussion refer the relevant reference.

## References

- IS: 4722-2001 - Rotating electrical machines specification
- IS: 7816 – 1975 - Guide for Testing insulation resistance of rotating machines
- IS: 11171 – 1983 - Specification for dry type power transformer
- IS: 12075 – 1987 - Mechanical vibration of rotating electrical machines
- IS: 12802 - Temperature rise measurement of rotating electrical machines
- IEC: 60034 - Rotating electrical machine
- IEEE: 115 - Test procedure for synchronous machines
- IEEE: C50-12-2005 - IEEE standard for salient pole 50 Hz synchronous generators/motor for hydraulic applications rated 5 MVA and above
- IEEE std. 1 - General principles for temperature limits in the rating of electrical equipment and for the evaluation of electrical insulation
- IEEE std. 4 - IEEE standard technique for high voltage testing
- IEEE std. 43 - IEEE recommended practice for testing insulation resistance of rotating machinery
- IEEE std. 95 - IEEE recommended practice for insulation testing of AC electric machinery (2300 V and above) with high direct voltage
- IEEE std. 115 - Test procedures for synchronous machines, Part I- Acceptance and performance testing  
Part II – Test procedures and parameter determination for dynamic analysis
- IEEE std. 275 - Thermal evaluation of insulation systems for alternating current electric machinery employing form wound preinsulated stator coils for machines rated 6900 V and below.
- IEEE std. 286 - Measurement of power factor tip-up of electric machinery stator coil insulation
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