Insulation Testing Large Rotating Machines

SCOPE & PURPOSE

This application note applies to large ac rotating machines rated at 10,000 kVA or greater and rated 4160 V or higher. It covers acceptance testing ofnew machines in the factory or on-site after installation. It also covers routine maintenance testing of machines that have been in service. In some cases, there may be other apparatus connected to the generator windings whose insulation systems also need to be monitored. This includes generator bus bushings and bus duct stand-off insulators.

Voltage withstand or proof tests are made to determine whether apparatus insulation has enough margin of integrity that it will not be likely to fail in service before the next test period. When further information about the status of the insulation system and its future reliability is desired, additional testing techniques can be applied. These techniques include, polarization index (P. 1.) testing, dissipation factor (power factor) testing and partial discharge testing. Partial discharge test equipment is available in forms suitable for both on-line monitoring and off-line preventive maintenance testing.

The justification for preventive ma' intenance testing is that it searches out an incipient failure during a planned outage, rather than at an inconvenient time, and with less risk of damage to the machine than might occur from an in-service System fault.

TEST CONSIDERATIONS

Many years of experience with powerfrequency high-voltage testing have resulted in the establishment of voltage levels and times of application that give reasonable assurance of insulation free from defects. The standard factory powerfrequency acceptance proof-test voltage is twice rated voltage to ground plus 1000 V. An acceptance test on equipment newly installed is commonly made at a voltage level of 75 to 85 percent of the factory test. Maintenance proof tests made after a period of service ordinarily will be at some lesser value. The exact test voltage levels aredeterminedbynegotiationbetweenthe issuer of any applicable warranty and the owner of the machine.

Successfully passing an acceptance or maintenance proof test does not guarantee against failure before the end of the next service interval. However, experience has shown that many weak spots are found in this way and fewer in-service failures will occur.

The voltage withstand, or proof test, has been the traditional method for testing rotating machines. It is necessary to take a machine out of service (off-line) to do a proof test. While the machine is out of service,verylittleadditionaltimeisneeded to perform a dissipation factor (power factor) or a partial discharge test. When property performed, these tests can provide an indication of the present status and future reliability of the machine's insulation system. The key to meaningful test results is archiving the test data over the life of the machine. In this way dangerous trends can be identified

TEST EQUIPMENT

Three types of test voltage sources can be used for testing generator insulation systems, DC, power frequency AC and very low frequency (VLF). The oldest technique is DC testing. It has the advantages that the test voltage source is relatively lightweight, easily portable and relatively inexpensive. Unfortunately, DC testing has the following major disadvantages:

- It does not stress realistically the end-turns of the generator winding.
- Many large generators of recent design have water cooled windings. The cooling water creates a relatively low resistance leakage path to ground which overloads the DC test voltage source.
- The leakage current through the cooling water is greater than the leakage current through the generator winding insulation. It is nearly impossi 'ble to separate and measure the two independently. This prevents polarization index testing. The only solution is to dry out the generator cooling system, which typically takes two or three days. As a result, DC testing is not used frequently for testing water cooled generators.

Without question, the most realistic stressing of generator windings is provided by the power frequency AC proof test. In this case, the generator is tested at the same frequency that it sees in normal operation. The AC test can be done immediately, without delays for drying the cooling systenl The savings of downtime for testing can more than pay for the cost of the test equipment, if lost revenue is considered. In addition, the power frequency test voltage source also permits measuring the insulation system dissipation factor (power factor) and partial discharge level.

The power frequency AC test set can be kVA rated to permit energizing one, or more, phase windings of the generator, plus other permanently connected items, if desired. The kVA rating of the AC test set is determined by the test voltage and the total capacitance of the load it must energize. The main component of the load energize capacitance is the capacitance of the generator phase winding to ground.

The disadvantages of AC power frequency testing are the size, weight and cost of the test equipment, when compared to DC test voltage sources. However, utility generating stations already have overhead cranes with lifting capacity for generator rotors, which far outweigh the power frequency AC test voltage source. Thus, it is a simple job to lift the AC test set from a truck and move it to the location of the generator, This typical situation overcomes the problems due to size and weight of the AC test set.

The third alternative test voltage source's the VLF 0.1 Hz test set. The VLF technique was developed in an effort to combine the advantages of power frequency and direct voltage testing, without the disadvantages. Experimental studies have shown that voltage stress distributions for frequencies as low as 0.1 Hz are not significantly different from those at 50 or 60 Hz.

A reduction of the test voltage frequency by a factor of 500 for 50 Hz, or 600 for 60 Hz, will reduce by this same factor the charging current taken by the capacitance of the generator winding. For this reason, the size and weight of the VLF test equipment also can be significantly reduced.

If there are concerns about deterioration of the generator insulation system during the application of test voltage, the VLF technique offers another advantage. The typical generator proof test is of one minute duration. For a VLF test this only allows six repetitions of the test voltage frequency, a reduction of 500 (600) times when compared with the AC power frequency test.

The VLF test technique also permits partial discharge testing with useful test results. However, 01 Hz dissipation factor (power factor) data will not be comparable to that taken at power frequency.

For off-line preventive maintenance tests, partial discharge test equipment is available in forms suitable for use with VLF, power frequency AC, or DC test voltages. Partial discharge test equipment is also available in forms suitable for on-line monitoring.

PREPARATIONS FOR TEST

Generators can be grouped into three major categories: air-cooled, hydrogen-cooled, and machines with liquid-cooled (oil or water) windings. Appropriate preparations are required, depending on which category generator is involved.

The generator can be tested with or without the rotor in place. However, it is preferable to test the stator windings after the rotor has been removed, because it is easier to observe and inspect any irregularities detected during the testing.

When the objective of the test is to determine the condition of the generator winding insulation only, it is recommended to disconnect everything else that is practical in the available time. Items that should always be disconnected include surge arrestors and capacitors. Potheads, bus-bar insulators and any other insulating surfaces should be clean and dry, if they cannot be disconnected.

When feasible, each phase should be isolated and tested separately with the other phases grounded. When possible, both ends of each phase winding should be connected together, whether the phase is to be tested or grounded. Testing one phase at a time gives a comparison between phases that is useful in evaluating the condition of the winding.

If the neutral point is not accessible, it is necessary to test all phases at the same time. In this case, it is recommended to connect all three phase points together to avoid surges at an open end in the case of failure, or flashover.

When testing all phases at one time, ordy the insulation to ground is tested. This is due to the fact that no stress is applied to the insulation between phase windings, as is the case when each phase is tested separately with the other phases grounded.

TEST CONNECTIONS

The test voltage source and the power separation filter of the partial discharge detection system should be solidly grounded to the frame of the generator under test.

The phases of the winding that are not under test should be grounded to the frame of the generator. When present, the following also should be grounded to the frame of the generator:

- Armature temperature-detector coils and the mo couples.
- Any other devices associated with the winding.

- Current transformer secondary's
- The rotor winding and shaft.

All ground connections should be made using wire with ample current carrying capacity (AWG 6, or larger) and robust physical strength. Care should be taken to insure that connections can not fall off during the test procedure, or subsequent grounding.

Whenever possible, the high voltage test connections should he spaced a minimum of 4 inches, plus 1 inch per 10 kV (peak), from grounded surfaces. It is recommended that the test connection leads be supported in air without use of solid insulation support whenever possible. If solid insulation is unavoidable, it must be dry and with adequate surface creepage distance. To prevent Corona from the test leads, sharp edges and small diameter wires should be avoided. Robust insulated connection leads, of the same type as used for the ground connections, are recommended. For off-line partial discharge tests, the high voltage electrode of the power separation filter is connected to the same point as the test voltage source (see Figure 1).

On-line partial discharge monitoring of all three phases can be accomplished safely by connecting the power separation filter of the partial discharge detection system across the neutral grounding transformer of the generator (see Figure 2).

TEST PROCEDURE

The test voltage should be applied to the winding gradually, preferably starting from zero, or less than 5% of the full test voltage. The test voltage should be raised, at a uniform rate, to the specified test level in not more than one minute. It should be maintained at the specified test voltage for the standard one minute test time and then promptly returned to zero and the winding grounded. Partial discharge test data can be taken during the proof tesl It is not necessary to energize the machine a second time for the collection of partial discharge test data. To avoid the possibility of damaging voltage transients. the winding should not be de-energized suddenly. Should a failure occur, the test voltage should be reduced immediately to prevent a repeat of the flashover or failure. In the event of a failure, the failed coil should be identified and electrically isolated to perrnit testing the remaining coils.

SAFETY CONSIDERATIONS

Adequate precautions must be taken to prevent anyone from coming in contact with the test circuit or the apparatus under test during the test time. Area partitioning warning tape, red warning beacons, energized when test voltage is available, and security guards are recommended.

Particularly after DC testing it is possible for dangerous voltage levels to buildup on the windings that have been tested. For this reasorl tested windings should be shorted to ground and kept grounded until the testing procedure is finished.

TEST RESULTS

Proof testing is conducted on a purely withstand basis. If no evidence of failure of any sort is observed by the end of the total time ofvoltage application, the winding is considered acceptable.

If polarization index, dissipation factor (power factor), or partial discharge test data is taken, it must be compared with similar data taken either on other phases of the same machine at the same test time, at a previous time, or on similar machines. This technique is very effective for detecting existing abnormalities and trends. This test datails used in addition to the proof test to provide an indication of the future reliability of the generator insulation system. No absolute accept/reject levels are published.

A normal rotating machine can have partial discharge signal levels of multi-thousands of picocoulombs with hundreds of discharge repetitions per cycle of test voltage. This contrasts dramatically with the typical test data for a power cable. Because of the high level of signal activity, it is advisable to record more than the maximum picocoulomb signal level, as is the common practice when testing cables.

Partial discharge test instrumentation is available that permits recording signal count, signal amplitude and signal phase angle, in addition to peak and average partial discharge signal levels.

CONCLUSION

All power generators need periodic maintenance, which is expensive and requires a lengthy out-of-service period. For these reasons, it is desireable to run a generator for the maximum time before taking it out of service for repairs, or coil rewinding. If the generator is left in service until a failure occurs, more extensive damage to the machine will occur and the out-of-service time needed for repairs will be increased significantly.

As a result of lost revenue from a generator, the cost for out-of-service time can be calculated easily. If preventive maintenance testing can prevent unscheduled outages and the resulting lost revenue, the cost of the test equipment will be recovered very quickly. Based on typical experience in recent years, Pacific Gas & Electric has estimated that their power frequency AC test set could save them more than $280,000 per year in lost revenue. It is certain that experience gained via the application of the new partial discharge test instrumentation to generator insulation systems will lead to more effective preventive maintenance test techniques. The end result will be improved capability to schedule outages and plan necessary maintenance work, while avoiding excessive damage due to on-line insulation system failures.

TEST STANDARD REFERENCES

IEEE 4	Techniques for Dielectric Tests
IEEE 56	Guide for Insulation Maintenance for Large AC Rotating Machinery
IEEE 115	Test Procedure for Synchronous Machines
IEEE 433	Recommended Practice for Insulation Testing oflarge AC Rotating Machinery with High Voltage at Very Low Frequency (VLF)

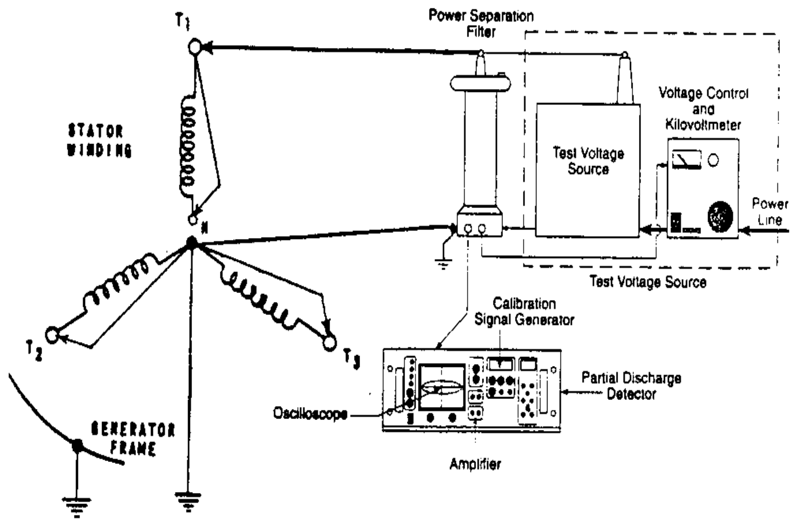

Figure 1. - Off-line test connection diagram for proof and partial discharge testing of a stator winding.

Note: The neutral connectionfor the phase winding under test is disconnectedfrom ground.

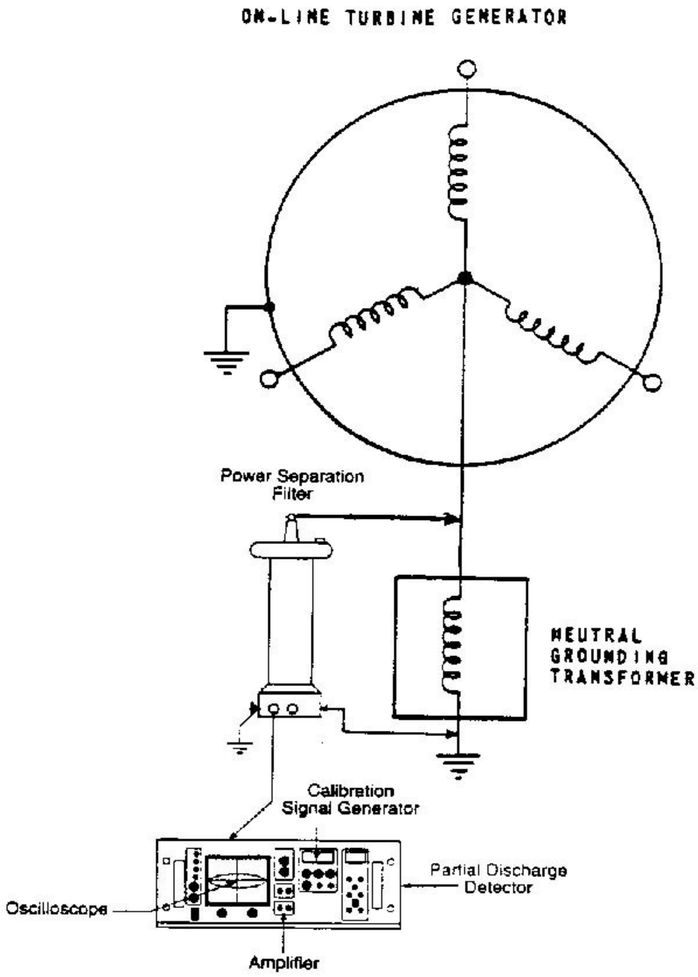

Figure 2. -- On-line test connection diagram for partial discharge monitoring of all three phases of a generator.

PARTIAL CUSTOMER LIST

Power Frequency AC Test Systems AC Test System Ratings

Westinghouse Power Generator Service Div., Pittsburgh, PA 100/60/30 kV, 1000 kVA

Westinghouse, Power Generator Mfg. Div., Pensacola, FL 00/60/30 kV, 1000 kVA

FURNAS

Rio de Janiero, Brazil 60/41/31/10 kV, 75OkVA

CHESF

Recife, Brazil 40/11 kV, 1750 kVA

Hydro Quebec Quebec, Canada 60/40/15 kV, 600 kVA

Pacific Gas & Electric San Francisco, CA 60/40/30 kV, 600 kVA

Korea Power Plant Service Co., Ltd. Seoul, Korea 75/35/15 kV, 750 kVA

Very Low Frequency (VLF) Test Systems VLF System Rating*

General Electric, Schenectady, NY 85 kV, 0.4 µF

American Electric Power, Canton, OH 100 kV, 0.6 µF

ENIEL, Milan, Italy 100 kV, 1.0 µF

CEGB, London, England 100 kV, 1.0 µF

BHEL, Hyderabad, India 100 kV, 1.0 µF

Electricity Supply Board, Dublin, Ireland 85 kV, 0.4 µF

Public Service of Indiana, Plainfield, IN 100 kV, 1.0 µF

Georgia Power Co., Atlanta, GA 85 kV, 0.4 µF

Duke Power Co., Charlotte. NC 85 kV, 0.4 µF

Alabama Power Co., Birmingham, AL 85 kV, 0.4 µF

Taiwan Power Co., Taipei, Taiwan 100 kV, 1.0 µF

*The "VLF System Rating" can be compared with 50 Hz and 60 Hz RMS system ratings needed to energize the same load capacitance at the same crest voltage (see the following table).

VLF System Rating Equivalent Power Frequency System

Crest Voltage Max. Load RMS Voltage kVA Frequency

85 kV 0.4 µF 60 kV 1130 50 Hz

85 kV	0.4 µF	60 kV	1360	60 Hz
100 kV	1.0 µF	70 kV	1540	50 Hz
100 kV	1.0 µF	70 kV	1850	60 Hz

TECHNICAL PUBLICATION REFERENCES

1. P.H. Reynolds and H. C. Manger, "Field Tests of Partial Discharge in Generators at Very Low Frequency"

2. P.H. Reynolds and V.M. Naik, "A Summary of Current Diagnostic and Quality Assurance Testing of Machine Stator Windings"

3. W. McDermid, "Insulation Systems and Monitoring forstator Windings oflarge Rotating Machines"

4. E.H. Povey and A.L. Rickley, Preventive-Maintenance Testing of 60/45/30 kV, 600 kVA Generator Insulation

5. F.T. Emery, "Radio Frequency Monitoring of Generators"

6. F. Ross, "Partial Discharge Analysis, Predicting Machine Insulation Failure"