Generator

Insulation Testing

The purpose of conducting an insulation test is normally to determine if the winding is satisfactory for operation at the voltage and load for which the apparatus was designed. There are several factors helpful in arriving at such a decision, and these may be divided basically into three categories:

I. Visual Inspection
II. Electrical Tests for Evaluation
III. Electrical Proof Test

Either or both of the first two items may reveal a condition which indicates that the winding is **not** suitable for service, however the absence of such data does not necessarily mean that the winding **is** suitable for service. The most positive answer may be obtained by following these with Item III which is an overpotential test at some predetermined level above operating voltage. If it is desired to perform a minimal amount of testing, Items I and III are the more important to determine suitability for service.

Generally the insulation system of electrical equipment deteriorates with age, however in the case of rotating equipment the majority of this deterioration usually is the result of mechanical or thermal action instead of dielectric stress. Thus, the test program is directed at searching out effects of such things as mechanical movement, vibration, overheating, or damage inflicted from external sources, in addition to effects of dielectric stress.

I. Visual Inspection

A thorough visual inspection by experienced personnel should be considered a basic part of any comprehensive test program. This would logically involve removing the field from turbine-generators to provide access to more of the winding. (Refer to Section 3470EM.)

II. Electrical Tests for Evaluation

There are a number of tests which are available at present to help evaluate the condition of a winding, and obviously with further advances in instrumentation other tests may be available later to obtain a more comprehensive appraisal. Following is a list of tests which may be performed to help evaluate a winding:

A. Insulation Resistance
B. Dielectric Absorption and Polarization Index
C. Direct-current Leakage
D. Power Factor
E. Slot Discharge and Radio Noise

A short discussion of these items follows:

A. Insulation Resistance

This test is probably the simplest and easiest to make of the normal series for helping to evaluate the insulation system of a winding. It may be made with an insulation resistance meter, "megger," which is calibrated to read directly in ohms or megohms. This applies a fixed value of DC voltage and is available in various ranges, 500 volts being a common value. It may also be obtained by using any of the available variable voltage DC sets which are equipped to measure applied voltage and leakage current, such as would be used in making a DC leakage test. From the measured value of voltage and leakage current, the resistance can be calculated.

Insulation resistance is subject to a wide variation with operating conditions such as temperature, moisture in or on the winding, and cleanliness. It will also vary with the capacitive charging current which depends upon the test voltage and the length of time that this voltage is applied. Many of the apparent inconsistencies of insulation resistance readings can be explained if consideration is given to these factors. Where initial and periodic readings are to be correlated, testing should be done at a definite temperature, voltage and length of time. Refer to Section 3610EM on Dryout relative to variations of insulation resistance with temperature.

A high value of insulation resistance is usually indicative of clean, dry insulation, but by itself is not proof that the insulation is free from mechanical or physical weakness. Such weakness may be of a type which does not affect insulation resistance at low voltage, but may be the cause of breakdown during the application of normal working voltage. Relatively low insulation resistance or sudden changes in insulation resistance should considered as a cause for careful investigation.

Any external equipment connected to the generator being tested such as field leads, field breaker, generator bus duct, transformer, etc., will obviously affect the reading. If it is not desirable to isolate such equipment, this must be taken into consideration in evaluating the reading. Should the reading be low enough to be questionable the external equipment should then be disconnected in order to further the investigation.

As a generator winding cools down from operating temperature the insulation resistance would be expected to **increase** if it is kept closed and dry. On the other hand, if the winding is exposed to very moist air as it cools down, it might absorb enough moisture to cause the readings to **decrease**. Obviously it is necessary to consider the surrounding conditions in order to evaluate a particular reading.

Megger tests of water-cooled stator winding insulation requires removal of all water from the flexible insulating connectors. Since draining will not empty water from all of the connectors, dry air must be blown through the winding. The air system must be capable of supplying approximately 1000 cfm at 25 psi. Additional drying can be accomplished by establishing a vacuum within the winding and connectors. Refer to armature liquid-cooling system of Instruction Book for specific instructions relative to draining the stator windings.

B. Dielectric Absorption and Polarization Index

The dielectric absorption test is an extension of the insulation resistance test for a longer period of time, in order to allow the value of the current to stabilize more, usually for a ten-minute period. This may be made with a motor-driven or electronic megger, or with a higher capability, high-voltage DC set.

Since the insulated winding of a large generator is in effect a large capacitor, and the capability of a megger set is quite low, it takes a long time for the megger to build up a stable charge on the winding. For this reason the reading will continue to change over a long period of time, if the winding is clean and dry. If the winding is wet or faulty, the leakage current may be high enough that the megger is not capable of building up a high charge at all.

The ratio of the ten-minute to the one-minute reading of insulation resistance is called the polarization index. On a turbine-generator field an index of 1.25 would normally indicate a clean dry winding. The stator winding might be expected to show an index of 2.5 or higher, except for water-cooled windings. The polarization index cannot be considered a criterion for determining the moisture content of the insulation of a water-cooled winding because of the inherent characteristics of the flexible cooling water connections to each stator bar. A value of 150 megohms or higher would indicate an acceptable degree of dryness for a water-cooled winding.

C. Direct-current Leakage Tests

This test is accomplished by applying a DC voltage in steps up to a previously determined limit or until abnormalities are found which dictate that the test should be terminated. The applied voltage at each step is plotted against the measured leakage current at that voltage, to form a leakage current curve. The shape and slope of this curve can be an important indicator in observing trends in the status of insulation.

Experience has indicated that this data can be of value as part of a test program, but should not be depended on alone as the only evidence. The magnitude of leakage current is influenced by surface moisture or contamination, and by conducting paths in or through the insulation groundwall. Thus, if a fault exists which then becomes contaminated with dirt or saturated with moisture, it would noticeably affect the leakage current curve. On the other hand it is possible for a break or fault to exist in the groundwall of the insulation and yet remain relatively clean and dry, as might be expected in a hydrogen-cooled generator. The leakage current curve probably would not show any perceptible change, and thus would not indicate any impending trouble until the voltage is high enough to break down the remaining gap, at which time failure will occur, often without warning. In general then it may be said that an abnormal rise in leakage current (or rapid falling off of leakage resistance) with increasing voltage **may** be indicative of an insulation weakness and should be investigated. The converse, however, is not necessarily true, since it is possible to have a serious insulation weakness which is not shown up by abnormal characteristics of leakage current or resistance.

Conducting leakage tests requires the application of voltage for periods in excess of one minute and it is, therefore, recommended that the maximum DC voltage be limited to a value of 2.0E, where E = rated line-to-line voltage.

Since this is a relatively simple and easy test to perform, and it can detect some types of insulation troubles it is reasonable to include it in a series of tests. It must be recognized however that it cannot be depended on for a high degree of reliability in determining suitability for service or breakdown strength of the insulation.

D. Power Factor

Under electrical stress, insulations have a dielectric loss which is measurable with suitable equipment. One method of measuring this property is with a special high-voltage capacitance bridge. Such a bridge measures capacitance and power factor of the insulation. Important changes to the integrity of the insulation can occur during the life of the insulation and may be reflected by changes in these properties. In order to aid in the evaluation of insulations with respect to possibilities of gross voids, puffing and thermal aging, measurements of capacitance and power factor should be made at several levels of voltage up to about rated line-to-ground voltage for the generator. This entails the use of a source of AC voltage with enough kva capacity to energize the winding to the desired voltage. While voltage is applied to the winding, readings of capacitance and power factor are made using the capacitance bridge.

E. Slot Discharge and Radio Noise

One of the deteriorating forces which may occur in high-voltage windings is corona. It is possible for corona to occur within the insulation if internal voids are developed in service, or it may be outside the insulation, if the corona suppression systems become inoperative. In the event that the slot corona suppression system becomes inoperative, the corona discharge may become very severe in intensity, and is specifically called "slot discharge." It may be possible to detect the presence of slot discharges through the use of a filter circuit, amplifier and oscilloscope, while the winding is energized with rated AC voltage.

Corona occurring within voids inside the insulation along with that which may be occurring outside the insulation in the area of the end winding is detectable with the use of a radio noise instrument. This measurement is made by coupling the measuring equipment to the winding while the winding is energized with an AC voltage.

The corona suppression material on the slot portion of the winding of large General Electric turbine-generators has been very effective in eliminating slot discharge phenomena, and thus the probability of detecting trouble with this test is quite low.

III. Electrical Proof Test (Refer also to Section 3590EM)

One of the most authoritative determining factors in establishing the suitability for service of a winding is an overpotential test. This will search out weaknesses which might not be located by any other means. It consists of the application of a voltage across the ground insulation, at a predetermined value higher than rated voltage. The amount of overvoltage to be used depends on several factors, one factor being the degree of reliability which the owner demands of the equipment.

New insulation when installed is tested at a considerably higher level than rated voltage, and if at any time in the life of the equipment the insulation strength reaches a level such that it is approaching a breakdown at rated voltage, it has obviously undergone a wide range of deterioration. Since this rate of deterioration is an unknown factor and cannot be predicted, one approach to reliability of operation is to test the winding periodically at a level of voltage high enough to provide a generous margin of safety for the next period of operation, and yet at a level of voltage which is not high enough to damage sound insulation.

An advantage of this type test is that weak coils may be replaced at a planned outage, rather than at a less convenient time. It also helps to avoid the very costly consequential damages which are usually associated with a service failure. It is desirable then that spare bars be available when making overvoltage tests on generator windings.

The objection has been expressed that if the owner does not have spare bars on hand, an overpotential test should not be recommended. If a weakness exists in the winding, the fact that the owner does not have spare bars does not pre-

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clude a service failure under peak load conditions. By taking advantage of outages due to other equipment in the station to plan a test program, if bar replacement is required, the effect on the over-all schedule will be greatly minimized.

Another objection to testing has been expressed that an overpotential test might fail a bar near the neutral section of the winding, which otherwise might run for a long time. The hazard in relying on weak insulation near the neutral is indicated in Fig. 1. With the neutral grounded through a high impedance, if a second point of weakness exists near the line end, a service failure near the line end or a ground fault on one phase of the generator bus will shift the apparent neutral to this point and produce a high voltage at the original neutral, possibly resulting in failure at that point also. **With a double fault inside the machine, core damage is almost inevitable.**

A water-cooled winding on which high potential tests are to be conducted should have the following precautions observed:

For AC tests the water should be circulating in the winding, or else the winding should be drained to remove water from the flexible insulating connectors. With water circulating in the winding during testing, there will be losses produced in the water which must be supplied by the test equipment. The magnitude of these losses will depend on the voltage used, and resistivity of the water.

For DC tests the water should be removed from the winding as outlined for megger tests.

AC Overpotential Tests

New generators are given overpotential tests in the factory before shipment in accordance with the values of voltage established by the American Standards Association (ASA C50.1) (2E+1000), where E = rated line-to-line RMS voltage. These values are based on the use of AC voltage. Based on present knowledge and experience the General Electric Company believes that this is the best method of testing this type of equipment. Since an AC voltage is present in the windings during operation, the AC test will provide weakness searching similar to that present during normal operation.

Specific instructions for testing, and suggested values of test voltage are tabulated in Section 3590EM, "High-potential Testing in Purchaser's Station."

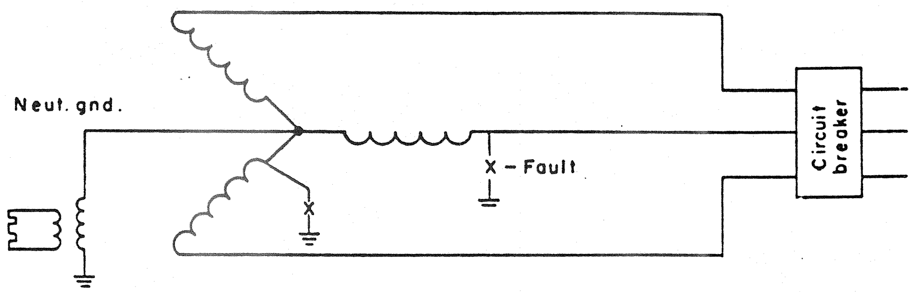

Fig. 1. Double internal fault

DC Overpotential Tests

This type of proof test consists of the application of an elevated DC test voltage to the generator winding insulation. It is felt that this should be a second choice for making a proof test, since it cannot be depended on to be as searching as an AC test for the type insulation weakness which may cause the insulation to fail during operation.

The equipment involved in making this test is lighter and smaller than that involved if 60-cycle AC voltage is used. For this reason it is sometimes chosen, as a matter of convenience and lower cost. The user should recognize the limitations of the test however, if a reliable proof test is desired.

Tests on new and old equipment, comparing breakdown values of the two types of voltage indicate that to achieve similar searching effects a higher value DC voltage must be used than AC. For several years this ratio has generally been accepted as 1.6 for insulation in service, and 1.75 to 2.0 for new, clean insulation. More recently the AIEE working committees have recommended that a ratio of 1.7 be used both for new insulation and for insulation in service. These figures are compromise values only, and the actual breakdown ratio may vary from about 1.2 to about 4.0. For this reason the LST-G Department has not recommended the use of DC for proof testing.

It has been interpreted in some cases that LST-G is opposed to the use of DC on the grounds that it is damaging to the insulation. **There is no basis to show that a normal overpotential test damages sound insulation to any measurable degree, using either AC or DC.**

A disadvantage of high voltage DC testing is the long time required to discharge the winding. A high voltage may remain on the insulation for a considerable length of time after initial grounding because of the slow leak-off through the high insulation resistance.

Low Frequency AC Overpotential Tests

The primary recommendation of the LST-G Department concerning the type of voltage for proof testing has been in favor of AC voltage. It is recognized that 60-cycle AC equipment with capability to test a large turbine generator winding is somewhat heavy and expensive. It is also recognized that although DC equipment is sometimes used in order to take advantage of its smaller size and lower cost, the LST-G Department feels that this is also a compromise in that there is a difference in the searching effects of the two types of voltage.

A new, low frequency high voltage test equipment has been developed, which for similar capability of testing large windings, is smaller and lighter than the comparable 60-cycle equipment. The output from this is an AC voltage at 0.1 cps. It achieves a searching effect much closer to that of the 60-cycle voltage than does a DC voltage. The basic reason for this is that the dielectric stress on the insulation is being continually reversed, whereas with DC voltage a charge is built up on the insulation in one direction only.

This provides an over potential test to determine the suitability for service of the winding at the voltage level agreed to between the manufacturer and the

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and the owner. It is not claimed that this test will provide any data for predicting insulation life other than as a go-or-no-go type of test, similar to that traditionally provided by the 60-cycle hi-pot test.

For specific voltage values to be used in a particular test, refer to Section 3590EM.

Method of Calculating Kva Requirement

Method of calculating kva requirement for high-potential testing when the capacitance of the winding is known:

1. Determine the charging factor F_c from the Table.

TEST VOLTAGE TO BE APPLIED / RATED VOLTAGE (LINE-TO-LINE)	1.0	1.3	1.5	1.7	1.9
F_c (CLASS B INSULATION)	1.0	1.03	1.05	1.08	1.12

2. The single-phase kva requirement can then be calculated by:

$$Kva = 2\ \pi\ f\ F_c\ C_{io}\ E^2 \times 10^{-9}$$

Where
- E = high potential test voltage (volts)
- f = frequency of applied voltage (cps)
- C_{io} = winding capacitance single-phase to ground (microfarad)
- F_c = charge factor

For winding capacitance refer to General Electric Company.