# TESTING OF LARGE ELECTRIC GENERATORS FOR SUITABILITY OF SERVICE

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## ABSTRACT

Evaluation of the actual condition of a generator is a challenging task. Each of the many tests which can be conducted to evaluate a generator has one or more of several limitations: cannot find local discrete weak areas without risk of insulation breakdown, gives averaging results only, insensitive to vital deterioration mechanisms, requires specialized equipment, personnel hazard. Inspection also has several limitation, e.g., many areas cannot be seen even with the best tools including robots, results are qualitative and highly operator dependent. Fortunately, however, the two approaches to generator assessment - inspection and test - are quite complimentary. The combination of a good testing program and thorough inspection by a skilled and trained individual can give a good assessment of almost all common forms of generator deterioration. This paper will address the testing portion of generator condition assessment.

A wide variety of tests is used in off-line evaluation of generators. Most are common to all types of machines, but some are used on specific classes of machines. The majority have been used since the infancy of power generation, but a few are of more recent development. Most of the tests are benign and will not harm the component under test. The primary exception is that of over-voltage testing, and this topic is considered in some detail in this paper. Since even under the best of conditions precise evaluation of the condition of a generator is difficult, it is generally better to use the full battery of tests when performing generator inspection and test.

This paper will discuss: Stator Over-voltage Tests, Off-line Partial Discharge Tests, General Stator and Field Tests, Stator Core Tests, and Liquid Cooled Stator Tests.

In this paper, which is heavily illustrated, these issues will be discussed rather comprehensively but in relatively non-technical terms. A better understanding of the strengths and weaknesses of available tests should assist owners of generators in implementing better maintenance practices, and thus reduce maintenance costs and extend reliable life of the generator.

## OVER-VOLTAGE TESTS

### TEST SAFETY AND SPECIAL CONSIDERATIONS

Because over-voltage tests are performed at lethal voltages, it is absolutely essential that test equipment operators be fully trained and certified before attempting to perform these tests. If the tests are not properly performed, both test equipment operators and plant personnel are at risk of death. This is not a theoretical concern; there are recent recorded incidents of death during performance of such tests.

While megohmmeters operate at relatively low voltage, 500 to 2500 Vdc, this voltage must still be considered dangerous. Although megohmmeters are designed for low output current, the voltage is sufficient to cause personnel injury due to reflex actions. Also discharge current of the capacitance of the winding under test may not be low. Thus for all field and stator megohmmeter tests, appropriate protective actions must be taken.

It is important to recognize that during every type of over-voltage test, on stator or field insulation systems, there is the possibility of failure to ground.

On stator windings, because of the nature of the systems and the high inherent safety margins, failure almost certainly will not occur during a properly conducted over-voltage test unless severe winding degradation has already taken place. Nor will good stator winding insulation be measurably degraded during the brief application of over-voltage.

Field windings operate at relatively low voltages, less than 750Vdc, and are generally designed with extensive creepage paths, which are subject to contamination. As a result, a good evaluation of field insulation can be performed with a megohmmeter test. Routine high potential testing of field windings is generally not recommended. However under specific circumstances, failure investigation for example, field high potential test may be appropriate.

**MERITS OF PERFORMANCE OF STATOR OVER-VOLTAGE TESTS**

The great importance of high potential testing results from the fact that stator insulation systems normally deteriorate at a modest rate. Unless subjected to mis-operation or other localized distress, in-service failure of a well-designed and properly manufactured system would not be expected for 30 to 40 years or more. Deterioration rates for differing conditions are shown pictorially in Figure 1.

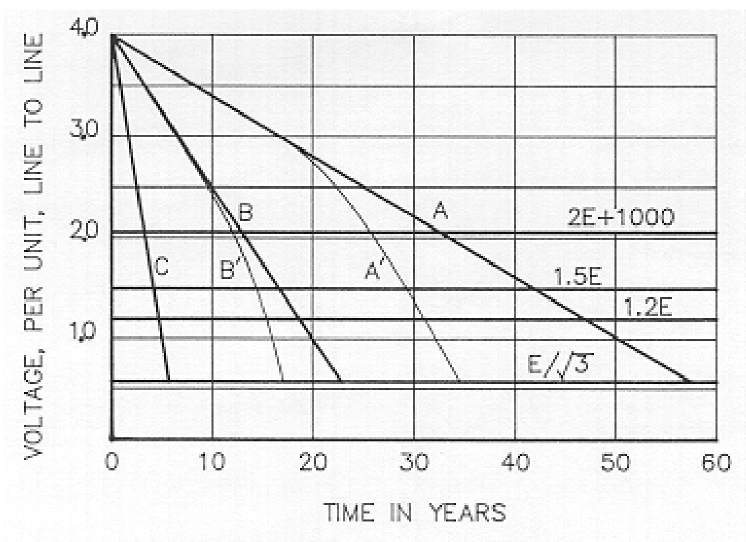


**Figure 1. Stator Winding Deterioration Rates**

Deterioration is shown as linear; this will be a reasonable approximation if machine operating conditions do not change. Linearity will be lost, of course, if an accelerating phenomenon develops, e.g., bar vibration, partial discharge, foreign material wear, core loosening.

Three curves of insulation system deterioration are shown:

Curve A - Well designed system with no mis-operation or localized distress.

Curve B - System of marginal design with no mis-operation or localized distress.

Curve C - System of deficient design, with built-in deterioration mechanism, e.g., loose wedges, poor voltage grading, tape migration.

Curves A’ and B’ show the impact of changing conditions due to a developing problem, e.g., foreign object, bar vibration, partial discharge degradation.

Figure 1 also shows:

- Machine rated line-to-line voltage (E)

- Line-to-neutral voltage, E/1.732

- IEEE Standard new machine high potential test value (2E + 1000)

- Commonly recommended high potential test values for in-service machines (1.5E and 1.2E)

Referring to Curve A, where failure at line-to-line voltage is assumed at 50 years, a 1.5E high potential test would give assurance against line-to-neutral failure of approximately 15 years minimum. A 1.2E high potential test would project no failure for at least another 11 years of operation.

Curve B indicates that even with an insulation system of marginal design quality, with an assumed line-to-line failure after 20 years, the assurance period is still about 6 years with a 1.5E high potential test.

With a marginal insulation system or non-linear and/or rapid deterioration, Curves C, A’ and B’, protection periods against service failure without system disturbance would be much shorter and the use of a full 1.5E high potential test would be more urgent.

Of course, deterioration of a specific insulation system will not be purely linear, and most good stator windings may be expected to operate much longer than 50 years without line-to-neutral service failure due to general deterioration.

**STATOR HIGH POTENTIAL TEST CONSIDERATIONS AND CONCERNS**

There are several important considerations and concerns relative to high potential testing:

Manufacturers often recommend an in-service test value of 1.5E. This recommendation is based on the knowledge that bars that have failed in-service high potential test invariably show severe insulation degradation due to operation. Thus it is believed that a voltage less than 1.5E is unnecessarily conservative. However, at the owner’s discretion a lower test voltage may be appropriate. As indicated in Figure 1, even a test at 1.0E will give some protection against service failure, although the margin may be small in the event of system disturbance. Generally speaking, a test level of at least 1.2E is preferable.

There is always the possibility of winding failure during over-voltage test. When this occurs, it is usually not possible to make a local repair of the failed location. Thus, unless previous preparations have been made (spare parts, repair personnel, outage time scheduled), outage extension may occur.

A winding may contain a weak area which is located near the neutral end of the winding. Such an area may continue to operate for a long period of time without service failure. However, it should be kept in mind that a system disturbance may result in elevating of the voltage at neutral and thus cause service failure at this location.

Full test voltage is applied to the entire winding, whereas in normal operation the voltage within the winding scales from zero at the neutral end to line-to-neutral voltage at the line end.

High potential testing becomes particularly important on a machine with general, serious deterioration, since first failure is likely to be at a location near line voltage. With high impedance grounding (common on larger machines), neutral voltage will become elevated. This will place the line end of the other two phases near line-to-line voltage and thus overstress weak bars in these locations. Should a second failure occur on the winding, extremely high current will flow through the faults. The resultant burning will be severe, and the current cannot be interrupted until the field voltage has decayed. The time constant of a typical field is about 5 seconds. Thus, it will take about 5 seconds for the field current to decay to roughly 30% of initial field current. If the machine were operating at rated load conditions, after 5 seconds there would still be sufficient field current to develop near rated open circuit stator voltage; this voltage will continue to feed the arc and increase the winding damage and machine contamination. Double winding failures have occurred on about 1/3$^{rd}$ of generally deteriorating stators that have failed to ground in service; each case resulted in a full stator and full field rewind, and often partial core restacking.

**THE HIGH POTENTIAL TEST DECISION**

In reaching the basic decision relative to performance of stator high potential tests, the owner is faced with divergent and conflicting alternatives: 1) perform a suitability-for-service high potential test and risk high potential test failure, or 2) omit high potential test altogether and accept increased risk of service failure, forced outage, and possible extensive machine damage. In the final analysis, depending on the importance of a particular machine to the system and other business and economic factors, judgment must be made among the options to high potential test at a selected voltage, perform a leakage current or step voltage test, or omit over-voltage test altogether.

But the basic principles remain. A properly conducted high potential test:

> Will not damage a winding that is not already severely deteriorated.
>
> Will give good assurance against service failure for a stator winding that is not experiencing aggressive local or general deterioration.

## COMPARISON OF MEGOHMMETER TO HIGH POTENTIAL TEST (AC VS. DC VS. 0.1 HZ)

### Components of Measured Direct Current

When voltage is applied to an insulation system by a megohmmeter or other DC test device, 3 components of current are measured. These components vary widely in properties:

Capacitive Charging Current - This component is caused by the charging of the geometric capacitance of the winding being tested. On generator stators and fields, the capacitance is relatively small and this component reduces to zero rather quickly, in seconds, and will not ordinarily be observed by the megohmmeter operator.

Leakage Current - This is a resistive current, the quotient of applied megohmmeter voltage divided by insulation resistance. As such, this component of current rises and becomes stable immediately. This current results from groundwall insulation flaws and surface leakage paths. If significant groundwall and/or surface contamination is present, the current flow will be high, and the megohmmeter resistance reading will be low. Conversely, if the insulation is dry and clean, leakage current will be low and megohmmeter reading high.

Absorption Current - This component results from molecular changes within the insulation material. It is a complicated physical phenomenon having to do with the molecular “dipoles” which make up the components of the groundwall insulation. These dipoles are randomly oriented unless placed in a DC electric field. When dc voltage is applied to the insulation, the dipoles tend to rotate slowly within the groundwall, so as to align with the applied voltage direction. Absorption current is the flow of current associated with the rotation of the dipoles, and decreases asymptotically toward zero over a period of several minutes.

### Megohmmeter

Megohmmeter testing is the safest of the electrical tests performed on insulation systems. If properly done, this test presents little risk of damage to the insulation and almost no risk of winding failure. This is a valuable test, and should be performed at each convenient opportunity.

Megohmmeter voltage ranges of 500 to 2500V are commonly used on stators. Because fields operate typically at less than 750Vdc, field windings can be satisfactorily tested with a 500Vdc megohmmeter. It generally is not recommended to use of a higher voltage megohmmeter, as this will place an unrealistically high voltage on the field winding.

The insulation resistance value will give an indication of overall insulation integrity, and may identify a fault that responds to relatively low voltage. Contamination, particularly with a conductive material or in the presence of moisture, will result in low megohmmeter insulation resistance readings.

Polarization index (PI), the ratio of the 10 minute megohmmeter reading to the one minute reading, will give an indication of surface and internal moisture. The mechanism of “polarization” is described above. Specifically, the rate at which the 3 components of DC current stabilize establishes the value defined as “polarization”.

If the insulation is dry, the predominate flow of current is consumed in reorienting the dipoles, and the current flow will asymptotically decrease to near zero. The corresponding resistance reading will then slowly steady out at a high level over a period of several minutes. The PI will also tend to be high, in the range of 1.5 to 4.0.

If the insulation is damp internally or externally, the predominate current flow will be high and resistive. A PI reading of 1.5 to as low as 1.0 may be expected.

One note of caution. A megohmmeter with a low-value full-scale reading (perhaps 1000 megohms or less) usually will not give a valid PI on a clean, dry winding. This results because the megohmmeter may read almost full scale after only 1 minute, and thus the reading will not properly increase between 1 and 10 minutes. The result will be an artificially low PI value.

Megohmmeter readings will vary widely from machine to machine, or on a given machine over a period of time. Judgment is required to interpret the megohmmeter resistance and PI values. For example, a low PI may be perfectly satisfactory if the absolute reading is high, as is often the case on good, dry field insulation. However, if both values are low, action generally is required before it would be considered safe to either high potential test or place the machine back is service. See below for suggested test values.

**General high potential considerations**

The single most effective electrical test evaluation tool for the quality of a stator winding is the high potential test. The choice of test voltage source is of secondary concern; all three commonly used systems are effective: power frequency AC, 0.1Hz AC, and DC.

In the slot portion of the winding, the 3 types of tests are roughly equally searching. But in the end winding, performance is quite different because the 0.1Hz and DC voltages stress the end winding insulation relatively more severely than operation or 60Hz high potential test. Thus use of DC or 0.1Hz AC will tend to increase the risk of inadvertent winding failure in the end arm regions.

Figure 2 shows the approximate voltage stress distribution across the groundwall insulation for the various test equipments: Curve 1 = 60Hz, Curve 2 = 0.1Hz AC, and Curve 4 = DC.

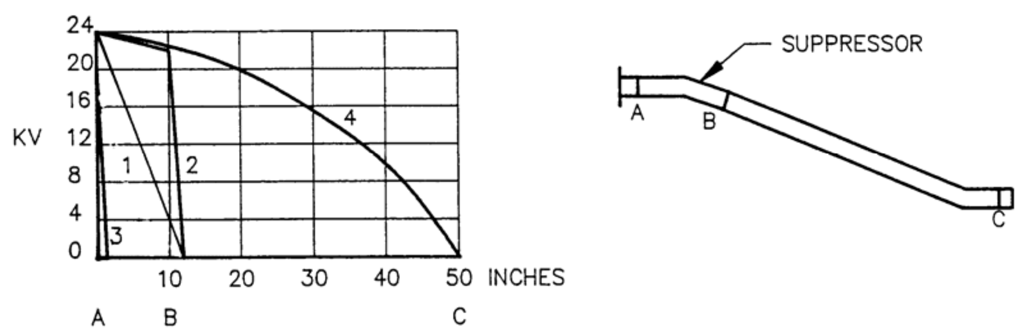


**Figure 2. Approximate Voltage Distribution Across Groundwall Insulation in Stator Bar End Region**

With 60Hz AC the voltage falls off quickly and will apply voltage across the groundwall for only a few inches beyond the slot grounding material, Curve 1. (The full length of the grading is not active on the relatively low voltages of maintenance high potential tests.) With DC, high voltage stress is applied across most of the end arm insulation, Curve 4. With 0.1Hz, nearly full test voltage is applied across the ground insulation to the end of the end arm grading, Curve 2. (On low voltage machines, this grading system will be applied perhaps 4-8” beyond the end of the slot grading material. On high voltage machines, the grading may extend up to 15” beyond slot grading.)

**Characteristics of the alternative test equipments**

Power-frequency (60Hz) Alternating Current - Most closely duplicates actual voltage stresses in the winding. Traditional test equipment was heavy and required a substantial power source. In recent years various types of “resonant” 60Hz high potential test sets have been produced and are readily available; while still heavy, these test sets are not bulky and do not require high power for operation. Figure 3. In addition, the resonant sets are lower power devices and tend to store lower energy during test, and thus may cause less burning should a failure occur.

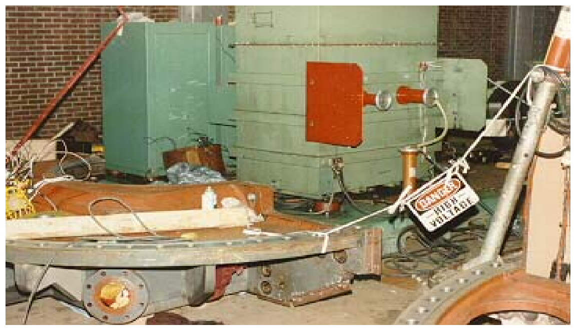

**Figure 3. 60Hz High potential Transformer**

0.1Hz Equipment - This test equipment was originally developed in the 1960’s to combine the advantages of DC and 60Hz AC. While light and requiring low power supply, the sets are bulky and subject to maintenance difficulties. Figure 4. This type equipment is currently in only limited use on generators.


**Figure 4. Van Mounted 0.1Hz High Potential Test Equipment**

DC - The test equipment is portable, light, inexpensive, easy to use, and low maintenance. Figure 5. If the winding under test is damp and otherwise contaminated, it may be possible to interrupt the test before actual flashover occurs. In the event of winding failure, there may be less damage at the failure site due to test set power and discharge of the winding capacitance.

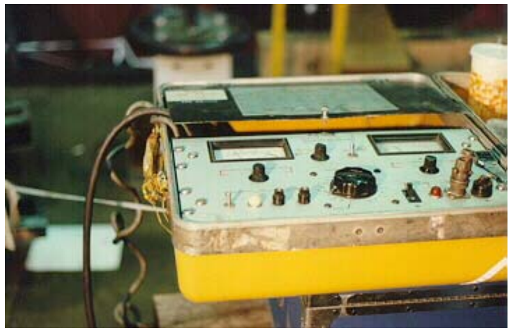

**Figure 5. DC High potential Equipment**

**Controlled-voltage Tests**

High potential tests are basically qualitative in nature, the winding either passes or fails. In order to develop quantitative information relative to insulation condition, 3 types of controlled voltage tests have been used: Fixed Incremental Steps, Time Graded, and Ramped Voltage. These tests are outlined in IEEE Std. 95, which is recently revised. Each method limits the maximum voltage to about machine rated line-to-line voltage, thus minimizing the likelihood of insulation failure. Using these procedures, the relationship of test current to test voltage is observed as voltage is built up to a predetermined value. If significant nonlinearity is observed, the voltage is immediately reduced.

Results of the test can be compared to earlier data on the same machine, as well as data from other similar machines. Thus it may be possible to reach general quantitative conclusions as to the overall condition of the winding.

On wet or contaminated insulation, impending failure of the insulation system at a point of weakness may be detected before failure. This would allow the operator to abort the test and avoid puncturing and/or tracking the insulation, although the insulation may still have been damaged. On the other hand, the protracted time of voltage application may cause insulation to fail that might have passed the relatively short hipot test, for example a marginally wet armature bar.

**OVER-POTENTIAL TEST PROCEDURES**

**Procedures and background common to all methods of testing**

The individuals performing the inspections and operating the test equipment must be thoroughly trained and qualified. Personnel safety procedures are paramount, but equipment safety is also important.

Prior to performing any over-voltage tests, the winding should be carefully inspected for overall condition and for possible localized damage. In addition, satisfactory megohmmeter readings should be obtained, both resistance and polarization index, before any over-voltage testing is done.

Typical values of polarization index on good windings are:

| | |
|---|---|
| Stators | 1.5 to 4.0* |
| Fields | 1.0 to 2.5** |

* Water cooled windings will be near 1.0 until fully dried internally. Air cooled generators, if contaminated, will often be near or at 1.0 until cleaned and dried.

** Acceptable values for over-potential test:

| | | | | | |
|---|---|---|---|---|---|
| Megohms | 25 to 100 | > | 100 to 200 | > | 200 |
| Minimum PI | 1.25 | | 1.10 | | 1.00 |

It may be found necessary to clean and dry either a stator or field winding before conducting over-voltage tests. The classic insulation drying curve is shown in Figure 6. Typically the insulation resistance value (and polarization index) will fall for the first few hours after heat is applied. If the insulation integrity is basically good, the values will then slowly increase over a longer period of time until satisfactory values are reached.

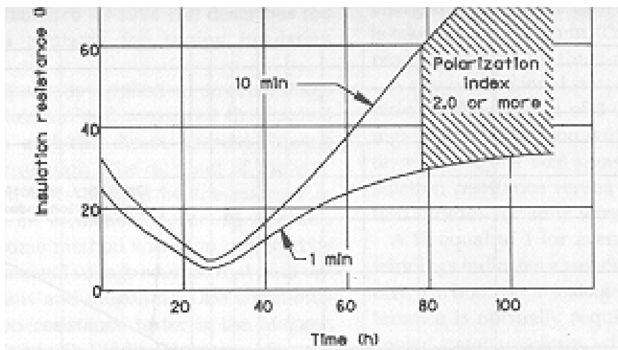


**Figure 6. Dryout Curves for Typical Field Winding**

**Safety**

Good safety practice should be followed in every step of the procedure. Personnel should be protected from electrical hazard as well as risk of fall or other injury. The winding to be tested must be absolutely isolated electrically from the power system. Phases, windings, and instrumentation not under test should be solidly grounded, as should be the test apparatus. Preferably, both ends of each winding should be shorted together. Sphere gaps should be used to check the calibration of the test equipment. Sphere gaps will also protect against excessive voltage over-shoot if set 5 to 10% above test voltage. Figure 7.

Before voltage is applied, the area around the machine to be tested should be isolated by recognized safety tape and signs, and with flashing lights(s) easily visible from all approach directions. If the machine is not small and compact, foot switches should be available as well as electronic communication equipment for use of individuals acting as protective guards. These individuals should be located at strategic positions around (and below) the machine. High voltage cable should be used between the test apparatus and the winding. Electrical conducting materials, such as disassembled components of the turbine-generator, should not extend from within the high potential test enclosure to beyond the protective tape.

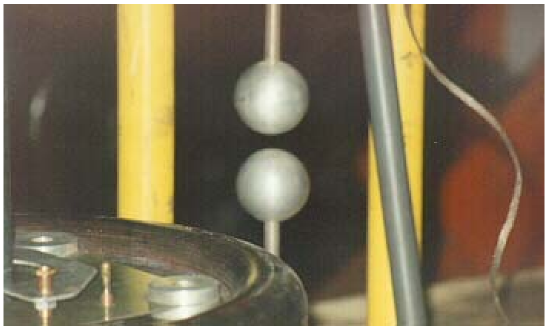

**Figure 7. Sphere Gaps in Use During High potential**

Figure 8 shows a typical, less-than-acceptable high potential test setup: protective tape too close to high voltage, metallic parts protruding under tape, no flashing lights. This setup does include sphere gaps and an appropriate sign, however.


**Figure 8. Inadequate High Potential Test Preparation**

Use of DC in any form of test requires special cautions. First, DC can charge nearby ungrounded electrically insulated objects, such as replacement armature bars. Thus any such components should be grounded if located within several feet of the test equipment. Second, after the test is concluded and the winding solidly grounded, the insulation of the tested winding will still retain a charge. The charge may not be fully dissipated for a considerable period of time, many minutes to an hour or so, depending on test voltage and conditions of the winding. (The charge results from the slow return of the "dipoles" back to random orientation condition.) At the conclusion of the test, the winding under test must be short circuited to ground for a period of at least 4 times as long as the test voltage was applied, and in no case less than 1 hour. Before bare hand contact is made, absence of voltage must be confirmed.

During high potential testing, there is the possibility of localized arcing or flashover to ground. These events may ignite insulating materials or combustible materials on the surface of the winding, for example, lubrication oil. For this reason, testing should never be performed on a closed generator with an air (oxygen containing) atmosphere. On a closed machine, the operators may not become aware of the fire, or if aware, may not be able to access the winding for extinction of the fire. Figure 9.

**Figure 9. Stator Winding Support and RTD Cable After Internal Fire Ignited by High Potential Test**

A closed machine may be high potential tested in a carbon dioxide atmosphere. Also high potential test can be done in a hydrogen atmosphere at elevated pressure, but test personnel must be certain that hydrogen purity is above the acceptable level, typically 95% or greater.

Test procedures should be in compliance with regulations and rules of the owner company, testing company, and government.

The test equipment must be in good working order and carry a valid calibration record. Over-voltage test should not be conducted without use of sphere gaps to verify calibration and protect against significant over-voltage.

No testing should be conducted without prior owner approval of the test, including test value. The test equipment operator must be certain to know the approved test value.

### Performance of AC high potential test (Power Frequency and 0.1 Hz)

Test voltage should be raised to the selected value at a steady, controlled rate. Care must be taken to be absolutely certain that voltage over-shoot does not occur. At the end of one minute at selected test voltage, voltage is reduced, again at a steady rate.

In the event of any personnel safety concern, or observed abnormality on the test winding, voltage should be immediately reduced to zero. (Preferably the test set should not be tripped, as this can set up transient over-voltages on the winding.)

The **peak** 0.1 Hz value approved by the industry is 1.63 times the 60 Hz **rms.** value, 1.15 times the **peak** 60 Hz value.

**Performance of DC high potential test**

Test voltage should be raised to the selected value at a steady, controlled rate not exceeding the output current capacity of the test set. Care must be taken to be absolutely certain that voltage over-shoot does not occur. At the end of one minute at selected test voltage, voltage is reduced, again at a steady rate within the capability of the test set to discharge the winding.

In the event of any personnel safety concern, or observed abnormality on the test winding, voltage should be immediately reduced to zero. (Preferably the test set should not be tripped, as this can set up transient over-voltages on the winding.) The special DC safety considerations discussed earlier must be carefully followed.

The DC value accepted by the industry is 1.7 times the 60 Hz **rms.** value. (In actual fact, there is not a simple direct relationship between the 2 types of voltage. Laboratory comparison tests have shown values as low as 1.414 and as high as 4.0. But the 1.7 multiplier is an acceptable compromise.)

**Step voltage test**

Procedures for conducting these three specialized DC tests are covered in IEEE Std. 95-1977. This document may be referenced for background information. Conducting of these tests should only be done by an operator trained and experienced in performing such tests.

The selected test voltage will be determined from known conditions of the winding, previous test results, and equipment history.

Briefly summarizing each of the tests:

**Fixed Increment Steps** - Voltage application is started at about 30% of the maximum intended test voltage (at which point insulation resistance and polarization index are usually obtained). Voltage is then raised in succeeding steps of about 3%, with each step held for one minute before proceeding to the next step. Current readings are taken at the end of each one minute interval. Unless abnormality is observed, steps are made in succession until the final level is reached. Data are plotted on log scale and should be a near linear curve. Any significant deviation from linearity is cause for concern and termination of test.

**Time Graded Method** - This test is more complicated than the Fixed Increment test. It is designed to reduce charging and absorption currents to negligible levels so that measured current flow after a prescribed elapsed time actually represents leakage current. The initial reading is again at about 30% of the maximum intended test voltage. During the initial 10 minute PI reading, the relationship between voltage and current is plotted on a log scale. From this plot, voltage steps are calculated from a formula contained in IEEE 95. The remainder of the test is conducted similar to the Fixed Increment test.

**Ramped Voltage Method** - This somewhat complicated test requires automated test equipment. Again the test is started at about 30% of intended maximum voltage, with a 10 minute reading to obtain polarization index. Voltage is ramped at a selected rate, typically 1 kV/min. The aim is to eliminate effects of dielectric absorption current, leaving only leakage current to be read, plotted and analyzed.

# OFF-LINE CORONA TESTS (PARTIAL DISCHARGE)

## GENERAL

**Equipment** - Several off-line tests are available for evaluating partial discharge of generator windings. (On-line tests are covered in Chapter 5.) Two general approaches are used: 1) test of the entire winding by phases or as a unit, and 2) search of local areas by use of a probe or wand. Both methods have significant strengths and weaknesses. Both require a discharge-free AC power source for energizing the winding to the required voltage, typically about line-to-line voltage (1.732 times line-to-neutral voltage). Resonant high potential sets are available, and these are smaller, lighter and less expensive than the standard high potential set.

**Test Sensitivity** - In both types of tests, all portions of the winding are at test voltage, in contrast to normal operation where bar voltage scales up from zero at the neutral end to line-to-neutral voltage at the line end. In both tests, the machine must be off line, and for the probe tests access must be available to the stator winding at the ends of the core. The whole-winding test does not allow for discrimination of actual partial discharge sites. Also since readings may be taken only at the ends of the winding, signals from sites distant from the sensing instrument will be attenuated. (This is not wholly bad, since these sites will operate at lower voltages in actual service.)

Because the machine is off-line, there will be no electromagnetic forces on the bars. Thus a bar which might be generating partial discharge because of bar vibration will not vibrate and will not generate partial discharge during the off-line test.

**Interpretation** - As is the case with on-line monitoring, Chapter 5, interpretation of results is difficult and uncertain. Trend review and comparison to duplicate windings may be more valuable than analysis of absolute readings. Also as with on-line monitoring, maintenance decisions cannot be alone based on partial discharge data, as data may be indeterminate or actually misleading. Efforts are underway in IEEE to converge the several test methods and gain a more definitive interpretation capability for all systems. This work may not be completed for many years yet.

## PARTIAL DISCHARGE TESTING

### General

On-line and off-line testing operates on the same basic principles. This subject is discussed in Chapter 5, On-line Monitoring and Diagnostics.

### Test Setup

Preferably each phase will be read individually. The sensor, a discharge-free coupling capacitor, is located on the input voltage line. Signal is read through a high pass filter into an oscilloscope or other recording/display instrument.

Both narrow- and wide-band measuring systems are in current use. Neither is ideal and there is as yet no standardization of band areas to be considered most significant.

**Procedure**

Voltage is raised until discharge pulses are first observed (discharge inception voltage - DIV), and readings taken. Voltage is then raised to selected maximum, and readings again taken. Voltage is then lower until discharge pulses extinguish (discharge extinction voltage - DEV), and a final set of data taken.

**Interpretation**

The 3 sets of data are then reviewed for trends and absolute values. No standardization yet exists on analysis of data, but some general principles apply: readings above 5000 pC may be indicative of winding deterioration, equal distribution of positive and negative pulses may indicate voids are within the stator bar groundwall insulation, preponderance of positive pulses may suggest voids on the insulation surface, and predominance of negative pulses may indicate voids at or near the copper.

## RADIO FREQUENCY (RF) PROBE

**Technical Background**

Partial discharge (PD) radiates radio frequency energy from the PD site. The RF probe is simply a modified AM radio loop-stick antenna which picks up this signal. The larger the discharge, the greater the AM signal. This signal is fed into an RF amplifier for measurement. The reading is not absolute, and is greater the closer the probe is held to a given PD site. However, an experienced operator can make a qualitative estimate of the intensity of the partial discharge.

**Test Setup**

Access requires that the field be removed from the stator. The probe is located on the end of an insulated stick, but a wire leads from the probe. Thus safety considerations are great, and extreme care must be exercised. (This test is more commonly applied to hydro generators.)

**Procedure**

Voltage is raised on the stator winding to the selected value. The individual bars are then probed with the antenna, including end winding and portion of the slot that can be safely reached. Readings are taken of any active site.

**Interpretation**

High readings tend to be associated with PD sites, although resonances within the stator winding circuit can give false readings. Thus interpretation is subject to judgment and highly operator dependent. However, a skilled and experience operator can often obtain useful data with this test.

## ULTRASONIC PROBE

**Technical Background**

Locations of serious surface degradation are likely to have high partial discharge activity. This surface activity will generate an acoustic noise, similar to that of a high voltage transmission line on a foggy day. The noise is primarily in the high tonal range, around 40kHz. A directional microphone may pick up this noise and identify the location of severe discharge. Discharges within the ground wall are unlikely to generate a noise that can be heard, thus this test is sensitive only to surface discharge.

### Test Setup

Access requires that the field be removed from the stator. The probe is located on the end of an insulated stick, but a wire leads from the probe. Thus safety considerations are great, and extreme care must be exercised.

### Procedure

Voltage is raised on the stator winding to the selected value. The individual bars are then probed with the microphone, including end winding and portion of the slot that can be safely reached. Readings are taken of any active site.

### Interpretation

High readings will tend to be associated with sites of high surface PD activity. Interpretation is subject to judgment and highly operator dependent. However, a skilled and experience operator may obtain useful data with this test.

## POWER FACTOR AND PF TIP-UP (DISSIPATION FACTOR, TAN δ)

### Technical Background

Power factor is the term commonly used to describe the measure of losses in a stator insulation system. For practical purposes, Cos ϕ, dissipation factor (loss factor) and tan δ are identical, since the angle between total current and capacitive current is small. (Cos ϕ approximately equals tan δ at small angles.) Figure 10.

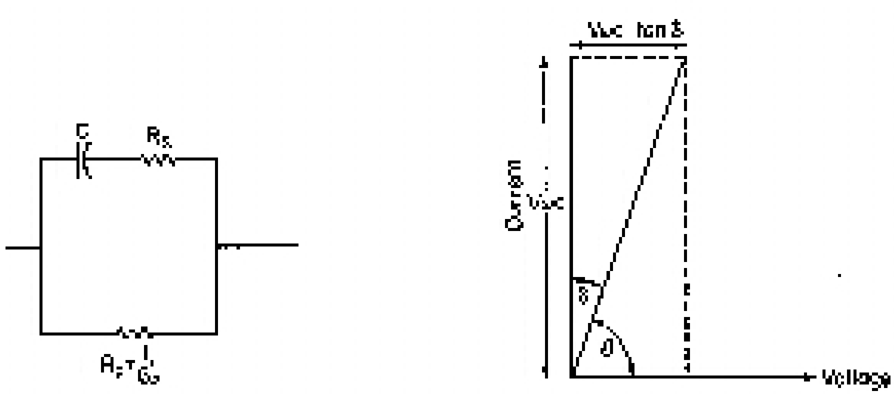


**Figure 10. Capacitor Current**

The stator insulation system is, in effect, a capacitor - an insulation system bounded by two electrodes: the copper conductor and the surface grounding paint. If it were a perfect capacitor, the losses in the insulation would be zero and the power factor zero. However, inherent voids and losses in the resin materials result in power factors of good insulation systems typically in the 0.2 to 1.5% range. Deteriorating systems may have power factors as poor as 5 to 10%, but a high power factor does not alone confirm that the insulation system is in poor condition.

In a perfect capacitor, losses would increase linearly with increase of applied voltage. However, in stator insulation systems losses tend to deviate upward from linearity as voltage is increased. This increasing loss rate results primarily from losses associated with partial discharges occurring in voids. The term "tip-up" is applied to this deviation, Figure 11. A stator insulation system in good condition typically will have a tip-up of 0.5 to 1.0, but values in excess of 1.0 do not necessarily indicate that the winding is in difficulty.

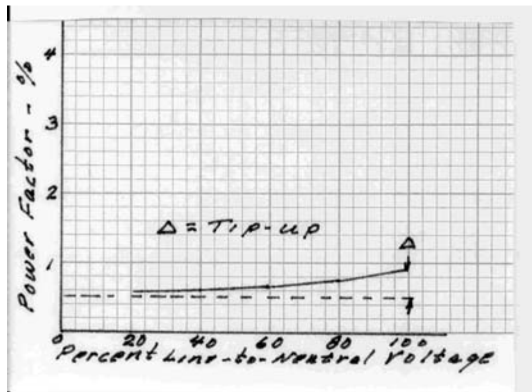


**Figure 11. Insulation Power Factor Vs Applied Voltage**

**Test Setup**

Required equipment includes a power frequency high potential transformer capable of reaching at least generator line-to-neutral voltage and a suitable capacitive-bridge measuring instrument. Preferably each phase should be measured separately.

**Procedure**

Test voltage is increased to about 20% of nominal line-to-neutral voltage, and readings taken. (At this voltage, partial discharge is unlikely to be present.) Voltage is then increased to the selected test value, typically line-to-neutral voltage, and the readings repeated.

**Interpretation**

Power factor testing is perhaps the most common elevated voltage test performed, often under the name "doble testing", and while the test itself is quite straight forward, interpretation is not. It is popularly believed that power factor and tip-up relate closely to winding condition, and this often is not the case. More likely surface contamination and moisture will be responsible for higher tip-up values, and perhaps high power factor values. On the other hand, very low values may not be indicative of good insulation system quality.

Power factor and tip-up tests are a useful test medium, and are worthwhile to perform. But the test results should be used only as a guide and not as an absolute measure of system condition. High, low, and "optimum" readings can be associated with insulation systems in good and in bad condition.

# GENERAL FIELD AND STATOR TESTS

## MECHANICAL TESTS

### Stator Wedge Tightness

Historically, tightness has been checked with a small (2 oz.) ball peen hammer. This is inherently subjective, but nevertheless, with some experience and training, an competent operator can make a good judgment of wedge tightness.

More recently, acoustic and mechanical test devices have been developed. This type equipment removes much of the operator variability and gives a permanent, quantified record. Figure 12. The field must be removed for the manual hammer test and hand-held tapper, but robotic equipment can perform the mechanized test with the field in place.

**Figure 12. Hand-held Stator Wedge Mechanical Wedge Tapper**

For designs which apply springs under the wedge, manufactures have developed procedures to measure ripple height through a series of small holes drilled in strategic locations along the top of the wedge. Robotic equipment is available for taking these readings with the field in place.

### Stator End Winding Modal Analysis and Resonant Frequencies

Modal analysis tests are used to assess resonant frequencies and looseness of end windings and connections. The tests are specialized in nature, and are performed with specialized equipment. Use of OEM or testing company personnel will generally be required to do this type testing. Particular skill and training will be required to interpret the results. Less sophisticated “bump” tests are commonly made on new windings, and on winding components suspected of possible resonance.

### NDE of Mechanical Components

Non-destructive evaluations are performed on retaining rings, wedges, forging, collector, fans, centering rings, couplings and bolts. Figure 13 & 14. Personnel with specialized training are required to perform the tests, and input from the OEM will be needed in the event of observing questionable results.


**Figure 13 & Figure 14. NDT Evaluation of Field Retaining Ring**

## OTHER ELECTRICAL TESTS

### Testing for field turn shorts

Several approaches are taken to assess turn insulation. These tests will not be described in detail here, since they are well documented in the literature. But in summary:

**Rotor Impedance Test** - Can be performed at stand-still (or at speed on fields with collector rings). A variable AC voltage is applied across the field winding. Changes in impedance are observed as a function of voltage and/or speed. Steps in impedance are an indication of speed or voltage sensitive shorts. Absolute impedance is also checked against earlier data, including as-shipped values. Figure 15.

**Figure 15. Power Supply for Measuring Field AC Impedance**

**Pole/Coil Drop Test** - Performed off-line, preferably with retaining rings removed. DC voltage is applied across the winding, and voltage is read on each accessible coil and pole connection, 6. Readings are compared between coils of same location, and with as-new condition. Voltage can also be applied using an excitation coil coupled magnetically to the field winding coil, Figure 17.

**Figure 16. Checking Pole/Coil Voltages with Retaining Ring Removed**

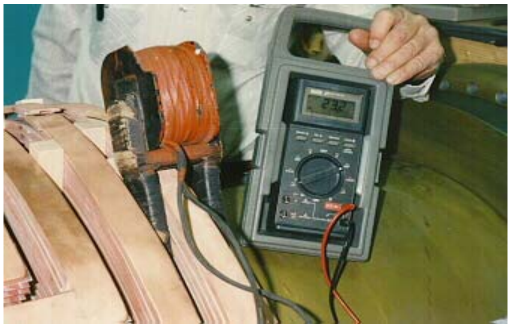

**Figure 17. Turn Short Excitation Coil**

**Turn Drop Test** - Similar to the Pole/Coil Drop test. Generally the retaining rings must be removed, Figure 18. However, on some direct cooled field designs, there may be sufficient access through the wedge ventilation holes to permit fully assembled testing. Data are examined for turns which show no voltage drop (change).

**Figure 18. Field Turn Voltage Drop Test**

**Flux Probe Test** - This on-line test requires installation of an air gap flux probe, Figure 19. This test is exceptionally effective and not difficult to perform. However, it special test equipment on computer programs are required, and thus the test is done by those specialized in this work.

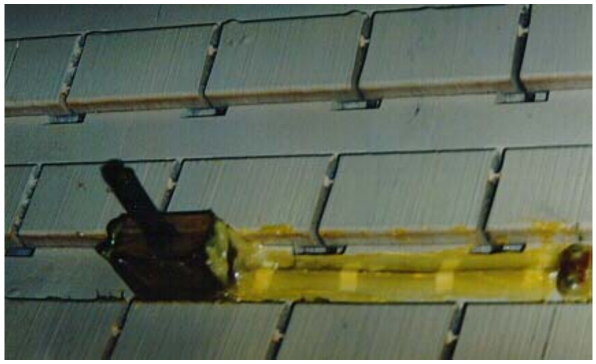

**Figure 19. Assembled Field Turn Short Flux Probe**

**Brush Holder Rigging Insulation**

Brush rigging components are easily accessible. Unless mechanical or electrical arc damage has occurred, insulation integrity generally can be restored with proper cleaning. Satisfactory condition can be confirmed with a 500 volt megohmmeter, reading >1 megohm. Test should be made separately on each pole, with the brushes lifted and all cables and leads disconnected.

**Bearing and Hydrogen Seal Insulation**

Designs vary widely between manufacturers, and many machines have been built with single insulation. On single insulated components, some disassembly is required and conducting of the test can be difficult. The OEM generator maintenance manual should be reviewed in preparation for testing insulation condition.

On double insulated components, the test can be easily conducted simply by connecting the test voltage source to the test lead; this can be accomplished on-line and without disassembly.

With either type of insulation arrangement, follow OEM recommendations relative to test voltage and satisfactory values. Test voltages will be low and resistance values of >1 megohm are likely to be fully satisfactory.

**High Voltage Bushing Loss Test**

This is a specialized test which should be done by qualified test personnel and performed in accordance with OEM recommendations.

**Winding Copper Resistance (Field and Stator)**

Because the resistance values are very low, readings must be accurate within at least 3 significant digits, using a double bridge or equivalent digital low ohm meter. Figure 20. (The “double bridge” simply means that the test instrument current is applied to the winding under test through one set of leads and voltage drop is measured by a second set of leads.)

**Figure 20. Digital Low Resistance Ohmmeter (DLRO) on the Left, and Megohmmeter to the Right.**

Typical values for field winding range between 0.012 and 0.32 ohms. Stator values are even lower, typically between 0.0008 and 0.013 ohms.

Values must be corrected for actual winding temperature. In order to obtain meaningful data, temperatures must be allowed to stabilize and temperature readings should be taken at several locations.

Results should be compared to new winding and previous service values. An out-of-range high reading on the stator may indicate failing connections, always a serious condition which must be corrected. The same would be true on fields, although the likelihood is lower and the damage potentially less severe. Low readings on fields are usually associated with turn shorts. On a field with about 100 turns, a single shorted turn would give a 1% low reading. Smaller fields usually have more than 200 turns, but individual turns shorts can still be detected. On a field with advanced deterioration, several turns may be shorted, and the condition easily detected.

## OTHER TESTS

### Insulation of Generator Monitoring Instrumentation

Electrical insulation used on instrumentation is low voltage, and any integrity checks should be in accordance with OEM recommendations. The devices may be harmed if excessive voltage is applied. Figure 21.

**Figure 21. Instrumentation Measuring RTD Insulation Resistance**

Procedures for checking accuracy will vary between devices, and these checks should also be in accordance with OEM recommendations. However, a rough check of accuracy of TCs and RTDs can be obtained simply by comparing the readings of the devices, since there are generally many devices reading near-identical conditions. Of course, machine temperature must be stabilized before this can be done, and there will be a fairly uniform small variation between the lower and higher portions of the machine (and from side-to-side on a sunny day for an outdoor unit).

### Stator Bar Turn, Group and Vent Tube Insulation

Turn and group insulation integrity of multi-turn coils is difficult to assess on an assembled winding. (It is not easy to do even on a single unconnected coil.) This test is therefore uncommon, since disconnecting of coils will be required to obtain meaningful data. The OEM should be contacted if turn insulation integrity is questioned.

Direct hydrogen cooled stator windings use insulated ventilation tubes. Tubes are insulated from each other and from the winding copper. Test procedures vary between OEM's, and OEM recommendations should be followed as defined.

### Gas Cooled Bar Flow Tests

Reliable operation requires that the ventilation tubes be able to pass design gas flow. These tubes on generators from certain OEM's tend to be thin and weak, and may also be vulnerable to blockage by foreign material. OEM recommended tests for evaluating gas flow should be followed as specified.

## STATOR CORE TESTS

### GENERAL

Confirmation of the condition of the core insulation can be essential, particularly in the event of known problems or questionable inherent quality. Also, testing may be advisable before and after maintenance work that directly or indirectly involves the core. These tests, however, may tend to be difficult, complex, expensive, and/or hard to interpret. In some cases, OEM input may be necessary. Tests should be performed by experienced, qualified personnel.

## LOW-POWER LAMINATION INSULATION TEST

A few types of low-power test equipment have been developed. The most common is the ElCid test. This test is conducted at about 4% rated flux density, a very low value. Meaningful results require good equipment properly operated. The test setup is shown in Figure 22.

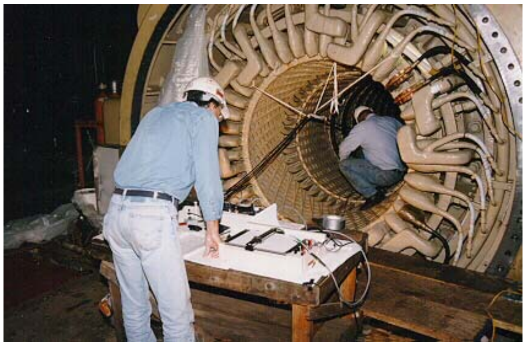

**Figure 22. Low-power Lamination Test Instrumentation and Excitation Coil**

There are several advantages of this type test: setup is short and simple, costs are low, quantitative results are obtained, and data are repeatable. In addition, there is no hazard to the equipment and little personnel safety risk. There are corresponding disadvantages: insensitive to damage that is not near the top of the tooth, may not detect damage in the core back-iron, the 4% flux level (which is associated with 4% inter-lamination voltage) will not cause current to flow unless the electrical connection at the defect is solid.

Overall, this is a valuable test. It is recommended this test be performed before and after any maintenance work is done which might affect the integrity of the core, e.g., stator rewedging, retightening core, partial or full rewind. Also the test can be useful for evaluating known or suspected damage or weakness of the core lamination insulation. However, the test is not sufficiently powerful as to alone justify restacking of a core.

Because specialized equipment and training are required, it is important that this test be performed by qualified and experienced personnel. Also, input from the OEM may be useful, as core design, quality and reliability varies between manufacturers.

## HIGH-POWER LAMINATION INSULATION TEST

Variously call “ring test” or “loop test”, setup is time-consuming, requires a long length of high amperage non-shielded cable, large power source, and necessary breakers and controls. This test also tends to carry inherent personnel safety risks. However, the test is often performed on suspect cores because it closely reproduces the conditions of actual service.

High-power variable voltage sources are not available. Since few turns are used in the coil, and turns must be adjusted in increments, exact selection of flux level is not possible. Also, current and power increase exponentially as rated flux density is approached. In selecting number of turns in the excitation coil, initially be certain to error on the side of too many turns.

Satisfactory test can be conducted at flux densities between 85 and 95% of rated flux; testing at or above 100% flux level should be avoided due to the hazard of experiencing gross test coil over-current.

Input from the OEM will be helpful in designing the excitation coil: core dimensions, rated flux level, magnetic properties of the core back-iron.

**THROUGH BOLTS**

Some manufacturers use a through-bolt design to apply pressure to the core iron. Because these bolts are cut by the excitation flux, they also generate a significant voltage, in the order of 200 to 1000Vac. Current flow cannot be permitted in these bolts, and they must be fully insulated from ground and from the core punchings.

The OEM should be contacted relative to test frequency and parameters. Since failure of this insulation can be damaging to the equipment, manufacturer insulation test and retightening recommendations should be closely followed. Otherwise major damage to the generator may result.

**END SHUNT INSULATION RESISTANCE**

Some manufacturers use an insulated end-flux shunt, Figure 23. Manufacturer recommendations should be followed to assure satisfactory operation.

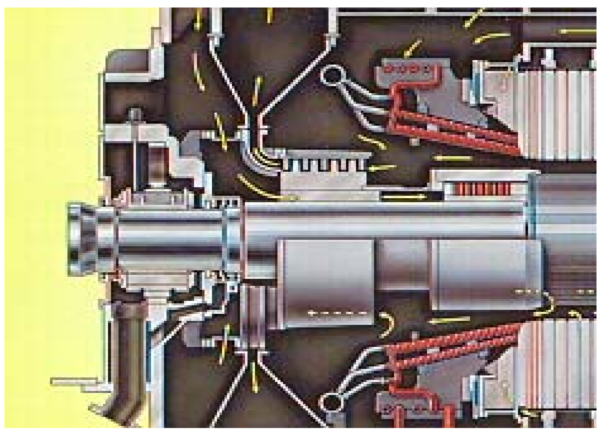

**Figure 23. Flux Shunt Location at End of Core (Westinghouse)**

**CORE TIGHTNESS**

Core tightness can be checked simply by assessing the amount of force required to insert a knife between laminations. A tight core will resist knife entry from light tapping on the knife with a small hammer, Figure 24. This is a crude test, but effective. It is not inherently damaging to the core if performed by a skilled workman, since lose of insulation integrity between two adjacent punchings is not measurably harmful to a core.

**Figure 24. Knife Test of Core Tightness**

A more scientific test can be performed by measuring the force required to locally expand a core tooth. This test requires customized tooling, is difficult to interpret and is not commonly done.

Typically, cores are simply retightened if looseness is suspected because of inherent design weakness, unit history, core inspection or other considerations. However, increased core pressure may increase the duty on the lamination insulation and cores should not be retightened without input from the OEM.

## LIQUID COOLED STATOR

### GENERAL

Liquid cooled stator windings contain thousands of joints with the potential for permitting leaks to develop. There are three general categories of joints that can become a source of hydrogen or water leak: 1) numerous flanged and clamped hydraulic joints and fittings, 2) many brazed pipes and fittings, and 3) the complex brazed hydraulic/electrical connections between the stator bar strands and the individual bar water supply header, Figure 25. In addition there is the possibility of cracking or other mechanical failure of pipes, hoses and fittings.

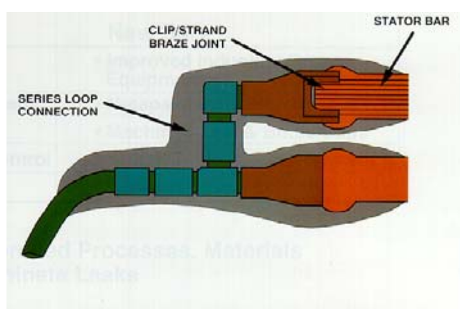


**Figure 25. Stator Bar Strand Header Design**

Leaks associated with loosening flanges, deteriorating clamp fittings or cracked piping may be benign or serious, depending on size and location. Small leaks typically will not result in winding damage so long as hydrogen gas pressure is always maintained above the stator cooling water pressure. Escaping hydrogen will simply be vented to atmosphere through piping provided for that purpose. But large leaks associated with piping, flanges, and fittings may cause major winding failure.

If hydrogen flows into a stator bar hydraulic circuit and displaces water flow, or if water flow is interrupted to individual bar circuits, the involved bars(s) will overheat and may fracture due to differential expansion between the hot bar(s) and the remaining winding. (Differential expansion in the order of .400" may be expected on long stators.) On the other hand, if water leaks from a winding hydraulic circuit, electrical creepage surfaces may be contaminated, causing flashover and severe winding damage.

Experience has shown that the third category of leak, that of the individual bar strand headers, is much more troublesome. Leaks in these areas generally are very small, and water leakage rates in the order of 2 or 3 $cm^3$/week can cause irreparable damage and eventual failure of stator bar groundwall insulation. Leaks of this type are difficult to detect, both due to size and location. On-line tests and vacuum and pressure decay tests are unlikely to detect a strand/header leak.

Methods of monitoring and detecting large leaks that occur while machine is operating, as well as maintenance procedures for locating all leaks including small strand-header leaks, will be described later.

Knowledge of the operating and maintenance history of the specific generator is important to assessing present conditions and progress of any deterioration which may be found. In addition, participation of the OEM may be necessary in order to assure understanding of design details of the generator which impact the decision making process.

## PERSONNEL AND EQUIPMENT REQUIREMENTS

### Personnel

Numerous, broad-ranging technical procedures are described in this portion of the guide. Personnel assigned to do this work should be familiar with operation of the sophisticated equipments used in the various tests and should understand the purpose, nature, and interpretation of the inspections and tests performed.

### Equipment

These tests are inherently complicated. In order to expeditiously and accurately perform the leak tests, several pieces of specialized equipment are necessary.

a) Flanges and other accessories to seal of the disconnected piping.

b) Skid capable of removing the bulk water from the winding, and to dry the remaining moisture from the system, Figure 26.

**Figure 26. Test Skid for Removing and Drying Water from Stator Windings (General Electric)**

c) High accuracy vacuum measuring instruments.

d) Accurate pressure decay instruments and thermometers, Figure 27.


**Figure 27. High Accuracy Pressure Gauge**

e) Supply of tracer gases and corresponding instruments. If helium is used, the instrument is particularly specialized, Figure 28.

**Figure 28. Gas Test Leak Sniffer and Instrument**

f) Simple capacitance meter and special electrodes for attachment to stator bar insulation. Figure 29. This test may not be sensitive to presence of water on Micapal II and other epoxy resin insulation systems.

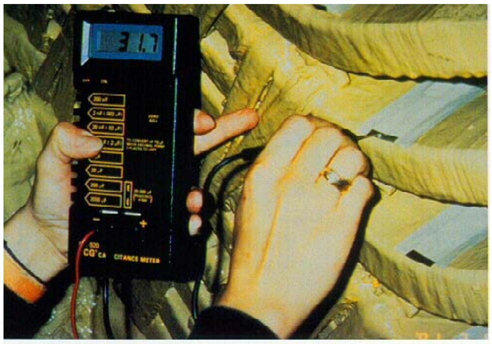

**Figure 29. Bar Insulation Capacitance Testing**

g) Flow continuity can be acoustically performed rather simply with specialized equipment and pickup. If the temperature transient method (flow continuity) is used, setup tends to be expensive and time-consuming, and conducting of tests is an elaborate procedure.

### Information Sources

Because these tests tend to be intricate to perform, input from the OEM may be helpful in planning and conducting of the tests. Interpretation is somewhat judgmental, and should be based on fleet experience, history of the unit under test, and input from the OEM.

### Time Intervals

On a normally operating unit with no known special concerns, checks and inspections should be performed on the following schedule:

Weekly - Check flow from the water cooling system ventilation line.

Minor Inspection (2-3 year cycles) - Vacuum and pressure decay tests. Tracer gas test (rotor removal optional).

Major Inspection (5-7 year cycles) - Vacuum and pressure decay tests. Tracer gas test (rotor removed).

### Precautions

The described tests and inspections are generally non-destructive in nature and are not inherently hazardous to personnel if performed with care.

Because there is the potential for severe winding failure associated with the various undetected failure mechanisms, it is important that the recommended tests and inspections be performed accurately and on a regular basis.

## ON-LINE TEST PROCEDURES

Three common methods of in-service leak detection are available: a) hydrogen gas dew point, b) the liquid detector alarm, and c) excess hydrogen gas flow from the liquid system vent line.

A high dew point level alone may not be cause for concern, but if dew point is high, particularly close attention should be given the other methods of leak detection.

If water is found in the leak detector, the gas flow from the liquid system vent should be immediately checked. If gas flow is normal, the water leak source is probably the hydrogen coolers, although small amounts of water may be inducted from a contaminated hydrogen gas supply.

Historically, checking flow from the liquid system vent line has been done by various manual methods, which are cumbersome but fairly effective. However, there is now available from OEM's instrumentation that will continuously monitor, display, and alarm vent line gas flow, Figure 30.

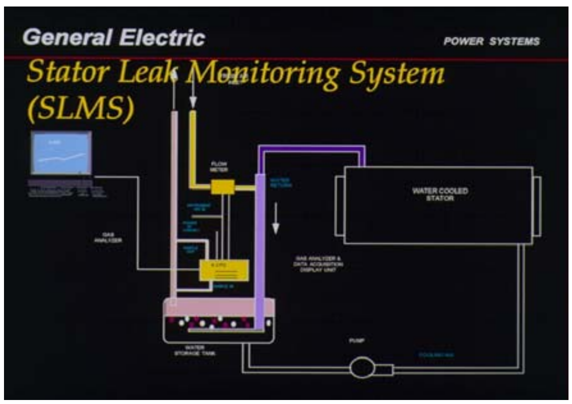


**Figure 30. Gas Leak Monitoring Equipment for Stator Windings**

If flow from the vent line is found to be excessive, damage to the generator may be imminent. Corrective actions should be taken in accordance with OEM recommendations.

Presence of incorrect water ph or accumulation of "green slime" in the cooling water filters may indicate that excessive hydrogen is getting into the water circuit.

## OFF-LINE TEST AND EVALUATION PROCEDURES

### Water Flow Verification

Two methods are available for verifying that water flow through the individual stator bar liquid circuits is correct: a) flow continuity test, and 2) recently developed acoustic flow measurement equipment.

Flow continuity test is a major effort and is performed off-line by establishing a temperature transient across the winding. This test requires: a) large heat source, 125-175 kW, to heat the stator cooling water to near 90C, b) instrumentation to rapidly read the stator winding RTDs and TCs during the temperature transient, and c) cooling water supply to establish the transient.

Acoustic equipment with the proper sonic pick-up can read individual hose flow magnitudes, on- or off-line. Reliability of this test equipment performance has apparently been found to be satisfactory.

**Water Removal and Internal Drying of the Liquid System**

It is essential that the stator liquid system be thoroughly dried internally before performing stator water leak testing (not including capacitance testing). Even small amounts of moisture within the winding can conceal a small leak and make the leak undetectable. Also, it is not practical to perform a vacuum decay test with moisture in the winding.

The most efficient method of removing the bulk of the water from the liquid system is through blow-down with dry air from a large pressurized holding tank. The last remaining moisture can then be removed in about 24 hours using a large pump to pull a high vacuum. (Application of heat to the winding can greatly shorten this process.) Manufacturers have equipment available specifically to efficiently dry liquid systems, Figure 26.

**Vacuum Decay Testing**

The primary advantage of vacuum decay testing is the sensitivity of the test. Decay measurements are made in units of microns, $10^{-6}$ torr. (One micron is equivalent to 0.00002psi, which is undetectable on a typical pressure gage, yet easily measured with common vacuum gages.)

Vacuum decay test measures the leak rate of the entire winding without requiring internal access to the generator. The test is relatively insensitive to changes in temperature and barometric pressure, and accurate results can be obtained in as little as one hour.

However, because of the extreme accuracy of the test, it is essential that all external connections be tight and all test components be in good condition. In addition, it must be recognized that the electrical isolating hoses may out-gas at a sufficiently high rate to simulate a very small leak. Windings that fail vacuum decay test and show indications of out-gassing must be further vacuum dried and retested.

**Pressure Decay Test**

Pressure decay test has three advantages over vacuum decay test: a) pressure decay provides up to five times the pressure differential, b) applies the pressure in the normal direction of water leak flow, and c) allows use of bubble solutions, Figure 31. These factors make it easier to find some leaks undetectable with vacuum.

**Figure 31. Testing for Water Leak using Bubble Solution**

Drawbacks to pressure decay testing are its insensitivity to small leaks, sensitivity to changes in environment (temperature and barometric pressure), and time required to obtain a significant increment of test values. On a typical test, 1.0 $ft^3$ must leak out of the system to register a change of 1 psi. Thus patience and extremely accurate instrumentation are required.

The liquid system must be completely dried before beginning pressure decay, since the high pressure may force moisture into insulation through a yet undetected leak. Therefore, it is preferable to conduct vacuum decay test before pressure decay test, and dry air or nitrogen should be used for pressurization.

Experience has shown vacuum and pressure decay tests to be quite complimentary and neither should be omitted.

**Tracer Gas Testing**

There are a number of tracer gases and tracer gas detectors on the market. Helium is the preferred tracer gas for testing water-cooled windings because of several properties: small molecule, inert, nontoxic, and non-hazardous. Figure 32. SF6 has also been used, because of its inherent sensitivity and low cost of detection equipment; however, there is some concern because SF6 is not inert and under certain conditions may combine with water to form an aggressive compound.

**Figure 32. Checking for Stator Winding Leak using Halogen Gas Detector**

Sensitivity of tracer gas can be greatly increased by bagging the individual series and phase connections, Figure 33. In numerous cases, tracer gas has found small leaks (as small as $10^{-4}$ std cc/sec) buried under the insulation that otherwise were not found with vacuum and pressure decay.

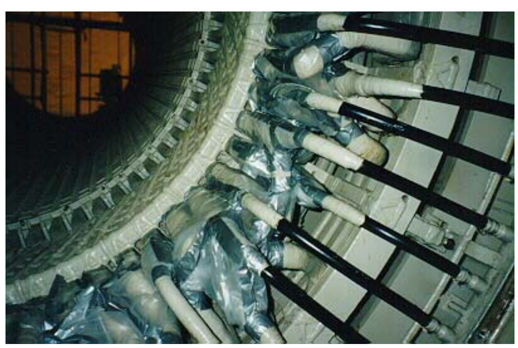

**Figure 33. Bagging of Series Loops for Stator Winding Leak Test**

Where bagging can not be applied, the sniffer must be brought within 2 or 3" to detect small leaks. Without bagging, tracer gas evaluation of a entire winding is probably impractical.

**Capacitance Testing**

Capacitance testing is used to detect moisture within the groundwall insulation. The test is performed with an inexpensive, readily available battery-powered capacitance meter. The test is nondestructive to the insulation Figure 34 & 35. The reading is taken in the end winding region, usually within a few inches of the end of the core. While the test is simple to conduct, access to the bars may require that the field be removed.

**Figure 34 & Figure 35. Capacitance Testing for Wet Insulation**

The intent of this test is to locate bars that are at high risk of in-service and/or high potential test failure. If a bar fails the test, water has penetrated under the groundwall insulation the full length of the bar arm from the strand header. Under these conditions, insulation deterioration will be significant, and the bar is not considered suitable for long-term service, even though it may pass high potential test.

Water within the stator bar groundwall will degrade the mechanical bonds and reduce the inter-layer electrical creepage properties. In addition, the hot water will dissolve the resin systems used on Thermalastic and Micapal, and other polyester-like insulation systems. Thermalastic-Epoxy and Micapal II resins, and other epoxy systems, are not dissolved by water, but the mechanical and electrical properties will be irreversibly degraded by the presence of water in the groundwall.

The capacitance test is based on the large difference between the dielectric constant of water and that of typical dry groundwall insulation, a ratio of about 4:1. Readings are taken for each top and bottom bar at both ends of the core. When plotted, unaffected bars will form a fairly tight “normal” distribution with a standard deviation value of about 2 to 3 units. Wet bars typically will fall significantly outside a smooth normal distribution curve. A bar which reads +3 standard deviations or greater is considered suspect and should be retested and further evaluated. A bar with a reading in the range of +5 standard deviations from average is almost certainly seriously damaged. Note, however, that because Micapal II insulation is less susceptible to water penetration of the groundwall insulation, capacitance readings of a wet bar may not be beyond the normal distribution bell curve.

Judgment is required in evaluating the data. For example, data taken by a skilled operator using good equipment will tend to have a smaller standard deviation value. Thus these higher quality tests are likely to reject a bar with a lower deviation value than data taken with less care.

Bars which are confirmed to fall significantly outside the normal distribution curve should be further investigated by stripping the series/phase insulation. Visual examination for signs of moisture should be made of the joint and groundwall tapes, along with further pressure decay, tracer gas and bubble solution checks. Furthermore, even if wet insulation or indications of a leak are not detected in the series/phase joint insulating materials, the bar ground insulation should be investigated for degradation.

**INTERPRETATION**

The broad scope and complexity of the various tests associated with assuring hydraulic integrity will require that personnel be fully qualified. Most bigger leaks will be easily found and required corrective action will be obvious.  But assessment of small leaks, particularly those under the groundwall insulation, may be difficult and involve a high level of judgment.

Because decisions must be made based on the specific design of the unit, participation of OEM engineers will generally be necessary.