AC HIPOT, DC HIPOT AND POWER FACTOR TESTS – PROS AND CONS

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ABSTRACT

Questions have been raised about the benefits, similarities and issues with the AC hipotential (hipot), the DC hipotential and the power factor tests. This paper will discuss each test and the information the test provides about the condition of an insulation system associated with rotating machine stator windings. The advantages and disadvantages of each individual test will be explored and compared to the other tests.

INTRODUCTION

This paper will focus on the more common tests performed in the industry such as the 60 Hz hipot test, the 60 Hz power factor test and the DC conventional and step/ramp voltage tests. The description of these tests will not apply to water-cooled stator windings since the test procedure and analysis differ for water-cooled units. This discussion will also focus on testing of stator windings and not on testing individual bars or coils. The pros and cons described under each test method will pertain to maintenance or diagnostic testing unless otherwise stated.

It is said that testing is a form of buying insurance. A test usually is performed to either assess the condition of the insulation or to proof-test the insulation to ensure it will be serviceable for the next three to five years. Testing is also performed to ensure the winding was not damaged during unrelated maintenance that may have inadvertently caused damage to the winding. Some tests are simple proof tests, while other tests provide diagnostic information as to quality and condition.

AC HIPOT TEST

The AC Hipot Test is a high-potential test performed with AC Voltage at 60 or 50 Hz. In definition, it is the application of an AC voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of the insulating materials. This voltage is applied from the winding conductor to the machine frame or ground.

The use of a 60-Hz high-potential test is particularly common as an in-process test at the factory and for acceptance tests on new windings. Such tests are conducted with an applied voltage of (2E + 1 000) Volts for 1 minute where 'E' is the rated line-to-line voltage of the machine [1]. For maintenance or diagnostic purposes, the test voltage is usually in the range of 1/2 to 2/3 of the acceptance test level or alternately between 100 and 150% of the rated line-to-line voltage of the machine [1,2]. If previously tested, typically the test voltage is decreased to a value less than the previous test voltage. The decreased value depends upon the machine type, size and age.

In order to test both phase-to-ground and phase-to-phase insulation, it is desirable to test each phase separately with the other two phases grounded. All terminals of the winding should be either energized or grounded directly. This test is considered a proof-of-service type test and the results are either pass or fail. The procedure can be found in ANSI/IEEE Standard C50.10-1990.

AC hipot tests are performed to detect weaknesses in the insulation and to provide assurance of the minimum strength of the insulation.

AC HIPOT PROS AND CONS

AC Hipot Cons

The AC Hipot test is considered a potentially destructive test. If the stator winding insulation fails this test, there will be a forced repair. Additionally, if there is a known weakness in the insulation which may be serviceable for several years until a replacement is found, performing an AC Hipot test may cause a premature failure. An example of this is an AC hipot failure at the neutral end [3]. Therefore, a risk assessment decision is necessary to determine whether this test is correct for a particular machine. The AC hipot test is typically performed during a planned outage. If this test is to be performed, extra time must be allocated in case the winding fails the test. Also, spare coils or bars must be available for the repair, if the unit fails the test.

Cons

- Destructive go – no go proof type test
- Forced repair
- Spare coils or windings must have on hand
- Extends outage time
- No numeric evaluation
- No trend data
- Large/heavy test equipment
- End-windings stressed very little
- Forces failure of a winding that may be still serviceable for several years (such as neutral end failure)

AC Hipot Pros

However, if a weakness in the insulation exists, this test will most likely seek it out. The test will identify general coil deterioration and localized incipient faults [2]. If the test is performed during a planned outage and a weakness is detected, this will eliminate a forced outage and benefit everybody involved economically. Also, by eliminating an in-service failure, excessive damage to the unit will be avoided. This is of particular importance in multi-turn windings where a turn-to-turn failure can be very damaging. If the groundwall insulation is in poor condition, the turn-to-turn insulation is almost always in much worse condition. Below is a list of the pros and cons associated with the AC hipot test.

Pros

- Identifies general coil deterioration
- Identifies localized incipient faults
- Pass/fail result, no ambiguities
- Planned repair
- Less damage than in-service failure
- Weakness is easily located
- Line end coils are stressed similar to in-service stresses
- A lot of industry experience
- Can perform on water-cooled units

DC HIPOT TEST

The DC hipot test is a high potential test performed with DC voltage that is higher than the rated voltage for a specified time to determine the adequacy against breakdown of the insulating materials. The typical test voltage is 1.7 times the value used in an AC high potential test. This test is not standard for water-cooled generators.

There are two types of DC hipot tests. One is a conventional DC hipot and the other is a controlled DC hipot. A controlled DC hipot test is performed by increasing the applied test voltage in a controlled manner. The measured current is monitored for indications of deterioration or defects. As a result, if the insulation appears to be failing, the test can be aborted in order to eliminate damage [4]. The DC stepped voltage and the DC ramped voltage tests are both considered a controlled DC hipotential test.

The conventional DC hipot test is considered a pass/fail test similar to the AC test. The voltage is slowly increased to a pre-determined over-potential value. It is then maintained at this value for one to ten minutes [3]. The detailed test procedures can be found in IEEE Standard 95.

The DC hipot conventional tests are performed to detect weaknesses in the insulation and to provide assurance of the minimum strength of the insulation. The DC step and ramp voltage tests will also detect weaknesses in the insulation, but the measured values of these tests can be recorded, analyzed, and trended for insulation deterioration, rather than a pass or fail outcome.

DC HIPOT PROS AND CONS

In regards to the pros and cons lists below, the pro or con applies to all methods of DC hipot testing unless the type of DC test is listed in parenthesis beside the pro or con.

DC Hipot Cons

The conventional DC hipot is a potentially destructive test similar to what was described under AC Hipot Pros and Cons. If the stator winding insulation fails this test, there will be a forced repair. Proper planning with the necessity of spare coils on site is required. In addition, a failure of a DC hipot test is less destructive on the insulation than an AC hipot test, and the failure mode or location may be hard to find. All DC hipot tests, conventional or controlled, require discharge time prior to applying AC voltage to the windings. The discharge time can range from 1.5 to 2 hours or four times the test duration, whichever is longer. When using DC instead of AC, the voltage stresses applied across the insulation does not duplicate the stresses when in operation.

Although the controlled DC hipot test can be aborted prior to insulation failure, there are some disadvantages that are worth mentioning. The analysis of the step voltage and the ramped voltage test requires experience and expertise in interpreting the results. A stable test voltage must be used when performing the step voltage test because slight fluctuations in the test voltage will result in large current fluctuations which may be erroneously interpreted as an insulation problem. In addition, the step voltage requires the voltage to be held for a specific time until the current decays to a constant value and the current at the end of each voltage step would be the insulation leakage current, which is the current that provides information about the condition of the insulation. It may be difficult to interpret results on insulation in fair condition due to masking from the decaying absorption current when performing the step voltage test. However, on poor insulation, difficulty of interpretation does not pose a problem.

Cons

- Destructive test (conventional)
- Forced repair (conventional)
- Spare coils/windings on hand (conventional)
- Extends outage (conventional)
- No numeric evaluation (conventional)
- No trend data (conventional)
- Less destructive test failure (compared to AC hipot) thus may be hard to locate problem
- Must discharge winding slowly
- Must ground winding for 1.5 to 2 hours or 4 times test duration
- Cannot perform on water-cooled units
- Doesn’t stress insulation same as 60 Hz hipot test or in-service operation
- Isn’t as sensitive as AC in detecting PD
- Dielectric absorption current masks insulation leakage current requiring complicated times and calculations (step)
- Slight fluctuations in current or resistance vs. voltage due to manual application of voltage steps (step)
- Expertise is required to interpret the results (controlled)

DC Hipot Pros

In regards to the controlled voltage test, the DC ramp test eliminates the problem with fluctuating test voltage because the instrumentation automatically ramps the voltage and the manual increase (human factor) in voltage is eliminated. Additionally, the DC ramp test linearizes the absorption current so that the insulation leakage current can be detected much easier. The biggest advantage of the controlled voltage tests is that the test can be aborted prior to failure of the insulation. Therefore a forced repair is avoided and the repair can be planned. Additionally, test data is obtained and can be trended over time. The controlled DC test plots will reveal the degree of leakage current, at what voltage it becomes significant, and also provide information as to groundwall delamination and cleanliness of the end turns.

The DC hipot test is known to stress the endwindings more than an AC hipot test. If the stator winding insulation system fails the conventional DC hipot, the failure is known to be potentially less destructive than the AC hipot failure.

Pros

- Can abort the test prior to failure (controlled voltage tests)
- Numeric evaluation of data available (controlled voltage tests)
- Detects impending breakdown best (ramp) due to improved test equipment
- Absorption current calculations and volt-time testing schedules eliminated (ramp)
- Detects groundwall delamination and contaminated end-turn grading treatment (ramp)
- Detects individual coils that absorbed water during coil brazing operations (ramp)
- Small/light test set
- Less destructive test failure
- Detects cracks and fissures in groundwall insulation
- Stresses the endwindings more

POWER FACTOR

Power factor testing of rotating machinery is a non-destructive AC test performed off-line at apparatus frequency. The test may be performed with the rotor in-place or removed. The stator winding is energized at incremental test voltages. Generally, the voltage is increased from 25% to 125% of the line-ground voltage. Power factor tip-up is calculated and defined as the power factor measured at the line-ground voltage minus the low voltage power factor (typically performed at 100% and 25% of the line-ground voltage).

Since power factor is a dimensionless quantity and thus can be compared amongst different volumes of insulation systems, data has been tabulated based on kV rating and insulation type (epoxy-mica, polyester, asphalt-mica). It is a measure of the dielectric losses of the insulation and provides valuable information about the insulation quality.

The power factor measurements are performed on each phase to ground with the other two phases grounded. This test typically indicates the condition of the coils within the slots. The interphase power factor measurements are performed between phases with the other two phases grounded, and these measurements indicate the condition of the endwindings. A power factor with a negative trend is typically a result of the non-linear gradient tape or paint at the endwindings, the geometry of the coils or bars, and the method in which the test set handles the measurement. A less negative result may indicate contaminated/dirty grading paint that must be cleaned to restore it to proper operating condition.

The low voltage power factor and watts measurements provide information on whether the insulation system was manufactured with low loss materials and processed properly. It also provides information on whether the insulation system is free from contaminants and moisture. Additionally, poor contact of the semiconductive slot coating with the core can be detected by an elevated low voltage power factor [6]. The power factor tip-up will detect excessive voids in the insulation due to defective or deteriorated semiconducting coating. In addition, power factor tip-up will also detect delamination of the insulation due to thermal stresses and partial discharge damage [6].

Measured charging current and capacitance values provide information about the physical condition of the insulation. A change in capacitance with increasing test voltage (i.e. the standard Doble test procedure) of 5% or more or when compared to a previous test, may indicate deterioration of the semiconducting paint or tape used to ground the coils in the slots. [7,8]

POWER FACTOR PROS AND CONS

Power Factor Cons

The measured power factor and capacitance results are an average value of the phase under test. Therefore, if the measured results are abnormal, it may be difficult to determine whether the cause is overall or an isolated coil or coil set. Since the power factor is not an overpotential test, an acceptable result does not prove that the winding will be serviceable for the next three to five years. Depending upon the voltage rating and the size of the machine, a resonating inductor may be needed to achieve the line to ground voltage. Typically, 13.8 kV machines and above require the use of the resonator, but in some situations, it is not necessary. It depends upon the capacitance of the insulation. The resonator extends the output capability of the test set at 10 kV to approximately 0.05 to 1.0 microfarad [6].

Cons

- Does not indicate exact location of problem
- Test set requires a resonator for test voltages above 10-12 kV
- The measured results are an average of the phase under test
- Does not provide assurance of a proof test in that the winding will be serviceable for the next 3 to 5 years

Power Factor Pros

The power factor test is considered a non-destructive test because it is performed at line to ground voltage. The test can easily be aborted if the measured values are indicating insulation failure. The measured test data can be compared to thousands of test results of various units collected since the 1970's. The measured results can be trended over time to determine if the insulation is deteriorated or contaminated. The test set, excluding the resonator, is small and automated, and power factor testing can be performed on water-cooled units as long as the water conductivity is less than .25 microsiemens per centimeter with the water flowing slowing through the system.

Pros

- Non-destructive test
- Test data limits
- Results can be trended
- Small/automated test equipment
- Test endwindings
- Can perform on water-cooled units
- Identifies overall contamination
- Identifies excessive voids in insulation
- Can detect significant deterioration of turn insulation

COMPARISON

Table 1 shows the comparison of all three tests based on the more pertinent pros and cons listed in this paper. The greatest difference is that the power factor test is not intended to be an overpotential test and is designed to test the insulation at the line to ground voltage. It is also a test designed to assess the quality and condition of the insulation. The power factor test data can be compared to guidelines and trended over time. Whereas the AC and DC hipot tests are intended to provide overpotential to the insulation, and in the case of the conventional DC hipot, the purpose of the AC and DC hipot is to proof test the insulation. Another important piece of information is whether the test can be aborted prior to failing the insulation, and if so, whether the weakness can be detected and located. If the insulation fails the AC hipot test, problems may arise with forced repair, but the problem and its location are easily found. If the insulation begins to fail the DC controlled voltage test of the AC power factor test, these tests can be aborted, forced repair avoided, but the problem and location may be difficult to find.

TABLE 1
Comparison of all Three Tests

	AC Hipot	**DC Hipot (W, S, R)**	**Power Factor**
Destructive Test	Y	Y (W)	N
Pass/Fail Results	Y	Y (W), N (S,R)	N
Water-Cooled Units	Y	N	Y
Stressed similar to in-service	Y	N	Y
Trend Data	N	N (W), Y (S,R)	Y
Easy to interpret results	Y	Y (W), N (S,R)	Y
Large Test Equipment	Y	N	N/Y*
Automated Test Set	N	N (W, S), Y(R)	Y
Numeric Evaluation	N	N (W), Y (S,R)	Y
Forced Failure	Y	Y (W), N (S,R)	N
Endwindings Stressed	N	Y	Y
Discharge Winding	N	Y	N

NOTE: In Table 1, W represents the conventional test, S represents DC step voltage test, and R represents the DC ramp test
*Only if the resonator is required

CLIENT INPUT

At the 2003 Fall Rotating Machinery Committee meeting, a client asked the group how many performed a hipot test as a routine base test on their generators. The client also wanted to know the advantages and disadvantages. One client responded that they perform an AC hipot as a routine maintenance test, but perform it early in their outage. The advantage is assurance that the generator is fit for service, and the disadvantage is if it is not, there will be some extensive rework. The client also has spare coils/bars on hand. The test voltage is dependent upon the age of the unit. If it is a new unit, the client will apply 2E + 1kV.

Another client performs a DC ramp test on their generators every three to five years. This client has 198 generators in their system, which all but three water-cooled units have been DC ramp tested and only two have failed during test in over 30 years of testing. One failure was due to a crack in a bar, and the other was due to vibrating strands that had cut through seven of the eleven layers of groundwall tape. This client wants to know the condition of their machines so they can schedule rewinds, and would rather fail a unit during an outage or when the water is low than have it fail when in service. The applied voltage is based upon the age of the unit and the condition it is in. [9]

CONCLUSION

All three tests have advantages and disadvantages. It cannot be determined that one test is better than the other. This is an individual opinion and policy issue. Each test provides some value that the other does not, and the overpotential tests provide some risk. The decision to perform which test should be based on many factors which were covered in this paper, as well as any other factors such as unit history, reliability required, insurance policy requirements, and so on.

ACKNOWLEDGEMENTS

I would like to give special thanks to Mr. Bert Milano of the U.S. Bureau of Reclamation who contributed to this paper.

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