Quality Evaluation of Generator and Motor Stator Windings

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ABSTARCT

This paper describes techniques to evaluate the quality of generator and motor coils/bars. The techniques include diagnostic tests, accelerated aging tests and dissection of coils/bars. The diagnostic tests (e.g. partial discharge tests, dissipation factor tests, and DC leakage current measurement) can assess the insulation condition. Accelerated aging tests attempt to simulate the insulation deterioration process during machine service. Dissection of the coils/bars can discover faults and problems inside the coils/bars which may not be revealed by the electrical tests performed.

1. INTRODUCTION

Faced with increasing pressure to increase unit availability and reduce maintenance costs, utilities are making great effort to improve generator/motor reliability and increase the service lifetime. Insulation failure is one of the major causes of forced outages of generators and motors. In order that generators and motors can operate reliably with good long-term performance, the first step is to ensure that new coils are manufactured to a high level of quality and meet the design specification before they are installed in generators and motors. New designs, new materials, quality-control programs and modified manufacturing processes used by manufacturers could affect the quality of coils/bars. When new stator coils/bars are purchased for new or rewind generators/motors, how does a generator/motor user know if the coils design meets the specification and the expected manufacturing quality? How can a generator/motor user find defects and problems in the coils/bars which they have purchased? Therefore machine users require an objective assessment of the winding insulation quality. This paper presents a quality assurance program for stator winding insulation. Such a quality program includes:

1. Accelerating aging tests:
    - Voltage endurance tests
    - Thermal cycling tests
2. Diagnostic tests:
    - Partial discharge tests
    - Dissipation factor tests
    - Insulation resistance tests and polarization index tests
    - DC LIpATEST
3. Dissection examination of coils/bars.
   Cross sections of coils/bars are examined under a microscope to inspect and identify any defects and insulation problems.

2. ACCELERATING AGING TESTS

Stator winding insulation is subject to electrical, thermal, and mechanical stresses during machine service. Those stresses cause aging of stator winding insulation and eventually lead to insulation failures. Accelerated aging tests subject coils/bars to a higher stress than the normal machine-operation stress within a short period of time to simulate insulation aging during long-term machine operation. Voltage endurance and thermal cycling tests are the most popular accelerated aging tests to check the quality of coils/bars.

2.1. Voltage Endurance Tests

Electrical stress is one of the major aging mechanisms that lead to stator winding failure. The voltage endurance test applies a high voltage (which is 3.76 times higher than the operating voltage) and a high temperature to coils for a short period of time (e.g. 400 hours) to accelerate aging of coils/bars. A typical set-up of the voltage endurance test is shown in Fig. 1.

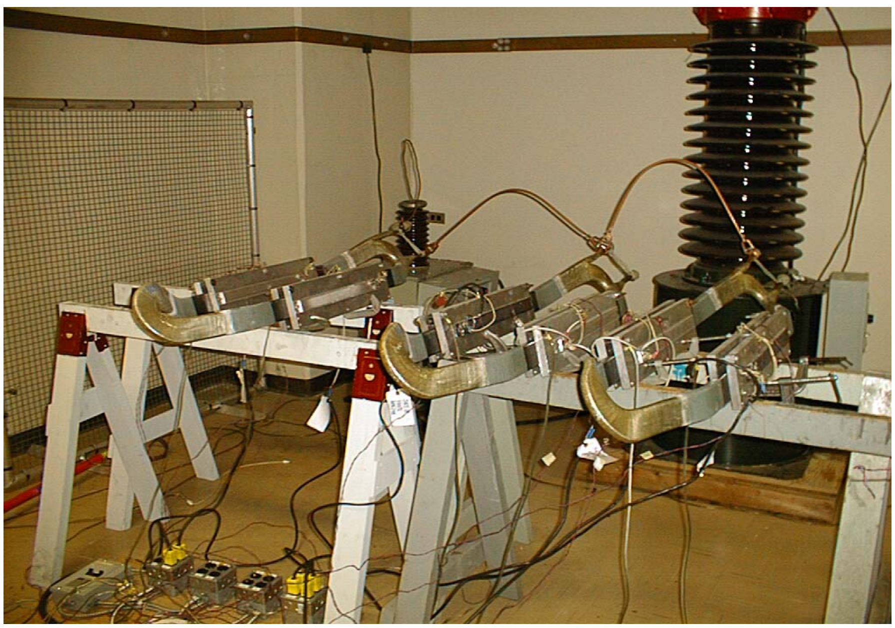


Figure 1 Voltage endurance test

The voltage endurance test is performed according to IEEE Standard 1043-1996 [1] and IEEE Standard 1553-2002 [2]. While the IEEE Standard 1043 essentially defines the procedure for performing voltage endurance tests on coils and bars, the new IEEE Standard 1553-2002 specifies test parameters and acceptance criteria. For example, a 13.8 kV coil under the voltage endurance test requires applying a 30 kV voltage and 100 ˚C temperature to the coil for 400 hours. The coil should pass the 400-hour test without failures. The number of specimens shall be at least four bars or two coils, but not more than 1 % of the number of bars/coils in the winding.

The new IEEE Standard 1553-2002 also specifies the acceptance criteria. *If less than 26% of the specimens on test fail between 51% and 100% of the minimum time-to-failure, then 2 additional bars/coils shall be put on test. All these remaining specimens must pass the test.* Figure 2 shows an insulation failure of a hydro-generator coil during the voltage endurance test.

Figure 2 Insulation failure of a stator coil in the voltage endurance test at 283 hours.

2.2 Thermal Cycling Tests

Pumped storage and run-of-river hydro-generators have frequent load changes. Large motors are exposed to frequent START/STOP operations. Rapid load changes result in heating and cooling cycles on stator insulation and this thermal cycling can cause:

- loss of bond between copper and insulation;
- delamination of groundwall insulation;
- deterioration of insulation.

To assess the insulation performance under the cyclic thermal stress, thermal cycling tests are performed according to IEEE Standard 1310-1995 [3]. The minimum number of test specimens is 4 bars or 2 coils. The test parameters for a 13.8 kV generator are:

- Test temperature: 40 °C – 155 °C copper temperature
- Test time: 500 cycles
- One cycle duration: approximately one hour with a pre-determined heating and cooling rate.

Figure 3 shows a typical temperature cycling recorded during a test on a hydro-generator coil. Assessment of insulation performance after thermal cycling tests is made by diagnostic tests, dissection of coils or voltage endurance tests.

The thermal cycling test and voltage endurance test can be applied to coils/bars either separately or simultaneously to test the insulation quality.

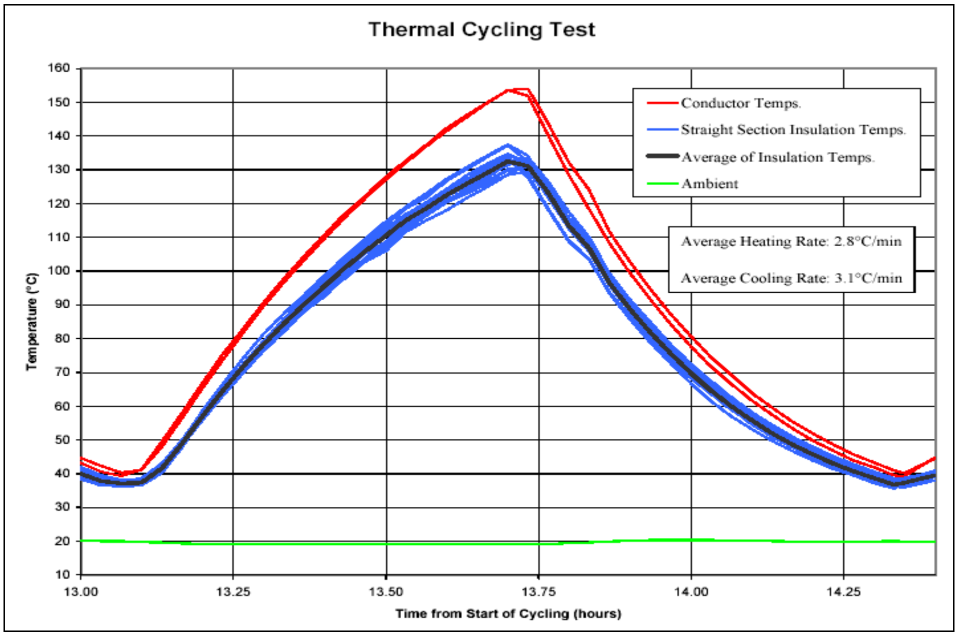


Figure 3 Thermal cycling test result of a hydro-generator coil

3. DIGANOSTIC TESTS

Several diagnostic tests can be performed before, during, and after accelerating aging tests to characterize changes in the insulation condition. The diagnostic tests commonly used are described as follows.

- **Partial discharge tests**

Partial discharge (PD) tests record the positive and negative PD magnitude, and the number of PD pulses to assess the integrity of the insulation. A typical PD test result is shown in Fig. 3. The high PD magnitude and high PD number indicates a poor insulation condition. Partial discharge tests are performed according to IEEE Standard 1434-2000 [3].

Since partial discharge levels in a single coil/bar are generally much lower than those recorded in a machine, the sensitivity of test equipment must be high enough to enable detection of PD signals in a single coil/bar. If the sensitivity is not high enough, PD signals may not be detected in a single coil/bar. In Powertech Labs, a specially-designed PDA instrument with a sensitivity of 2 mV is used to measure PD activity in a coil/bar.

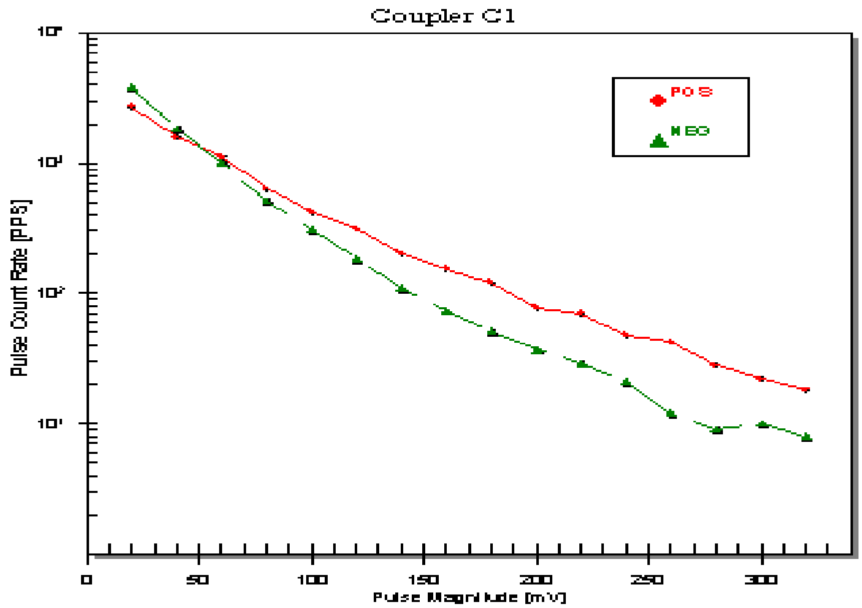


Figure 3 Partial discharge test result

- **Dissipation factor and tip-up tests**

The dissipation factor is a measure of the dielectric loss within stator insulation. The dissipation-factor test is performed from 2 kV up to 16 kV for a 13.8 kV coil/bar. The dissipation factor tests are performed according to IEEE Standard 286-2001 [4]. In general, the higher the dissipation factor, the poorer the insulation condition. The higher the tip-up value, the poorer the insulation condition. Figure 4 shows a dissipation-factor test result before and after a voltage endurance test. Increase of the dissipation factor in Figure 4 indicates insulation degradation after the voltage endurance.

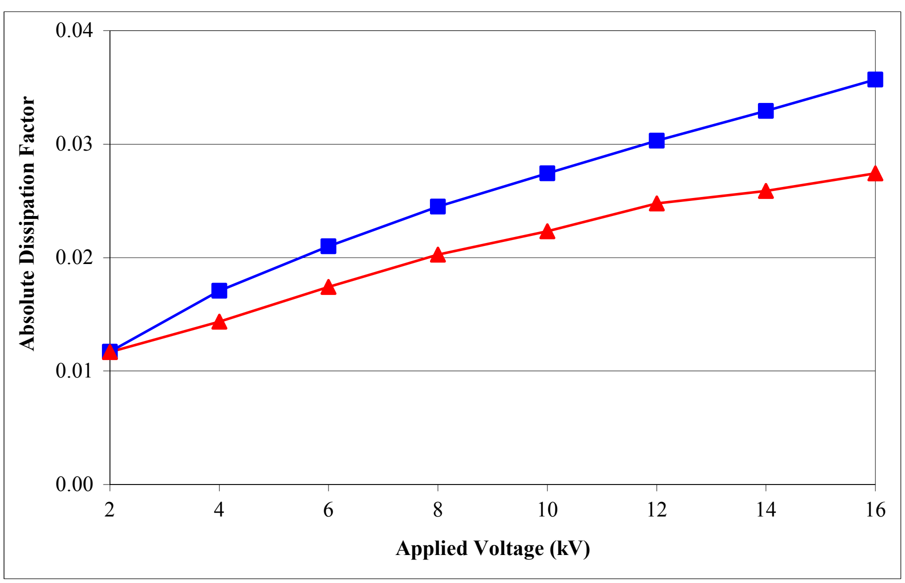


Figure 4 A dissipation-factor test result before and after a voltage endurance test

- **Insulation resistance and polarization index measurements**

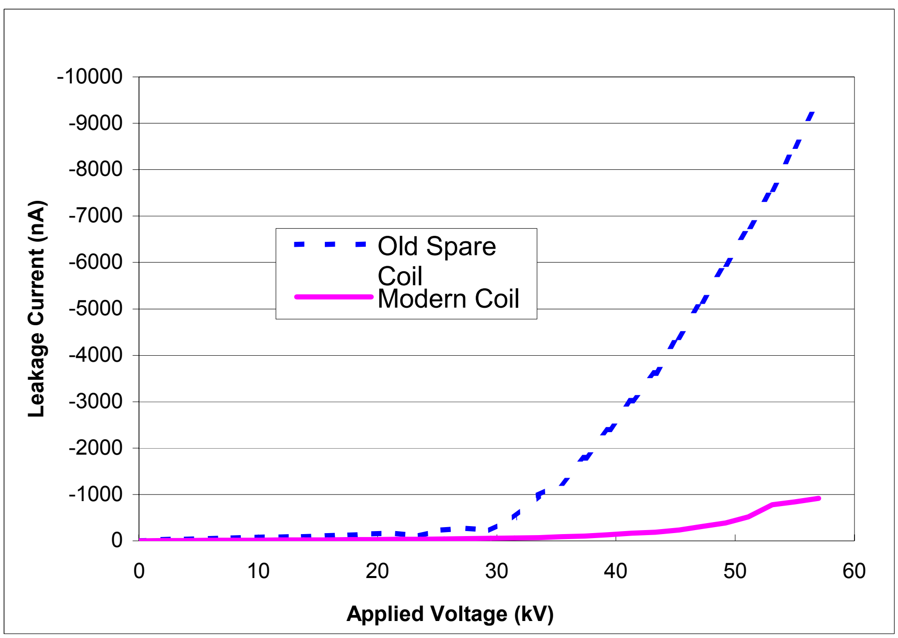
Insulation resistance and polarization index measurements are conducted according to IEEE Standard 43-2000 [5]. Normally, insulation resistance and polarization index tests have the same results before and after an accelerating aging test. If insulation resistance decreases after an accelerating aging test, it indicates a change of the insulation condition.

- **LIpATEST to measure leakage current**

LIpATEST is an instrument developed by Powertech Labs to measure the leakage current of an insulation system under the DC high voltages up to 60 kV. The LIpATEST instrument controlled by a computer applies a multi-step voltage to an insulation system and records the DC leakage current at each step automatically. A graph with the measured leakage current against the applied DC voltage is presented. The current sensitivity of the LIpATEST instrument is 0.1 nA. Therefore the LIpATEST instrument is much more sensitive than insulation resistance tests (100 nA) to measure the leakage current in an insulation system.

Figure 5 shows a LIpATEST test result to compare a 40-year-old spare coil and a new modern coil. The old spare coil has a much higher leakage current (appoximaetely100,000 nA at 50 kV) than the new coil (7000 nA at 50 kV), although the insulation resistance tests on both coils showed the same value. High PD activity and high dissipation-factor values were also measured in the old spare coil. The LIpATEST test made the same conclusion as the PD tests and dissipation-factor tests: the insulation condition of the old spare coil is poor.

More information on high voltage DC testing of stator coils can be found in IEEE Standard 95-2002 [6].



. Figure 5 A LIpATEST comparison between a 40-year-old spare coil and a modern coil.

4. DISSECTION EXAMNINATION OF COILS

Dissection of a coil is to cut cross sections of the coil at several locations and examine them under a microscope controlled by a computer. Dissection of a coil provides an opportunity to visually inspect any defects within the insulation system.

- Large voids within stator insulation.

Voids within stator insulation cause partial discharges under high voltage stress that can lead to insulation breakdown. Unfortunately, the electrical tests on coils/bars are not able to identify the size of the voids. Dissection of the coil is the only approach to measure the size of the voids and to discover the extremely large voids. The size of each void can be measured under a microscope controlled by a computer, as shown in Fig. 6.

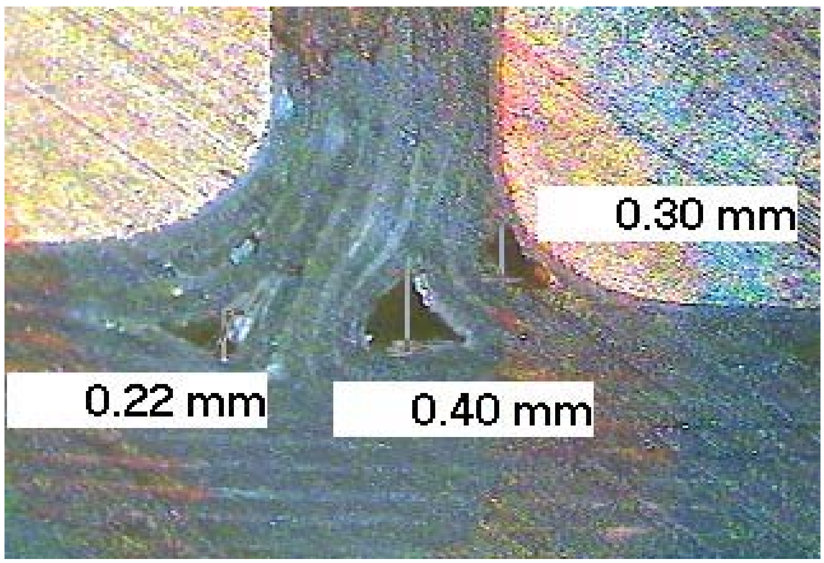


Figure 6 Voids within stator insulation under a microscope

- Insulation thickness measurement.

Insulation thickness determines the electrical stress on groundwall insulation. Each machine has a design specification for the electrical stress on groundwall insulation. However, manufactured coils might have the thinner insulation than the design specification and therefore a higher electrical stress than the designed stress level on groundwall insulation. The location with an insulation thickness 2.17 mm in Fig. 6 can produce a higher electrical stress than the other area. The high electrical stress on groundwall insulation could reduce the machine service life. Therefore, the examination of the insulation thickness and electrical stress are important to ensure long-term reliability of machine service.

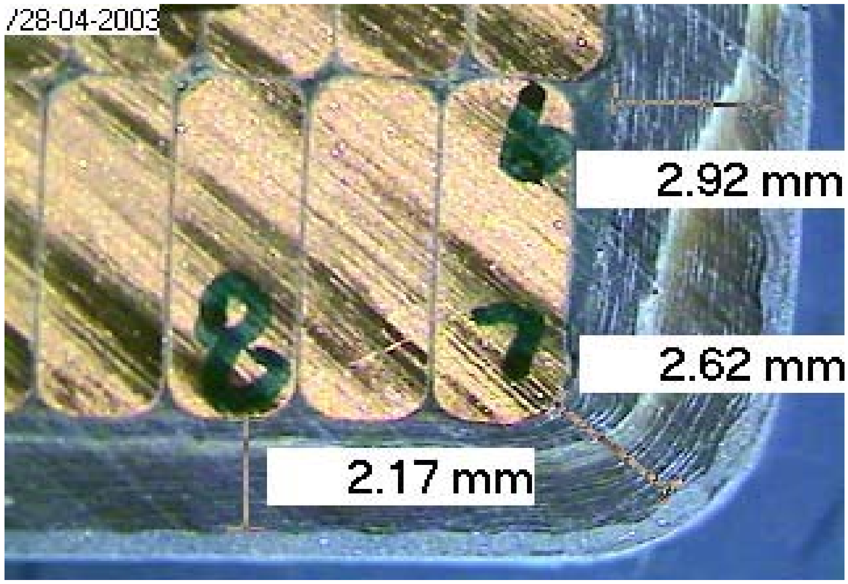


Figure 7 Groundwall-insulation thickness measured by a computer-controlled microscope

- Insulation defects in coil manufacturing

Figure 8 shows some defects in coil manufacturing found by dissection and examination. The light circles indicate voids. Those voids can cause partial discharge activity under high voltage stress. The dark circles indicate the groundwall tape folds and the semi-conductive tape intrusions into the groundwall insulation. The groundwall tape folds can degrade dielectric strength of groundwall insulation. Those semi-conductive tape intrusions reduce the effective thickness of groundwall insulation and therefore increase the local electric stress on groundwall insulation.

Figure 8 A typical dissection examination of the cross section of a stator bar

- Analysis of insulation failure

Microscope examination of a coil that failed in generator service discovered that the insulation failure was caused by partial discharge activity within the coil, as shown in Figure 9.

Figure 9 Microscope examination of coil insulation failure

5. CONCLUSIONS

A quality assurance program for generator/motor insulation is presented. The program provides machine users an objective tool to assess the quality of stator insulation to ensure reliability of long-term machine service. The program has been practiced on near 1000 coils/bars in Powertech Labs for more than twenty years. It has been proven that the program can identify design and manufacturing defects and as a result improve winding life reliability.

A large database with the test results of coils/bars for last 25 years has been established. The test result of a coil/bar can be compared with that of the similar coils/bars in the database to assess the quality of the coil/bar under test. For example, if PD activity of a coil under test is much higher than the average PD activity of a group of the similar coils in the database, PD activity of the coil under test may be considered high.

The quality assurance program can be applied to prototype and production coils/bars. If problems are discovered in prototype coils/bars through the tests, remedial action may be taken to improve the manufacturing quality in the production run. Spare coils are stored in power plant for years. Their performance and quality may be doubtful. The program can also check if spare coils/bars can still perform as expected in the future.

6. REFERENCES

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Authors

Hugh Zhu *(Ph. D., P. Eng.) is a specialist Engineer with Powertech Labs. He has worked in diagnostic testing and condition assessment for generator and motor insulation for fourteen years. His current interests include accelerated aging tests, partial discharge tests, EL CID tests, dissection examination of coils, and insulation failure analysis. Dr. Zhu is a member of several Working Groups to develop IEEE Standards for machine insulation testing. He has published more than 30 technical papers in this field. He can be reached at hugh.zhu@powertechlabs.com.*

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