

USING MEASUREMENT RESULTS TO DIAGNOSE THE CONDITION

OF HIGH- VOLTAGE ROTATING MACHINES

PART 1

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Diagnosing the condition of complex systems such as high-voltage rotating machines has never been a simple task. Design requirements, the use of different materials, and demanding operating conditions require multiple off-line tests and on-line monitors to provide information on the machine's condition. Some tests only yield simple measurement results without high diagnostic value. This article describes the application of various off-line test techniques to assess stator and rotor insulation and stator core.

TESTING ROTATING MACHINES

Although electrical rotating machines can be divided into two very broad groups — motors and generators — and can be of different designs, they all have a rotor and a stator. The two main parts of a stator are the stator core and the stator winding, which consists of a conductor and insulation (Figure 1). The stator core of a typical large rotating machine can weigh 220 tons; it can be 15–25 ft long, with an internal diameter of 5 ft. It is built from a stack of insulated steel sheets or laminations, each 0.3–0.5 mm thick, coated on each side with a layer of electrical insulation to prevent current flow between them.

Core failure commonly occurs when the insulation on a group of laminations is damaged and an electric circuit is created. The machine's rotating magnetic field induces a current along the circuit, which in turn creates a hot spot within the stator core. The stator winding of a high-voltage rotating machine

is usually made of form-wound bars or multi-turn coils installed in stator core slots. The conductors are commonly made of copper; various types of insulation have been used over the last 100 years, most based on the application of mica materials in various forms. Two distinctive parts of the stator winding are the slot and the endwinding.

The failure mechanisms that affect the condition of stator winding insulation can broadly be grouped under thermal, electrical, ambient, and mechanical causes. The coils and bars are exposed to large mechanical forces at twice the ac operating frequency as well as much larger forces in the case of machine faults or system disturbances. Several means of mechanical support are used to prevent winding movement, both within slots and in the endwinding area. Within slots, the wedging system, which consists of a top wedge and sometimes side wedging, is usually sufficient to prevent movement of the stator winding. However, at the endwinding areas on both sides of the core, this task is more complex, since axial movement

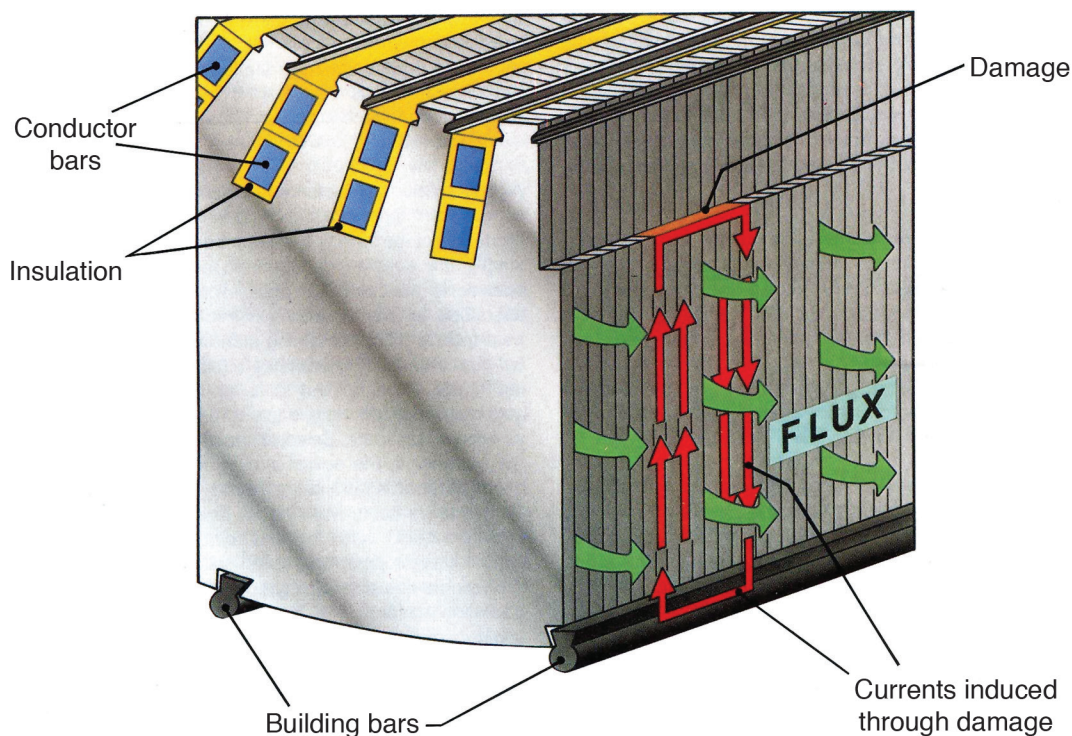


Figure 1: *Stator Core Cross-Section*

of the winding due to thermal dilatation must be allowed. Radial and tangential movement of the endwinding in normal operation and during faults should be limited. The preferred method is to use non-magnetic and usually non-metallic brackets, braces, support rings, and spacer blocks.

As a result of such a complex design, many off-line and on-line tests have been developed to help assess the condition of rotating machines.

HV MACHINES OFF-LINE TESTING

Typical tests can be divided into off-line and on-line, each having advantages and disadvantages. Off-line testing requires machine shut-down and an external source of energy, while on-line tests generally require installation of a sensor during shut-down; the sensor will be used once the machine is back in operation. Off-line electrical stator winding tests can be divided into ac and dc tests.

High Potential Testing

A high potential (HIPOT) or dielectric withstand test (Figure 2a) can be performed using an ac or dc power supply. The purpose of the test is to detect major problems in the insulation. The expectation is that high voltage applied to the stator winding will result in insulation breakdown at the location of a problem. Although insulation in good condition can survive voltage levels much higher than those recommended for ac or dc HIPOT, this test is destructive in its nature

and is of limited diagnostic value. The test can be performed in various ways, as described in IEEE 95 and IEC 60034 for dc power, IEEE C50.10 and IEEE 43 for ac power frequency, and IEEE 433 for 0.1 Hz HIPOT testing. AC and dc HIPOT tests are not diagnostic tests, since the winding either passes or fails. Insulation condition is not indicated except a pass or fail criterion. HIPOT testing of the stator and rotor windings has similar diagnostic value, but it should be noted that winding-rated dc operating voltage is much higher in rotor HIPOT tests.

Insulation Resistance Testing

The insulation resistance (IR) test (Figure 2b) can be applied to stator and rotor windings and has been used since the introduction of electrical rotating machines. The purpose of the test is to measure the resistance between the conductor of the rotor or stator winding and the rotor or stator core. Since stator or rotor winding insulation is not perfect, the measured resistance is not going to be infinite, and with a lower measured value, it is more likely that a problem is present. IR testing is usually done by applying dc voltage between 500 V and 10000 V. Acceptance guidelines provided in IEEE 43 make this test a useful tool to detect contaminated or wet windings. One major problem with IR testing is that the measurement results are strongly dependent on temperature (ambient and winding) and therefore cannot be easily compared. Some experiments have indicated that a temperature change of 5–20 degrees C can result in a 50 percent reduction in the resistance of

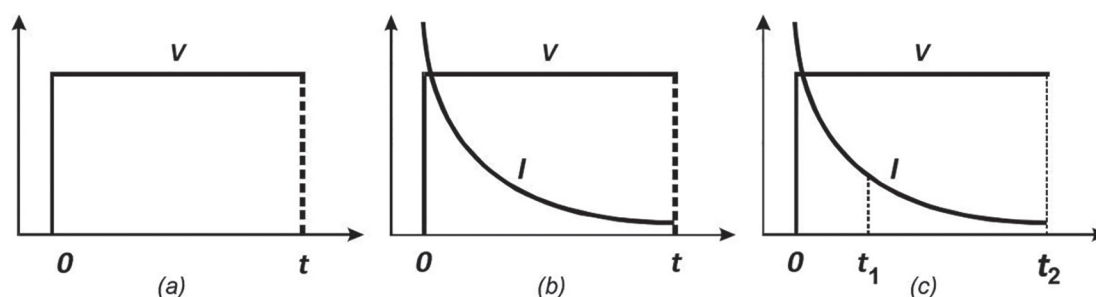


Figure 2: *High Potential (HIPOT), Insulation Resistance (IR), and Polarization Index (PI) Tests*

modern polyester and epoxy insulations. Given that attempts to correct measurement results at different temperatures to a standard temperature (40 degrees C) are not very reliable, the diagnostic value of this test is also not very high.

Polarization Index Testing

The polarization index (PI) test is an improvement over the IR test because it is relatively insensitive to the effects of temperature change. PI is the ratio of the measured insulation resistance after applying dc test voltage for ten (t_2) minutes and at one minute (t_1) (Figure 2 (c)). In some cases, IR values are measured after 60 seconds and 15 or 10 seconds, or after 5 minutes and 30 seconds. PI test results are highly dependent on ambient humidity and cannot be corrected; comparing results is therefore impossible. Although the results of IR and PI tests are numerical values and can be seen as an improvement over HIPOT testing, the diagnostic value of these tests is still limited by ambient condition changes and a lack of agreement on an acceptable time ratio for the PI test.

TIME STEPPED VOLTAGE TESTING

The timed stepped voltage test is an improvement over the previously described direct voltage tests. For this test, direct high potential is applied in a series of several voltage steps at regular time intervals as shown in Figure 3(a). Current readings are taken at the end of each interval, and the I-V (current versus voltage) readings are hand-plotted on graph paper. During and after testing, the data is examined for increases in conduction current or other variations versus applied potential, which are possible indications of stator insulation weakness. Since the maximum test voltage is above the normal operating stress, the test can also serve as a proof test. To minimize the effects of dielectric polarization, the test voltage may be held at each level long enough to allow the polarization current to

decay to a negligible value. Since it is usually not practical to hold the test voltage at each level long enough to make the polarization current negligible and to shorten the time required to obtain the I-V curves of stator insulation, complex voltage-to-time schedules were developed (see F.R. Schleif).

The basic idea of these test schedules is to adjust the voltage in steps according to a predetermined, diminishing time schedule so that the polarization component of the measured current is proportional to the applied voltage (Figure 3b). In effect, the voltage-time schedules attempt to linearize the polarization current so that relative changes in the conduction current become more readily discernible. Nevertheless, even with the use of graded time intervals, it may be difficult to detect subtle changes in conduction or ionization. A time stepped voltage test generally requires two people: one to monitor the time intervals and record the measured data, the other to apply the voltage steps and read the current meter. Tests performed in this manner rely on individual judgment and actions to control the test time intervals, apply uniform voltage increments, and accurately read and average a fluctuating current meter. This human factor can result in poor data quality and impact repeatability of the measurements. Such uncertainty decreases confidence in the data and may even lead to misdiagnosing insulation condition, therefore minimizing the diagnostic value of this test.

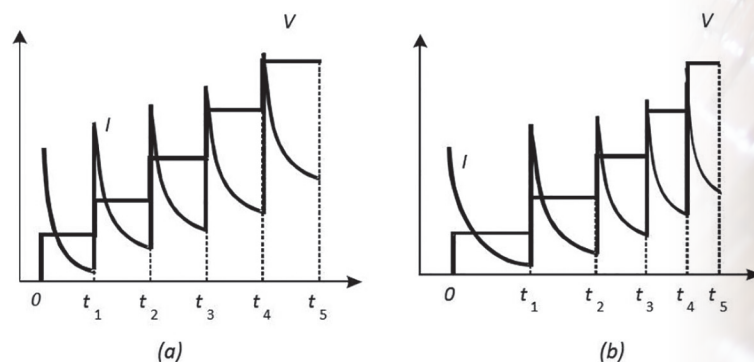


Figure 3: Time-Stepped Voltage Testing

DC RAMP VOLTAGE TESTING

A third variation and further improvement over other direct voltage tests is the dc ramp voltage test where dc voltage is linearly increased at a constant rate from zero to the maximum test voltage. This method represents a major advantage. As a result of the steady increase in voltage ($dV/dt = C$, usually 1 or 2 kV per minute), the capacitive charging current is constant; the test result is shown graphically, so this can be ignored, unlike in any other dc test. The total current (sum of capacitive, polarization, and leakage currents) is plotted versus the applied voltage. The graphical presentation of the test result is a more helpful diagnostic tool. In the case of defect-free insulation, the measured current increases linearly with applied voltage, and any deviation from the expected linear response can be easily observed. Figure 4 shows a typical result from a new epoxy-mica insulation system. IEEE 95 provides general guidelines and some typical dc ramp test results. Since this test method is the most sensitive way to detect leakage current instability, it is superior in detecting problems that cannot be identified by other tests, such as incompletely cured epoxy insulation or moisture within insulation.

Figure 5 indicates the dc ramp test results for all three phases of a 30 MVA, 6.9 kV generator after installing a new winding. Only phase B results were acceptable, while a major deviation from the expected linear response is easily visible in phase A and phase C results. AC and dc HIPOT tests and the PI test did not indicate

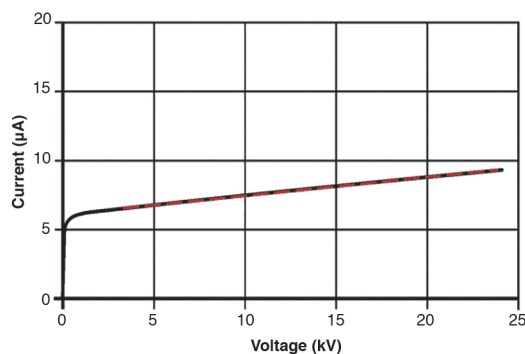


Figure 4: Typical DC Ramp Voltage Test from New Epoxy Mica Insulation

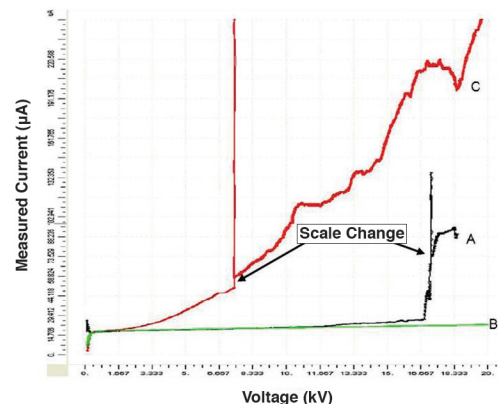


Figure 5: Unacceptable DC Ramp Test Result on Phases A and C

the presence of problems on phases A and C. After detection by the dc ramp test, many other tests failed to identify the location of the insulation problem. The winding was sectioned first into parallel sections and then into coils, and the dc leakage current was measured to locate two faulty coils on phases A and C.

Although as potentially destructive as any other HIPOT test, the dc ramp test is most likely to help a user avoid failure during the test. Based on the experience of the United States Bureau of Reclamation, the failure rate after 5,400 tests was lower than 0.01 percent or just four sudden failures without precursor to a failure. The diagnostic value of this test compared to other dc and ac HIPOT tests is significant. The comparison of dc ramp results from the same or different machines is a useful tool for detecting stator winding insulation problems.

STATOR CORE TESTING

Traditionally, the only method of testing inter-laminar insulation in stator cores was the high flux ring test (or loop test). This requires the rotor to be removed and a massive excitation winding to be installed through the core to generate a circumferential (ring) magnetic flux around the core. To provide the required level of flux (typically 80–100 percent of rated flux), several loops of high-voltage, high-current-carrying capacity cable must be connected to a large power source (3–4 MVA for a 500

MW generator). Ideally, the core is energized for a few hours to produce measurable tooth-tip temperature rises for deep-seated faults located near slot bases. Hot spots are then detected using thermal sensing equipment. The principal disadvantages of the loop test are the installation of the winding, the high power requirement, high-voltage safety concerns, the difficulty of detecting deep-seated faults, and the risk of further core damage due to the absence of normal cooling systems.

Electromagnetic Core Imperfection Detector

Although the diagnostic value of the high flux ring test is not low, the difficulties related to excitation requirements led to development of a low-power core test known as the electromagnetic core imperfection detector (EL CID). EL CID also uses a temporary ring flux winding, but it is much lighter and requires only a 3 kVA supply for a typical 500 MW turbine generator or less than 5 kVA for a large hydro generator. The flux level required is only 4 percent of the rated value, so only small currents flow through any damaged area (typically between the fault and rear building key bars as shown in Figure 5). Core heating from such currents is insignificant, but EL CID detects the actual currents using a very sensitive electromagnetic technique; faults are readily detected even if they are located deep down in the slots between the teeth.

Chattock Potentiometer

A special pickup coil known as a Chattock potentiometer is used to measure the magnetic fields produced in the air by current flowing along the core surface. The voltage induced in the coil is proportional to the line integral of the magnetic field along its length, i.e., to the magnetic potential difference between its ends. Since the core fault current circuit has significant resistance, the fault current is substantially in phase with the fault voltage and in-phase quadrature (shifted by ninety degrees) from the excitation flux. EL CID exploits this

phase relationship and virtually eliminates the signal from the excitation current by using a phase-sensitive detector to measure this quadrature component of the fault current (the core fault heat producing component). The component in phase with the excitation current is called the PHASE (or P) and the component indicating the core imperfections is referred to as the QUAD (or Q) component.

To carry out the EL CID test, the Chattock is adjusted to the slot/tooth width and scanned along each and every tooth pair. The current responses (Y-axis) and the distance from the core end (X-axis) are recorded. These traces are examined, and faults are apparent when the quadrature component exceeds a certain threshold. In a perfect, fault-free, uniformly constructed generator, a slot QUAD trace would be a straight line along the zero axis and the PHASE trace would be another straight line with an offset depending on the excitation current. In practice, however, a number of effects can cause QUAD trace deviation from zero level (e.g., stator winding currents, varying core loss).

Analyzing QUAD Traces

At the standard excitation level of 4 percent of rated flux, a QUAD current level of 100 mA was established in the early days of the technology as a threshold above which more detailed examination is required. Although correlation with thermal tests depends on a number of factors, the 100 mA QUAD threshold corresponds approximately to a rise of 5–10 degrees C in the core temperature. Faults are identified and located by examining the traces measured along and around the core, correlating features on adjacent slots. Figure 6 shows laboratory measurements on a section of core with three artificial faults, each of equal severity and each 0.4 in long, applied at various positions on a tooth. The shape and polarity of recorded adjacent slot QUAD traces is used to identify the location of the fault. The amplitudes of the measured currents were fairly constant (Y-axis) even for fault C near the bottom of a slot.

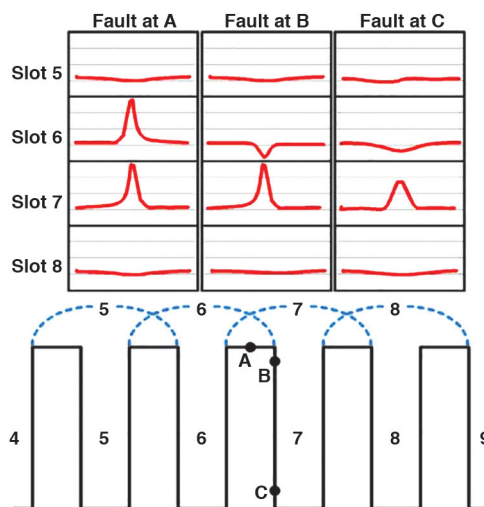


Figure 6: EL CID Quad Traces Fault Location Analysis

EL CID Advantages

This higher sensitivity to deep-seated faults is one of the important advantages of EL CID over the high flux ring test. Many field test comparisons verified the sensitivity of EL CID in comparison to the high flux ring test; all confirmed that for every hundred mA of QUAD current, the temperature increase at the fault was in the range of 5–10 degrees C for all three types of high-voltage rotating machines (hydro and turbine generators and motors).

The correct interpretation of the EL CID test result depends on the polarity of the measured QUAD response in relation to the polarity of the measured PHASE signal, both recorded by the instrument. If the QUAD signal has the opposite polarity to the PHASE signal at the same distance, then a core fault lies within the span of the Chattock. This criterion is also important to properly recognize heat generating faults from various core imperfections that would not cause hot spots and therefore would not be detected by the high flux ring test. As a result, interpretation of EL CID results is relatively simple, thus increasing the test's diagnostic value.

CONCLUSION

Condition diagnostic analysis of rotating machines has evolved from off-line testing to a combination of off-line tests and on-line monitoring. No single test is perfect or sufficient to completely diagnose the condition of a rotary machine, and presenting multiple measurement results graphically is frequently more valuable than a simple numerical reading. Further improvement can be gained by combining visual inspection with information from on-line monitors that use multiple technologies, including partial discharge, rotor flux, shaft voltage and current monitoring, and endwinding vibration monitoring. Watch for more information on these technologies in Part 2 of this article.

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USING MEASUREMENT RESULTS TO DIAGNOSE THE CONDITION

OF HIGH- VOLTAGE ROTATING MACHINES –

PART 2

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Diagnosing the condition of complex systems such as high-voltage rotating machines has never been a simple task. Design requirements, the use of different materials, and demanding operating conditions require multiple off-line tests and on-line monitors to provide information on the machine's condition. Part 1 of this article described the application of various off-line test techniques to assess stator and rotor insulation and stator core. Part 2 addresses the additional improvements that can be gained by combining visual inspection with information from on-line monitors that use multiple technologies.

On-line testing has many advantages, including two that are the most important: The machine does not have to be stopped for the test, and normal operating conditions (temperature, current, etc.) are present. However, on-line testing requires permanent or temporary sensors to be installed. The two tests performed most frequently with the machine in operation are the partial discharge test of stator winding and the detection of shorted turns in the rotor winding.

ON-LINE PARTIAL DISCHARGE TESTING

Partial discharges (PD) are small electrical sparks resulting from the electrical breakdown of a gas (for example, air) contained within a void or under a highly non-uniform electric field. If the void is within an organic solid or liquid, PD will degrade the organic material and may eventually cause the electrical insulation to fail. In addition to causing this electrical aging, PD may indicate thermal, mechanical, and environmental aging in high-voltage apparatus. For example, operating at high temperature may create voids within the epoxy-mica insulation of a stator winding; this can delaminate taped insulation systems. Similarly, mechanical stresses can lead to gaps, and contamination by partly conductive coatings can lead to high localized electrical stresses on insulation surfaces that result in discharges into the air.

When a partial discharge event occurs, electrons flow very fast from one side of the gas-filled void to the other. Since the electrons are moving close to the speed of light across a small distance, the measured pulse has a very short duration — typically a few nanoseconds. The PD current pulse creates a disturbance, and pulse current and voltage flow away from the PD site. Various types of permanent or temporary sensors are installed to detect PD on-line. Any sensor (also called a coupling device) sensitive to high frequencies can detect PD pulse currents; however, not every sensor will provide sufficient noise-to-signal ratio.

Capacitive (high-voltage coupling capacitors) and inductive (various antennas and high-frequency current transformers) sensors are commonly used types. Typical capacitances range from 80 pF to 1,000 pF. A capacitor is a very high impedance to high ac (50 or 60 Hz) voltage, but is a very low impedance to the high-frequency PD pulse currents. The sensor and PD detector (test instrument) selected will determine the frequency range of the whole system. On rotating machines, low-frequency (0.8 to 10 or 20 MHz) and high-frequency (40–350 MHz) methods are commonly used.

The major obstacle to establishing a proper diagnosis based on on-line PD measurement is the possible presence of noise or electrical interference. Electrical interference can come from corona on air-insulated transmission and distribution lines, power tool operation, arc welding, poor electrical contacts, electrostatic precipitators, etc. All produce sparks and/or discharges that create current pulses similar to PD. Separating this noise from test-object PD is important. Noise mistaken for PD will give a false indication of insulation deterioration, reducing the usefulness and credibility of the PD test. The most effective way to reject noise and outside PD is to apply hardware methods. One method measures the rise time or width of the pulse: A fast rise time (< 6 ns) pulse is likely to be PD in the stator winding, while a noise pulse tends to have a longer rise time due to transmission line dispersion as the noise pulse propagates along a power cable to the motor or generator.

Another method depends on the propagation time between a pair of sensors: Two capacitive sensors per phase are mounted on the machine terminals, separated by at least 2 m, or on two parallel paths within a hydro generator. Since the current pulses have a finite transmission speed on a busbar or power cable, PD pulses will arrive at the sensor closest to the stator winding first; outside PD from other equipment connected to the power system will arrive at the other sensor first. Digital logic can then determine on a pulse-by-pulse basis whether the pulse is stator PD or PD from

other equipment. Both of these hardware-based signal separation methods require measurement system bandwidth of 100 MHz or more in order to distinguish small differences in arrival time or accurately measure the rise time or pulse width. If only one sensor per phase is used, it is impossible to detect the direction of the pulse arrival, i.e., its place of origin within the rotating machine or externally. This compromise (use of just one sensor per phase) can have a significant impact on the quality of data collected from all machines except smaller machines connected to a power system with sufficiently (longer than 100 ft) long high-voltage cables.

Most instruments used to collect PD data measure the number of pulses per second, as well as the polarity, amplitude, and phase position of each pulse. Using that data, various graphs can be generated to display the results from one or more measurements for trending purposes. In addition to noise interference, understanding measurement results and the credibility of various methods used in PD data collection are major concerns. The possibility of false positives, which may result in concluding that problems are present in the winding as a result of noise or misinterpretation, and the occasional (wrong!) claim that on-line PD monitoring can detect ALL insulation problems both create difficulty in using PD results for diagnosis.

The absence of standards defining acceptable levels of PD in rotating machines, along with uncertainties related to measurement methods and the fact that calibration is not possible all tend to minimize the diagnostic value of

this technique. However, standardization in selecting the sensor and instrumentation used for data collection on a large number of machines (more than 10,000) provides conditions for statistical data evaluation. More than 600,000 on-line PD results were collected and compiled to indicate the distribution of pulse amplitude (Q_m) levels on machines of different voltage classes and sensor installation methods. The range in Q_m from all the tests for each particular operating voltage was established for each set of the above factors. A sample of the statistical distribution is shown in Table 1.

For example, for 13-15 kV stators in hydro generators and pump-storage units, 25% of tests had a Q_m below 35 mV; 50% (the median) had a Q_m below 93 mV; 75% were below 193 mV; and 90% of tests yielded a Q_m below 376 mV. Thus, if a Q_m of 400 mV is obtained on a 13.8 kV hydro generator, it is likely that this stator is deteriorated, since it has PD results higher than 90% of similar machines. In fact, significant stator winding insulation deterioration was observed in over 200 cases where a machine was visually examined after registering a PD level greater than 90 percent of similar machines.

Publishing these results, together with taking the PD trend into account, seems to have reduced the risk of both false positives and false negatives and improved the test's diagnostic value. An attempt was also made to study the correlation of PD level to visual observation. In 216 cases, PD indicated various failure mechanisms, such as contamination, design and manufacturing problems, and vibration. As

Table 1: *Pulse Amplitude (Q_m) Distribution for Hydro generators with 80 pF Coupling Capacitors Installed*

Rated kV	6-9 kV	10-12 kV	13-15 kV	16-18 kV	> 19kV
25%	12	19	35	37	67
50%	33	50	93	118	142
75%	72	111	193	334	441
90%	201	231	376	687	838
95%	322	389	561	1016	956

a result of a large number of installations using the same type of PD sensor, a standardized data collection approach, and the well-established correlation between PD patterns and insulation condition, PD monitoring identified many pending service problems, prevented a significant number of generator service failures, and has resulted in a major cost saving to the power generation industry.

DETECTING ROTOR WINDING SHORTED TURNS

Two types of rotors are generally used in synchronous electrical machines: round, for high speed machines, and salient pole for lower speed machines. A turbine generator rotor usually consists of a solid forging made from magnetic alloy steel and copper windings that are assembled in slots machined in the forging. The winding is secured in slots by steel, bronze, or aluminum wedges. At each end of the rotor, the end sections of rotor winding are supported by retaining rings. Modern rotor winding insulations are made mostly from epoxy, polyester glass, or Nomex™ laminate strips and channels. The strips are used to provide inter-turn insulation, and molded channels are used to provide ground insulation. Rotor insulation should be designed to withstand electrical, mechanical, thermal, and environmental stresses.

For moderate and large hydro generators and pumped storage generators, the most common type of salient pole rotor has a strip-on-edge winding on each pole. Such windings are composed of strips of copper that are fabricated around the pole piece much like a picture frame. Electrical insulation, most commonly fiberglass reinforced epoxy, is used to insulate each copper turn from adjacent turns, as well as provide ground insulation between the copper and the rotor pole. Failure of the rotor winding insulation can result in shorted turns. Shorted turns on a rotor may lead to unbalanced magnetic pull, which in turn may cause an increase in bearing vibration. However, shorts can exist with no increase in vibration; thus, bearing vibration is not an

infallible way to detect rotor winding aging. The condition of rotor winding insulation is difficult to assess during a shutdown due to limited access and the frequently intermittent nature of faults at operational speed and at standstill. Consequently, on-line testing is a more effective way to detect shorted turns.

FLUX MONITORING

Flux monitoring using temporary or permanently installed flux probes on turbine generators has been used since the early 1970s. Flux measurements are used to determine the existence of turn-to-turn shorts in the rotor winding. All of the methods available are based on measuring relatively weak stray flux (rotor slot leakage flux) using flexible or non-flexible polymer-encased stator wedge mounted probes. The stray flux is proportional to the total ampere turns in each rotor slot. If shorts develop between turns in any slot, then the ampere turns in that slot drop, and stray flux across that slot is reduced. The magnitudes of these stray fluxes can be measured using portable or permanently installed instruments, and shorted turns can be identified by comparing the difference in induced voltages from pole to pole. The main challenge in existing technology is the need to manoeuvre the turbine generator load to achieve the maximum sensitivity of measurement to every slot of a rotor. This, together with issues including the type of hardware and algorithms used for the detection of shorted turns, has limited the use of this technology in the power industry.

To overcome this problem, new hardware and algorithms were developed in an attempt to make the flux test more sensitive to shorted turns in all coils, even if the generator load could not be changed to align the flux density zero crossing (FDZC) with every slot.

- The temporal and magnitude resolution of the hardware was improved compared to the conventional test.
- Concentration was focused on the main magnetic flux rather than the leakage flux.

INDUSTRY TOPICS

- Three proprietary numerical methods were developed to improve the sensitivity to small differences between pole A and pole B main flux plots.
- The results from the three algorithms were compared to develop an index of confidence in the finding of the presence (or not) of shorted turns in each coil.

The new approach can be used with conventional wedge-mounted coils that protrude into the air gap. An alternative probe can be glued to the stator core tooth rather than the stator wedge. This probe directly measures the main magnetic flux that passes through the core tooth. A typical measurement result from

a two-pole turbine generator is shown in Figure 1. The grey line indicates the measured signal; the green line measures the integrated signal.

The vertical green line indicates the position of FDZC, a point with maximum measurement sensitivity at coil 6 (Figure 1). With load increase, the FDZC will move toward lower number coils, but will never reach coil 1. The measurement result shown in Figure 1 is of very low diagnostic value, since the pole-to-pole difference, per coil, is not visually detectable, so no judgment on the presence of shorted turns can be made. The graph shown in Figure 2 is more useful, but still lacks a clear and easy means to detect the existence of shorted turns.

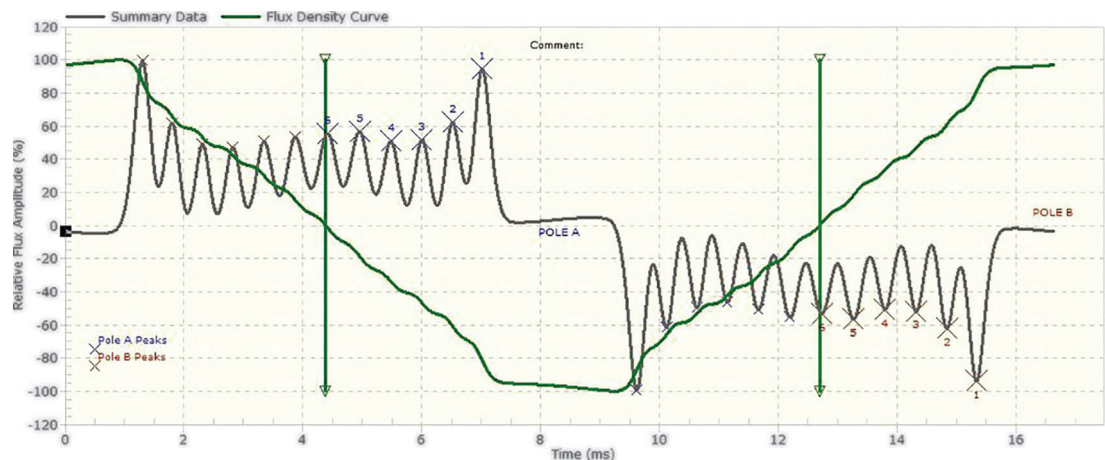


Figure 1: Low-Load Two-Pole Turbine Generator Test Result

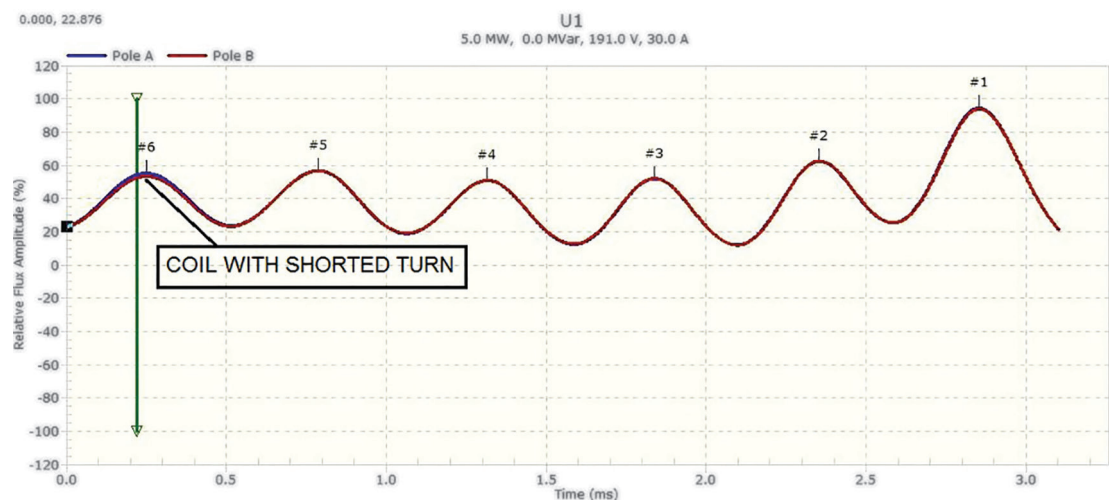


Figure 2: Pole-to-Pole Comparison Indicating Difference in Flux Peak per Coil

Using multiple algorithms resulted in great improvement in analysis reliability, providing measurement results can be used for diagnosis (Figure 3).

CONCLUSION

Analysing the condition of rotating machines has evolved from off-line testing to a combination of off-line tests and on-line monitoring. No single test is perfect or sufficient to completely diagnose the condition of a rotary machine, and presenting multiple measurement results graphically is frequently more valuable than a simple numerical reading. Further improvement can be gained by combining visual inspection with information from on-line monitors that use multiple technologies, including partial discharge, rotor flux, shaft voltage and current monitoring, and endwinding vibration monitoring.

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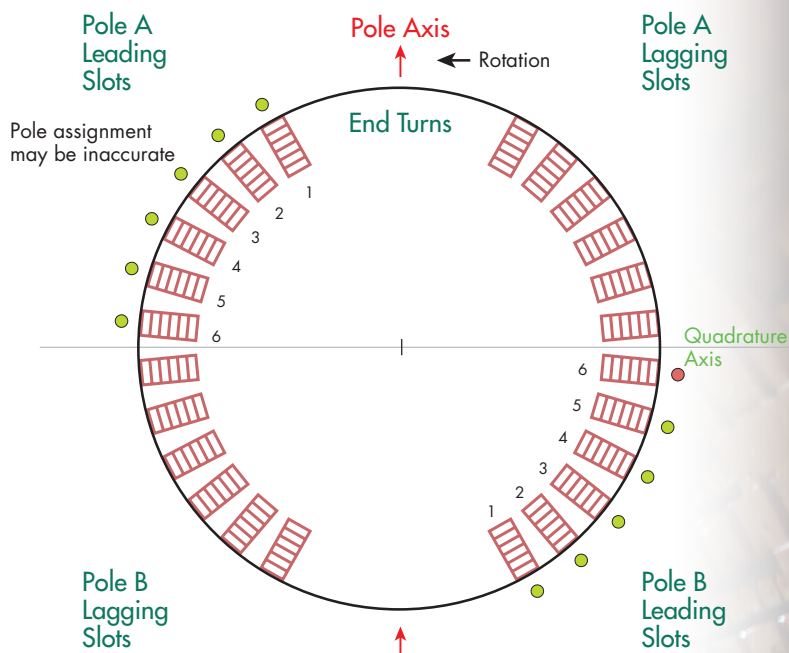


Figure 3: Identification of Pole and Coil with Shorted Turn

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