IRIS POWER

TURBOGENERATOR CONDITION-BASED MAINTENANCE SOLUTIONS

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MANAGE YOUR RISK

Qualitrol-Iris Power is the world's largest provider of asset monitoring and diagnostics solutions for high voltage motor and generator windings.

IRIS POWER | GUARDII+

CUSTOMER VALUE

>80k	#1	>700k
Global sensor installs on rotating machines	On-line monitoring provider for motor and generator windings	Test results in Iris Power's on Partial Discharge database

CONDITION BASED MAINTENANCE

Predictive Maintenance (PdM), also called Condition-Based Maintenance (CBM), has rapidly become the best method to minimize overall maintenance costs of turbogenerators. CBM is an approach to planning maintenance where equipment is removed from service when, and only when, an on-line monitor gives an indication that some failure mechanism may be present. Thus, equipment shutdowns are NOT based on operating hours, the number of stop/starts, or the elapsed time since the last maintenance shutdown. With CBM, the time between maintenance outages can be significantly increased in well-made generators. CBM also reduces the risk of in-service failures, with the accompanying higher repair costs.

Having confidence in planning maintenance, based on the actual condition of the generator, involves the following prerequisites:

On-line monitors that are able to detect most of the failure mechanisms that are likely. If not, unanticipated failures may occur, which undermine confidence in the CBM approach.

There must be few false alarms. That is, if a monitor indicates a problem, an actual problem must be present.

The sensors and the monitor itself should not lead to a failure, and the monitoring cost must be a small percentage of the generator cost.

IEEE Standard 1129: "Guide for On-Line Monitoring of Large Synchronous Generators" recommend on-line monitoring as one of the most effective ways to minimize long term maintenance costs and to reduce the risk of unexpected generator failure.

BENEFITS OF CONDITION BASED MAINTENANCE ON TURBOGENERATORS

- The time between generator shutdowns can be extended if monitoring reveals that the rotor and stator are in good condition. This increases availability, and helps to avoid failures caused inadvertently during the shut-down inspections (such as leaving a tool in the machine).
- Problems can be found at very early stages, allowing for a maintenance shutdown to be planned at a convenient time. Experience also shows that if most problems are detected at an early stage, repair costs are often less than 1% of the rewind cost that would be incurred if the failure were permitted to occur in-service.
- Rewinds and other major repairs are based on need rather than the calendar or operating hours – or the desire of machine manufacturers and service organizations to generate after-market revenue.

Historically, vibration analysis, lubrication oil analysis, and thermography have been used as CBM tools on the mechanical components of machines. However, in the past the rotor and stator windings have generally required regular shutdowns of the machine for off-line tests and inspections to be performed.

Off-line testing includes insulation resistance, polarization index, stator core loss, stator wedge tests, capacitance and dissipation (power) factor tests for the stator winding, and rotor winding tests, such as impedance tests and recurrent surge oscilloraphy (RSO).

Over the past 35 years, our extensive research (primarily funded by machine users or organizations representing machine users, such as EPRI and CEA) has developed and/or refined several technologies that can detect most rotor and stator winding problems in turbogenerators during normal service.

THESE MONITORING TECHNOLOGIES INCLUDE:

- Reliable measurement of stator winding partial discharges (PD) using on-line methods.
- Detection of shorted turns in turbogenerator rotor windings using magnetic flux monitoring.
- Detection of stator endwinding vibration.
- Rotor shaft ground brush current and voltage monitoring.

The Iris Power GuardII+ monitor has been designed to be a continuous monitoring platform to incorporate one or more of the above technologies into a single, flexible format with a common hardware platform, database and interface.

With all these on-line monitoring technologies, as well as temperature monitoring, the majority of turbogenerator aging problems can be detected and addressed well before in-service failures occur. Qualitrol-Iris Power and its staff have been at the forefront in bringing these new monitoring technologies to utilities.

In addition to the on-line condition monitors, Qualitrol-Iris Power is the world's leading manufacturer of off-line testing tools to confirm the existence and determine the severity of any issues found by on-line monitoring.

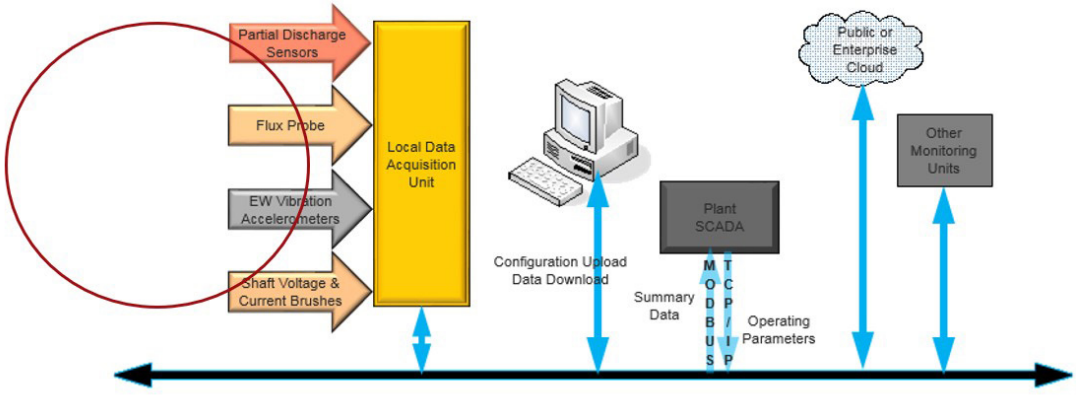
GUARDII+ – INTEGRATED ON - LINE MONITORING FOR TURBOGENERATORS

Iris Power GuardII+ is a continuous on-line monitor that integrates, into one instrument, the ability to detect multiple issues in turbogenerators. The GuardII+ system has a flexible, modular design that can incorporate a variety of technologies and sensor inputs to make the most efficient, cost-effective monitor to detect the most likely failure processes for a particular turbogenerator.

The GuardII+ starts with a basic hardware platform, to which up to four hardware modules (PD, flux, endwinding vibration and shaft V/I) can be added. There is a single user interface for all the monitoring technologies, as well as a single (SQL) database where the data is stored.

The GuardII+ communicates with the plant's own computer system and the utility's intranet via Modbus over TCP/IP. The GuardII+ can also be operated in a "stand alone" mode where data is downloaded to a notebook computer or USB drive.

One Monitor for Four Technologies



Benefits of the GuardII+ Condition Monitoring System:

Condition Assessment by Machine Owners

Due to technology for reducing noise, and advanced algorithms to convert sensor signals to information, most endusers can interpret the data themselves, free of the commercial bias of generator manufacturers and machine repair companies. Iris Power was created by the utility industry to provide third-party tools and technical advice that has the interest of machine owners in mind.

Turnkey solution

Where facilities have existing sensors for PD, flux, endwinding vibration, shaft monitoring and/or air gap, a continuous monitor installation does not require an outage, and the installation effort is limited to providing power to the monitor, configuration, and if desired, running a communication link to a remote Windows™ computer. Combined with the Iris Application Manager (IAM), one can collect data from multiple rotating machines which can be monitored continuously at the same time. This lowers the burden on plant personnel to collect data.

The GuardII+ monitoring system can monitor from one to four technologies based on user needs. The endusers can start with a GuardII+ that monitors, for example just PD, but then easily add flux, endwinding vibration and/or shaft monitoring modules at later times.

Customer education

The data can be easily interpreted by a maintenance professional after participating in a training seminar offered by Qualitrol-Iris Power's experienced engineering staff and world-class generator experts.

Monitor generator condition from anywhere in the world

Many turbogenerator operators are increasingly requiring continuous on-line monitoring to assess machine condition. Via a company's intranet, utility experts located anywhere can determine the need for maintenance without having to travel to the plant. The GuardII+ system has been specifically designed to interface with central condition monitoring centers that many utilities are setting up.

Customized Data Storage

The GuardII+ software enables continuous data collection and storage (which creates a lot of, often redundant, data) or storing only critical data using sophisticated triggers based on operating conditions or events (such as a rapid increase in endwinding vibration).

Reliable prediction

GuardII+ system has undergone unique and rigorously researched methods to overcome the electrical interference (noise) which is typical in most plant environments. This ensures reliable and repeatable measurements with a low probability of false alarms.

Unlike monitoring systems developed by machine manufacturers which usually require the monitor output to be transmitted to the manufacturer's facilities for analysis, the GuardII+ plus system has been designed to allow the data to be contained entirely within the utility, and needs no connection to the outside world, as long as the plants are connected by their own secure intranet.

Ease of configuration

The GuardII+ monitors can be configured and upgraded with additional technologies, such as rotor flux or shaft voltage and current monitoring and endwinding vibration.

STATOR WINDING PARTIAL DISCHARGE MODULE

Stator winding insulation aging is the primary cause of generator stator winding failure. Stator insulation problems lead to 40% of rotating machine forced outages, according to an EPRI survey.

Partial discharges (PD) are small electrical sparks that occur within aging electrical insulation in stator windings rated 3kV and above. The PD occurs whenever there are small air gaps or voids in or on the surface of the insulation. Normally, well-made stator windings that are in good condition display little PD activity.

However, over 70 years of experience has shown that as a stator winding deteriorates from winding vibration in the stator slots, operation at high temperatures, or contamination from oil, moisture and other chemicals, the PD activity will increase by a factor of ten or more. Thus on-line PD monitoring detects most of the main root causes of stator winding insulation aging and failure on stators rated 3.3 kV and above. Since PD monitoring can be performed during normal generator operation, and generally gives two or more years of warning before there is a high risk of failure, on-line PD monitoring has become a very powerful tool for predictive maintenance.

Qualitrol-Iris Power is, by any measure, the world's largest supplier of on-line partial discharge monitoring systems for generator stator windings. The key reason for our success is a measurement method that is reliable, objective and easy to use:

The technology explicitly separates stator winding PD from other similar types of electrical signals, called noise. Noise, which is usually relatively harmless, comes from power system corona, brush sparking on slip rings and shaft grounding arrangements, power tool operation, variable speed drives, etc. Other PD technologies require considerable human expertise to separate PD from noise or need expertise to continuously adjust filters, clusters and gates to separate PD and noise. The Qualitrol-Iris Power digital noise separation technology allows automatic, unsupervised noise suppression. False indications of stator winding problems are tracked by Qualitrol-Iris Power and have been shown to be <1.5% of machines where high PD is suspected.

The Qualitrol-Iris Power system allows for an objective interpretation of the test results by technicians who have received as little as two days of classroom training. The primary reason for this can be attributed to the extensive database of test results that Iris Power has collected and updates frequently. In most cases, it is easy for a machine user to determine in minutes if the stator winding has insulation problems.

Qualitrol-Iris Power's customers have published dozens of technical papers with well over 200 case studies on the effectiveness of the technology.

ON-LINE PD MONITORING

On-line PD monitoring involves the permanent installation of pairs of 80 pF sensors on the terminals and bus of the machine. Alternatively, on higher power turbogenerators, stator slot couplers (SSCs) may be installed in the stator winding. The PD signal from these sensors are monitored via a PD module within the GuardII+ continuous monitoring system, or using portable instruments called the TGA-B (80 pF sensors) or TGA-S (SSCs).

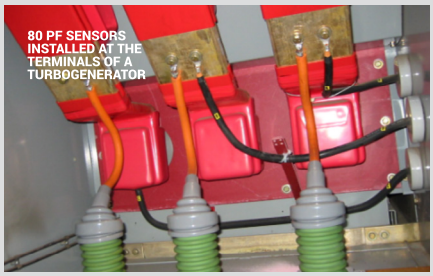
The on-line monitoring package used to detect PD in turbogenerators normally involves the permanent installation of six 80 pF epoxy mica capacitive couplers, two per phase. One of the couplers is located as close as possible to the machine terminals and the other downstream on the isolated phase bus (IPB) at least two metres separated from the machine coupler. This "directional" installation and the calibration of the sensors are optimized to ensure reliable digital separation of noise and PD pulses.

With over 80,000 PD sensors in service for as long as 25 years, the Iris Power 80 pF epoxy mica sensors, rated 6.9, 16 and 25 kV, use proprietary design and manufacturing techniques to ensure safety and reliability in operation. The sensors exceed all of the requirements for PD sensor reliability in IEEE 1434 and IEC 60034-27-2.

As an alternative to the 80 pF sensors, SSCs may be installed in the stator winding. Typically, SSCs are installed on large (> 200 MVA), hydrogen-cooled turbine generators. These sensors, because they are installed on the stator winding, offer increased immunity to electrical interference.

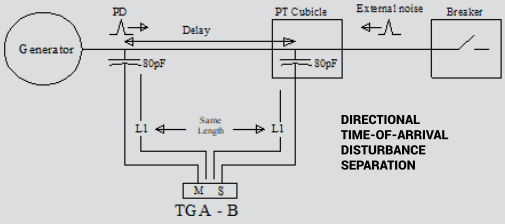
Stator slot couplers are directional antennae that may be installed between the top wedge and the top stator bar, as a retrofit, or between top and bottom bars in a new winding. Usually, two-pole generators require six SSCs with additional SSCs needed on four-pole generators depending on the winding configuration.

The signals from the PD sensors are measured with the PD module in the GuardII+ platform. Commissioning software allows the user to define the turbogenerator in terms of operating voltage, power output, insulation



80 PF SENSORS INSTALLED AT THE TERMINALS OF A TURBOGENERATOR

design and the preferred sequence of measurements of the PD sensor pairs. The IAM display software produces trend plots over time, as well as the phase-resolved PD (PRPD) plots which can aid in identifying the root cause of any stator winding insulation deterioration that is found. Alternatively, these plots can be made available to the plant computer or central condition monitoring center.



NOISE SEPARATION USING TIME OF FLIGHT

The low frequency disturbances from the power system are suppressed using the Iris Power 80 pF capacitive sensors. The sensors attenuate all low frequency electrical noise below 40MHz leaving only the machine partial discharges to be analyzed.

Independent research and IEEE/IEC standards shows the PD signal to noise ratio is much higher above 40 MHz. Low frequency solutions like those using 1000 pF couplers do not block the noise, leading to a higher risk of false indications. This the time of flight noise separation principle described in IEC and IEEE standards.

DIRECTIONAL TIME-OF-ARRIVAL

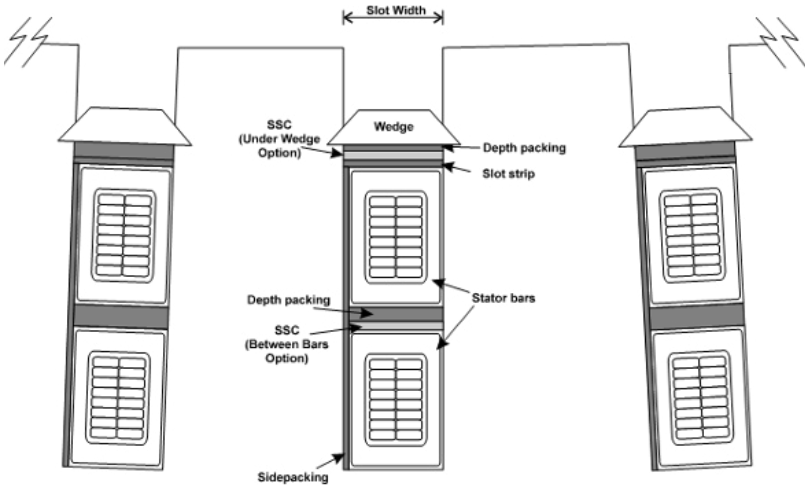
Disturbance Separation. In a directional coupler installation, pulses arriving at the Machine (M) sensor first are classified as Unit PD, pulses arriving at the System (S) sensor first are classified as System Disturbances (Noise), while those arriving at both sensors within the Delay time are called Bus Disturbances (Noise). The delay time is measured as part of the coupler installation verification process.

LF vs VHF

Decades ago all PD detection was performed in the low frequency range (below 1 MHz), since it was believed that PD "deeper" in the winding would not be detected in the very high frequency range used by the Iris method. Independent research has shown that attenuation is actually modest in the VHF range, and that PD will only rarely occur deeper in the winding, since the voltage is lower in on-line tests. This is why VHF on-line PD detection in machines today is by far more popular than LF detection.

SSCs

Like the Directional (BUS) installation, the SSC installation has two sensors, one on each end of the antennae. It categorizes pulses by direction of arrival. The delay time between pulse arrivals is a function of the sensor design and does not require calibration during installation. Pulses arriving at the "Endwinding" sensor first are classified as Endwinding PD, pulses arriving at the "Slot" sensor first are classified as Slot PD, while those arriving at both sensors within the Delay time are called Under PD.

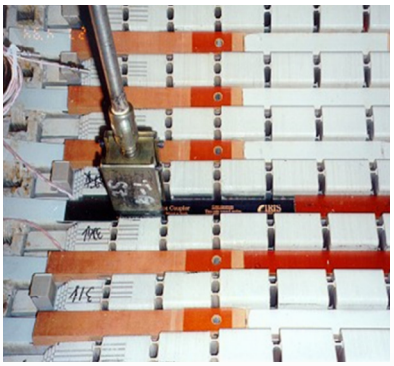


LOCATION OF SSCS

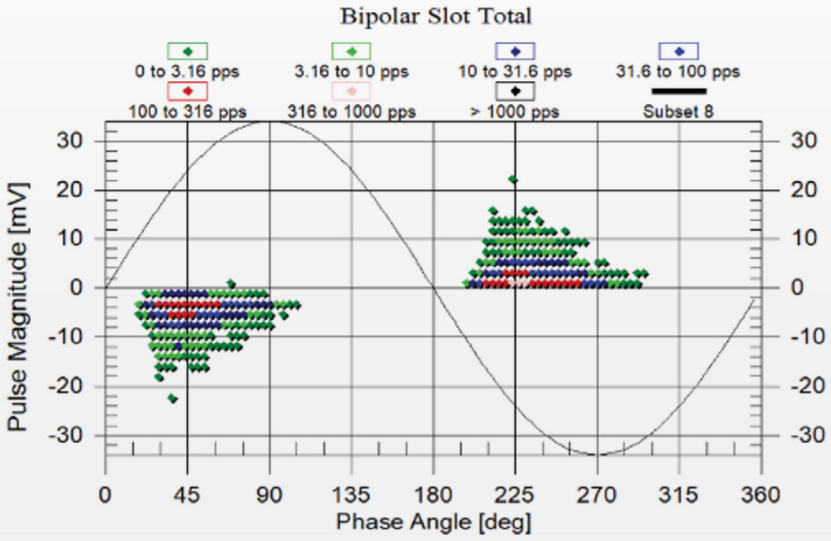
PD signals collected with the GuardII+ continuous monitor allows the data to be collected automatically, and without having to visit the generating station. The GuardII+ monitor is essential for utilities that have a centralized condition monitoring center, and allows the detection of problems at the earliest possible time.

Furthermore, continuous monitoring using the GuardII+ system facilitates better trending of the insulation condition, since the PD data can be trended at the same operating conditions.

FAILED TURBOGENERATOR STATOR WINDING



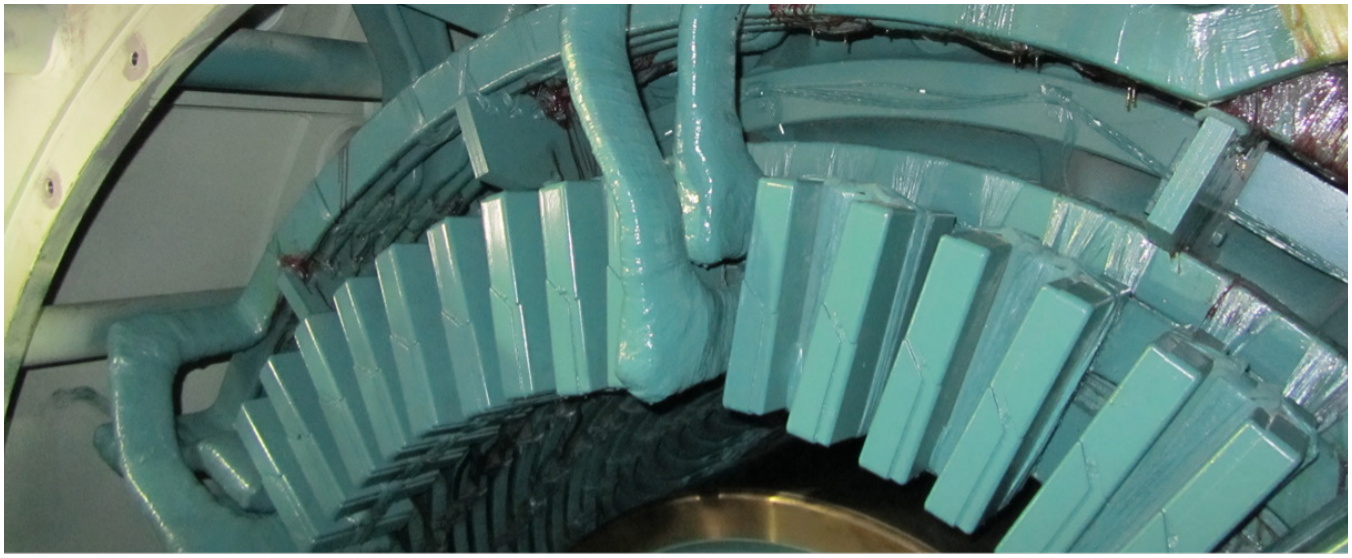
SSCS BEING INSTALLED ON A TURBOGENERATOR



PRPD PLOT

STATOR ENDWINDING VIBRATION MODULE

PD is a symptom or cause of most stator winding insulation problems. However, PD monitoring cannot detect all the aging and manufacturing issues that can lead to stator failure. In turbogenerators, the stator endwindings (that is, the portion of the coils outside of the stator slot) and their mechanical support can become loose and vibrate for the following reasons:



Aging/loosening of the endwinding support and tie structure due to mechanical aging, thermal aging and thermal expansion/contraction due to load cycling.

Poor design of the endwinding bracing system with mechanical natural frequencies close to the primary magnetic forces of rotational frequency and twice line frequency (100/120 Hz).

Abnormal operating events such as short circuits resulting in the deflection of endwinding components beyond their mechanical limits.

These factors can lead to the endwinding components vibrating relative to each other due to magnetic forces. The vibration can abrade the high voltage insulation on the coils (fretting), and may also lead to cracking of the coil/bar insulation just outside of the stator slot. In severe cases, endwinding vibration may cause the copper conductors to fatigue crack, leading to high arcing currents. Eventually, any of these issues can lead to catastrophic stator winding faults.

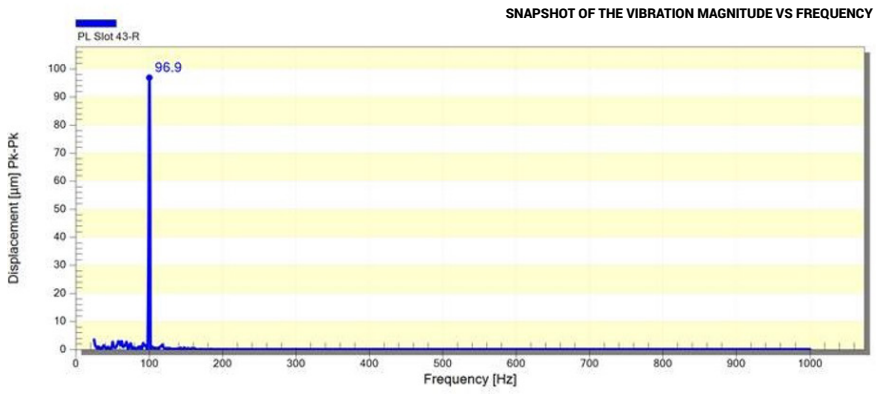
ON-LINE ENDWINDING VIBRATION MONITORING

Measuring endwinding vibration is not easy – since the coils are operating at high voltage and the high currents in the coils lead to high magnitude fields – both of which affect the operation of conventional piezo-electric vibration sensors. Worse - the grounded piezo electric sensors could lead to a ground fault. Thus Qualitrol-Iris Power developed a non-metallic fiber-optic accelerometer for this purpose.

The third generation fiber-optic sensor is called the EVAII. It meets all the requirements of endwinding vibration monitoring in IEC 60034-32, and will not affect the operation of the generator in any way. Considerable effort has been made to improve the reliability of the fiber optic accelerometers which has plagued earlier generations of sensors.

The Iris Power GuardII+ technology is a robust and cost effective continuous on-line endwinding vibration monitor that revolutionizes the detection and alarming of the presence of endwinding looseness and vibration in turboogenerator stator windings. This system simultaneously collects vibration data in parallel from up to 32 fiber optic accelerometers in real time, providing maintenance staff with a tool to trend and analyze endwinding vibration including both local and global operational deflection shapes (ODS) plots. Thus unexpected failures due to endwinding vibration can be virtually eliminated, and repairs can be implemented at much lower cost than if an in-service failure is permitted to occur.

INSTALLATION OF A FIBRE OPTIC PROBE



SNAPSHOT OF THE VIBRATION MAGNITUDE VS FREQUENCY

The Iris Power GuardII+ endwinding vibration module utilizes state-of-the-art electronics and high-speed parallel signal acquisition to process the vibration signals and display the displacement across the frequency range of interest as well as ODS plots.

Once configured, the monitor requires no user intervention, will alarm when significant vibration levels are detected, collect additional data when vibration amplitudes are rapidly increasing, and is ideal for fingerprinting and trending the vibration as the endwinding and support system loosens with aging.

SHAFT GROUNDING MODULE

Because the rotor is spinning within a magnetic field from the stator, it is possible for turbogenerator rotors to build up AC and DC voltage. Causes of voltage build-up on the rotor include:

- Potential applied to the shaft as result of rotor winding ground fault or voltage spikes from the excitation system
- Asymmetry of magnetic fields caused by design, manufacturing details, rotor winding shorted turns or by large stator core faults
- Flux generated by axially magnetized turbine and generator parts

The induced voltage on the rotor may be sufficient to breakdown the thin film of oil between ground and the rolling elements in the bearings. Such bearing discharging can pit the bearing surfaces and contaminate the lubricating oil, leading to a catastrophic bearing failure.

Many turbogenerators are equipped with shaft grounding brushes to limit the shaft voltages to a safe level, and thus preventing bearing failure.

SHAFT GROUNDING BRUSHES ON A TURBOGENERATOR

Shaft voltage and current monitoring

The purpose of shaft grounding monitoring is to indicate the presence of high levels of shaft voltage and/or measure the current flowing through the shaft brush to ground. If the shaft voltages are high, or the currents through the brush are too low, then the shaft grounding system is not performing its task, and the risk of a bearing failure increases. Shaft brush monitoring may also provide additional benefits, including:

- Avoiding unexpected mechanical failures of the bearings by identifying poorly performing brushes for replacement.
- Identifying the quality of repairs or maintenance on brushes
- Prioritizing maintenance on machines in your fleet where it is most needed

On-line shaft brush monitoring using the GuardII+ requires the permanent installation or modification of one or two voltage brushes. In addition, resistive shunts can be inserted between the shaft grounding brush(es) and ground to measure the currents from 1 or two brushes. Shaft current and voltage signals are continuously measured by the GuardII+ shaft grounding module to trend and alert when grounding maintenance is required. Installation of the voltage brushes and connection to the shaft grounding brush may require a short generator shutdown, depending on the type of the brush installed.

The trend over time of the rms and peak-to-peak shaft voltages and brush currents will indicate when shaft ground brush maintenance is required. Further diagnostics are also possible by monitoring the change in voltage and current harmonics over time.

ROTOR WINDING SHORTED TURN MODULE

Surveys of machine owners consistently indicate that rotor windings are the third most likely cause of generator failures, after mechanical and stator winding failures. For this reason, in 2004, Iris Power embarked on a major R&D program to develop better methods to warn of impending failure in rotor windings.

As with stator winding PD monitoring, the goal has been the development of tools that can be used and interpreted by plant personnel (if desired), yet still have a low risk of false indications. Although the original research focused on salient pole rotors, the technology is also applied to turbogenerator round (or high speed cylindrical) rotos.

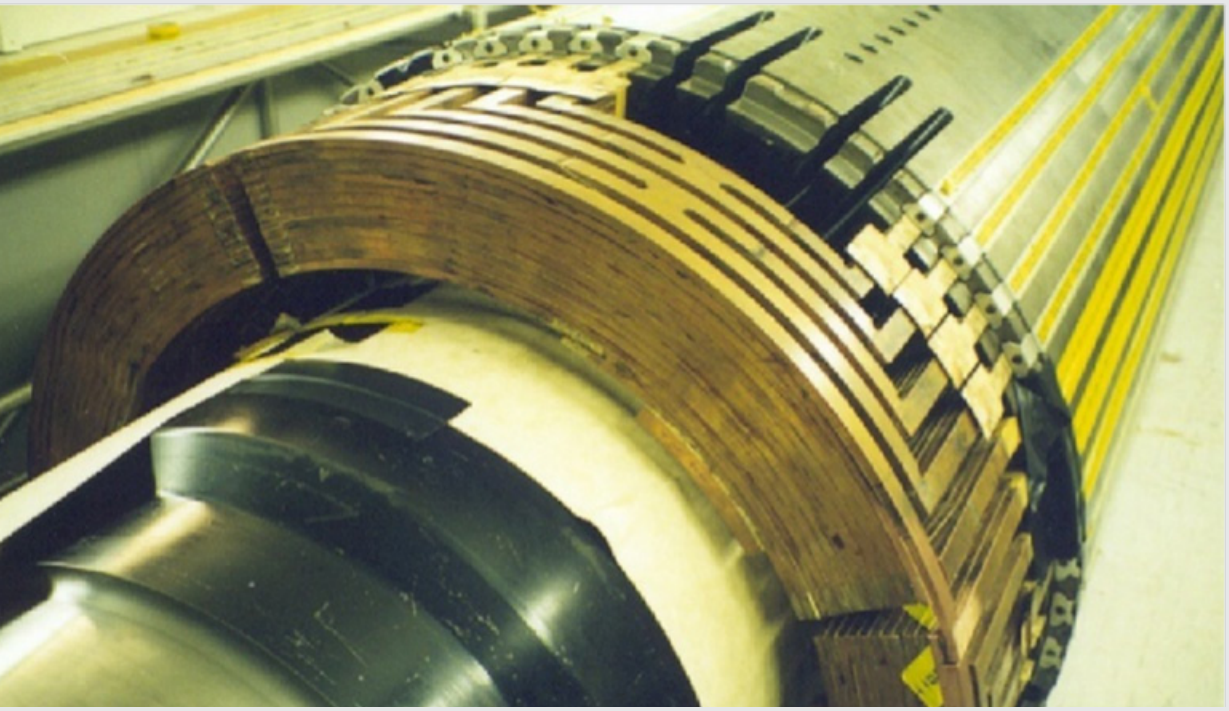
In two or four-pole cylindrical rotors, each pole consists of an assembly of insulated copper conductors that are installed in slots machined in the rotor forging. The copper conductors are insulated from one another (turn insulation), and from the rotor forging (ground insulation). The rotor winding insulation will degrade during operation due to thermal aging, rotor current cycling and/or partly conductive contamination in combination with high mechanical compression stress caused by centrifugal forces. Usually the turn insulation ages faster than the ground insulation because it is much thinner than the ground insulation, and exposed directly to both higher compression forces and higher temperatures.

Thus, more and more turns shorts are likely to occur before a ground fault occurs. Generally, turn insulation shorts on a turboogenerator will not cause operational difficulties. However, if the number and severity of turn shorts increase over time, it is an indication that general insulation aging is occurring and a ground fault may be imminent. The development of a reliable on-line method to detect the shorted turns allows operators to identify the poles (and coils) with shorts and their severity during normal operation.

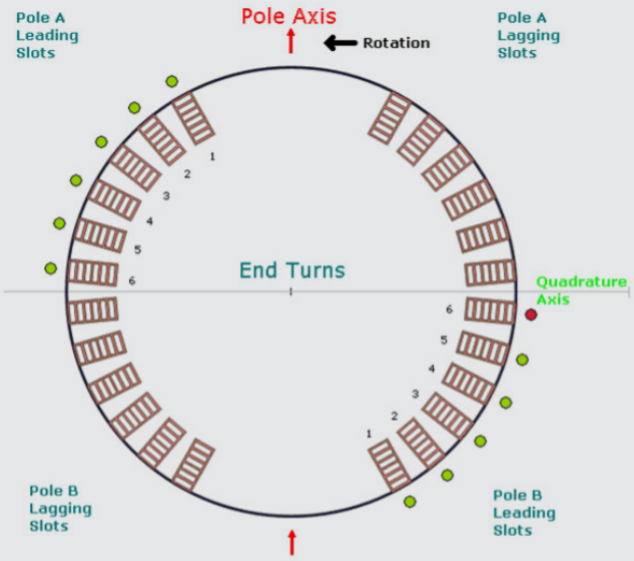
ON-LINE ROTOR FLUX MONITORING

Qualitrol-Iris Power introduced the world's first commercial on-line monitor to detect shorted turns in salient pole rotor windings in 2005. The Iris Power technology requires the measurement of the main magnetic flux in the air gap between the rotor and the stator.The magnetic flux is detected by means of a single sensor called the TF Probe™ or FF Probe™ that is permanently installed by gluing it to a stator core tooth during a suitable, short outage. The TF Probe sometimes can be retrofitted with the rotor in place. The output of the probe is a voltage that is proportional to the main magnetic flux crossing the air gap, as the rotor rotates. A reduction in magnetic flux as a pole passes the sensor implies a shorted turn may be present. The turn short detection technology may also be used with conventional leakage flux probes that are installed on the stator wedge.

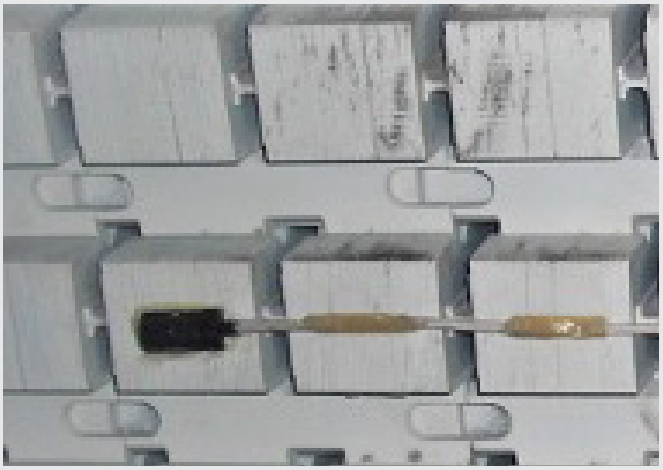
Algorithms unique to cylindrical rotors have been developed and implemented in the rotor flux module of GuardII. This module detects the perturbations in the magnetic flux caused by shorted turns. If a shaft sync signal is provided, the rotor pole containing the short can be identified. All measurements and calculations are done within the rotor flux module. The TFProbe signals can also be analyzed by means of the portable Iris Power RFA-R instrument. The GuardII+ with the rotor flux module provides plots identifying poles and coils with likely shorts. It also trends the short severity vs time, which can provide information on if the rotor ground insulation is also deteriorating, and may fail.



HIGH SPEED CYLINDRICAL ROTOR WITH ENDWINDING RETAINING RINGS REMOVED



EXAMPLE OF THE RESULT FROM ON-LINE FLUX MONITORING SHOWING A POSSIBLE SHORT ON COIL 6, POLE B



TF PROBE MOUNTED ON THE STATOR CORE

Beyond Continuous Monitoring Using GUARDII+

In addition to integrated continuous on-line monitoring of rotating machine rotor and stator windings, Qualitrol-Iris Power offers a complete selection of tools for motor and generator winding condition assessment, including:

- Portable instruments to collect and analyze the on-line PD and flux signals for those who do not wish continuous on-line monitoring
- Off-line and low-frequency on-line PD sensors and instruments
- Many tools to confirm the rotor and stator winding condition, including capacitance and dissipation factor tip-up testers, DC Ramp testers, polarization/depolarization current tester, RF corona probe tester and stator wedge tightness testers
- The EL CID low core flux tester to find damaged core lamination insulation in stators and rotors
- Stator wedge tightness tester
- Specialized courses by some of the best known motor and generator experts in the world
- Winding condition assessment studies

To support customers in the use and interpretation of the GuardII+ monitoring system, Qualitrol-Iris Power has some of the most knowledgeable tubrogenerator winding experts in the world on its staff. Iris staff have written two books on the subject (Electrical Insulation for Rotating Machines, 2nd Edition, published by Wiley/IEEE Press; and Condition Monitoring of Rotating Electrical Machines, published by the IET).

Our experts spent many years working for both turbogenerator manufacturers and utilities in the design, testing, inspection and maintenance of turbogenerator windings, and have contributed to most of the relevant IEEE, IEC, and ISO standards for turbogenerators.

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