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GUIDE FOR ON-LINE MONITORING OF TURBOGENERATORS

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GUIDE FOR ON-LINE MONITORING OF TURBOGENERATORS

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1. INTRODUCTION

In 1999 a report about “On-Line Condition Monitoring Tools for Large Turbine Generators” was prepared by WG Conveners Don Rose and Mal Park (AU) on behalf of SC A1. A short summary of this report was published in ELECTRA, No. 216, October 2004 and the whole report appeared on the SC A1 website in 2004.

As a maintenance programme that optimizes costs and maximize machines availability are two of the most important aspects to be taken into consideration by the owners of the power plants, late in 2007 it was decided to to update the previous work to the current State-of-the Art. A new questionnaire was conceived and distributed to all members of the Study Committee involved with turbo-generators (about 46 members). It was proposed to incorporate into the document the physical, mechanical and chemical parameters to be monitored and the type of devices used to measure them.

The main objective of this study, undertake by WG A1.11, was to survey actual and recommended practices for on-line monitoring and in so doing identify the best practices for maintenance procedures and strategies to follow. With this goal the new questionnaire aimed at investigating the following aspects:

a. The current use of on-line monitoring systems

b. The effectiveness of on-line monitoring systems

c. The future development of on-line monitoring systems

The questionnaire received 13 answers from 8 countries: Australia (AU), Brazil (BR), France (FR), Japan (JP) (3 answers), Romania (RO), Russia (RU), Spain (SP) and United States (US) (4 answers).

This Technical Brochure presents the results of the present work.

2. DEFINITION OF AN ON-LINE MONITORING SYSTEM FOR ROTATING MACHINES

The aim of an on-line monitoring system for electrical rotating machines is early detection and information about changing machine conditions during operation which later on may result in high wear or malfunctions. An on-line monitoring system consists of:

- Special measuring sensors located at selected components of the machine
- Signal transducers to convert the sensor signal into an information stream which is send to the measuring equipment
- Software controlled measuring device forming characteristic monitoring parameters
- Data transmission protocol and hardware to connect standard I&C
- Specialized software for monitoring, trending and analysing the measured parameters

For large rotating machines like turbo-generators different monitoring modules are combined to a supervisory control and monitoring system for condition based diagnosis and prediction.

3. GENERAL COMMENTS ABOUT ON-LINE MONITORING SYSTEM FOR LARGE TURBO-GENERATORS

Generally, on-line monitoring systems are used mainly for larger generators with a power rating above 300 MVA having direct hydrogen or water cooled windings. But there is a tendency to extend on-line monitoring also for indirect hydrogen or air cooled generators with ratings below 300 MVA. On-line monitoring is mainly applied to units with strategic importance in the utilities assets.

- Users, consultants and manufacturers of rotating machines are the most interested groups on generator monitoring systems.
- Depending on type of modular monitoring system it may be offered by measuring equipment manufacturers or by generator OEMs (Original Equipment Manufacturers). In either case they may include supervisory monitoring and diagnostics.
- The measurement of standard operation parameters, such as temperature, pressure, flow, bearing/shaft vibration and electrical parameters can be considered as the important on-line

measures for basic monitoring methods. Using additional parameters and new sensors together with intelligent measuring devices and sophisticated analysing software a supervisory on-line monitoring system that covers the important generator components can be build up in a modular structure. Together with expert knowledge it can lead to a powerful diagnostic system.

On-line monitoring systems support predictive maintenance strategy that could allow for better outage scheduling, operating flexibility, better fuel use, improved efficiency, and more efficient spare part management.

In recent years there has been an increasing number of devices for on-line monitoring of various generator parameters. Many such parameters can be cost effectively monitored today in comparison to the cost and availability of such data acquisition equipment as little as 10 or so years ago. Factors that the generator asset manager needs to consider when determining what if any on-line monitoring to place on some or all of the generators under his/her control are:

- Equipment reliability and maintenance costs.
- Benefit of increased reliability or earlier detection of impending failure.
- Cost of equipment, installation and training.
- Reduction of insurance costs.
- Future benefit of additional information for generator condition determination.
- Value of information.
- Cost of data archiving and retrieval.

The most recognized benefit of early detection of incipient faults is the major savings that could be achieved in repair costs. The purpose of monitoring is to try to prevent major catastrophic failures and turn them instead into failures that can be repaired at a reduced cost during a planned outage.

4. PARAMETERS OR COMPONENTS TO BE MONITORED AND DEVICES USED

As a result of the questionnaire the following items list all electrical, mechanical and chemical parameters to be monitored and the type of device to measure them:

4.1. Thermal decomposition of insulation materials in hydrogen or air cooled machines

Generator Condition Monitor (GCM): A device, which detects and analyses micro particles in hydrogen or air coolant to detect local thermal decomposition of insulation materials or special tagging compounds applied to machine components. It requires off-line analysis in a laboratory to identify the insulation materials or to differentiate the tagging compounds released into the coolant due to overheating.

4.2. Hydrogen leakage

- Leaking through housing, into sealing oil (bearings) or cooling water (H_2-cooler)

  Hydrogen Make-Up Rate Monitor: A device with a sensor system which determines the degree of hydrogen coolant loss corrected by operating parameter influence.

- Leaking into stator winding cooling water

  Hydrogen-Into-Water Leakage Monitor: A device to detect hydrogen in the stator winding water cooling system and measuring the rate of H_2-leakage into stator winding water coolant.

4.3. Hydrogen gas purity

Efficiency of generator operation depends on hydrogen purity because a mixture of hydrogen with water vapour, oil dust or air will raise the gas density and therefore significantly increase windage losses.

Hydrogen Purity Analyser: A device for detecting the presence of impurity gases in hydrogen coolant and measuring hydrogen content in %.

4.4. Hydrogen dew point

Moisture content in cooling gas can result in creepage discharges or break down of high voltage stator winding insulation. It may also indicate water leakages at coolers or direct water cooled windings. To control dew point temperature during start up after maintenance stand still is important because absorbed moisture may condense at cool parts of the machine and spread water droplets onto the stator winding.

Hydrogen Dew-Point Monitor: A device that measures moisture content in hydrogen coolant and expresses it as dew point. This is used as an operational / maintenance aid for ensuring hydrogen dryness and avoiding creepage discharges at wet insulation surfaces. Useful indicator for water leakages at direct water cooled rotor windings.

4.5. Stator winding temperature monitoring (AU, JP2)

The mean value of stator winding is controlled by a minimum of six slot RTD's acc. to IEC 60034. Additional slot RTD's often used at large machines due to the fact that failed sensors in the slot cannot be repaired without rewinding the stator. The temperature of all stator winding slot RTD's is monitored at the control room panel. (see also 4.7c)

The temperature of direct hydrogen or water cooled stator windings may be controlled by measuring the individual stator bar temperature. (see 4.6)

4.6. Direct hydrogen cooled stator winding

In direct gas cooled stator windings the temperature rise of hydrogen cooling gas can be measured with fiber optic temperature sensors placed at the cooling duct outlet of stator bars. Prototype installations at direct hydrogen cooled stator windings of large turbine generators (850 MVA, 21 kV) have been running for several years to get monitoring experience.

4.7. Stator winding cooling water condition

To avoid clogging of hollow conductors on direct water cooled stator windings and to detect a leakage in the cooling water system the following parameters can be measured:

(a) Water conductivity (BR)

Stator Cooling Water Conductivity Monitor: A device for monitoring the purity of stator cooling water by measuring its electrical conductivity.

(b) Dissolved oxygen (US2)

O_2-Monitor / pH-Monitor: Controls dissolved oxygen content and/or pH-value in cooling water as an indication of clogging risk or cooling water leakage.

(c) Individual stator bar temperature measurement (JP2)

Generator Temperature Analyzer (GTA): Monitors the cooling water temperature at the warm side outlet of each stator bar and correlates it with generator load, temperature and H_2-pressure to identify hollow conductor plugging. Same principle also used for direct hydrogen cooled stator windings.(see also 4.5).

4.8. Partial discharge activity at stator winding

Various monitoring systems are used to measure PD activity at stator windings and arcing effects at intermittent current connections (e.g. slot discharges, broken strands). They use different ways of detecting PD signals at the stator winding and different frequency ranges for PD measurement and analysis.

Measuring sensitivity depends on noise reduction strategies and on the capacitance value of the coupling capacitors. It can be said that the measuring sensitivity is improved, both in magnitude and number of pulses of partial discharge detected when the capacitance value of the coupling capacitors increase.

Figure 1 shows an example of a PD (at the white bands) occurring due to deterioration of the slot conductive coatings and/or the silicon carbide stress relief coatings.

Figure 1: Example of a PD (at the white bands) occurring due to deterioration of the slot conductive coatings and/or the silicon carbide stress relief coatings.

4.8.1. Coupling devices / Sensors

(a) Using existing surge capacitors and a high frequency current transformer at grounding lead as coupling device (AU)

(b) Coupling capacitors at phase insulated bus bars – one or two couplers per phase (Figure 2) (*)

(c) Coupling capacitors direct at the generator high voltage terminals (Figure 3)

(d) Coupling via transformer or additional capacitor at generator neutral connection

(e) Broad-band antenna in selected stator winding slots (Slot Coupler at line end or embedded RTD)

(f) Using insulated water manifolds of direct water cooled stator windings as an antenna for PD inside the generator

Figure 2: Coupling capacitors at phase insulated bus bars

Figure 3: Coupling capacitors direct at the generator high voltage terminals

(*) The installation and the number of couplers must take into consideration economic and technic aspects. The definition of the number of couplers is associated with the physical dimensions of the machine as the high frequency signals are attenuated along the stator windings. Then, if a great length of the winding is to be inspected a greater number of couplers must be installed. However, in the majority of the cases, in small and medium size machines, one coupler in each phase is sufficient for a good evaluation of the winding conditions.

4.8.2. PD monitoring systems

(a) Broad band PD monitor in the low frequency range of 10 kHz – 30 MHz

(b) Radio Frequency Monitor (RFM) in the MHz frequency range – narrow band or broad band system

(c) High Frequency Monitor up to a few hundred MHz

(d) Electro Magnetic Interference EMI PD spectrum measurement with a narrow band frequency analyzer

The monitor system to be used to measure the partial discharge activity depends on the capacitance of the coupling capacitors. With lower values of capacitance must be used a monitor system able to measure higher frequencies. However, as the stator winding may be considered as a long transmission line with resistance, inductance and capacitance, the attenuation of the signal increases at high frequencies making the measurement of the signals more difficult.

Thus, to establish the best coupling capacitor simulations must be done, considering some values of capacitance, and inserting signals of different frequencies at the beginning of a phase winding. These signals are captured at several points in the winding and their attenuations will allow to determine the best coupling capacitor.

4.8.3. Noise suppression methods

Although PD data can be collected using many different techniques, the important criteria for any measurement made during normal generator operation is the ability to deal with electrical interference or noise. With the machine in operation and connected to the power system, many sources of noise are present including power system corona, slip ring sparking, poor electrical connections external to the stator winding, local power tool or arc welding equipment operation, etc. All of these can generate pulses with characteristics similar to PD, which can often be orders of magnitude larger than the actual PD levels in the winding. Without techniques to eliminate these noise sources, on-line PD measurements made by a non-expert can conclude the stator winding is deteriorated, when in fact it is not. Such false indications can reduce the credibility of PD testing. Thus, it is critical that any on line measurement technique include methods to separate noise from PD.

To this end, the following methods were developed to separate the noise found in on line measurements from the pure stator winding PD signals. Thus, it became possible for on-line PD testing for machines to be performed and interpreted by plant electrical staff with minimal training or detailed understanding of PD phenomena.

(a) Phase window gating with additional noise antenna input

(b) Digital filtering in time or frequency domain

(c) PD source identification by pulse travelling time measurement

(d) Phase separation by multi-channel measurement at two or three phases in parallel

4.9. Stator end winding vibration (BR,CA)

Stator End winding Vibration Monitor: A device using piezoelectric or fiber optic accelerometers to measure and monitor end winding (overhang winding) vibration activity, which can occur as a result of loosening of the windings supports caused by operational overstressing events such as faults, switching surges and mal synchronization that could strain and relax the support structure . Most of the vibration related aging mechanisms are time dependent and are affected by the extensions of inspection periods.

The accelerometers are connected to an acoustical measurement system and a computer for analysis of the motion. Depending on the end winding parts to be monitored different sensors have to be used.

(a) Piezoelectric accelerometers: Placed at grounded bracings of end winding supports.

(b) Fiber optic sensors: Accelerometer without metal parts directly fixed to end winding coils, which may be on high potential. (Figure 4)

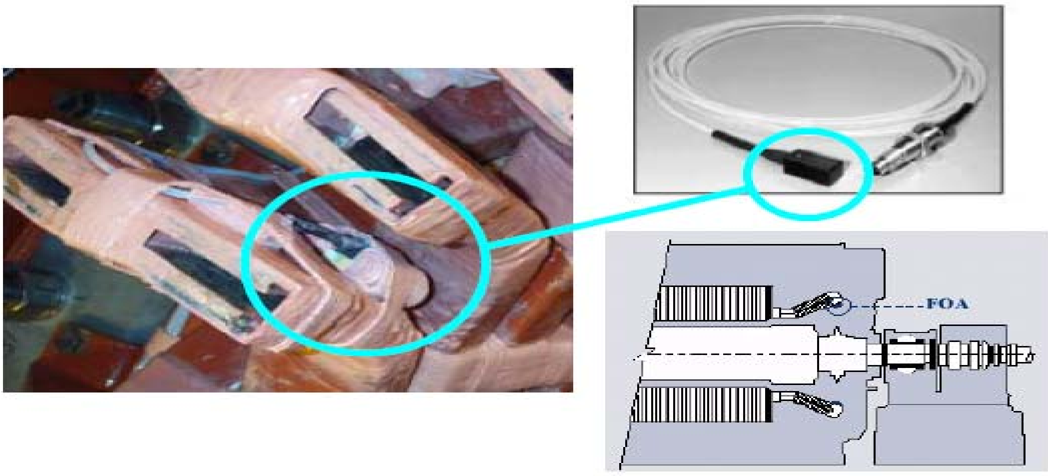

Figure 4: Fiber optical accelerometer and details of its assembly at turbo-generator stator end winding

4.10. Stator frame and core vibration (BR)

Stator Core/Frame (SCF) Vibration Monitor: A measuring device with accelerometer sensors (or similar) connected to the stator core or/and frame for vibration measurement. For example, it may detect loosening of core/frame components or structural deterioration.

4.11. Stator core lamination vibration (used only by FR)

Audio Detector - Stator Core Lamination Vibration: A device using audio frequency sensors for identifying vibration of stator core laminations caused by looseness of core pressing.

4.12. Stator bar vibration (CA)

Stator bar vibration Monitor: This is a monitoring system that uses capacitive sensors to identify problems occurring in the stator wedges which radially fix the copper windings against electromagnetic forces caused by poles passage. If wedges loose their compression power, what usually occurs after some years, vibration amplitude of the bars will increase causing friction between bar and slot and as a consequence an abrasion on conductive component of the bar and its insulation which may lead to:

a) Abrasion of semi-conductive painting and insulation drives to a drastic increase of partial discharges that destroy insulation from the inside.

b) Partial discharges weaken insulation, causing more abrasion.

c) The increase of bars vibration decrease heat exchange between bar and slot, contributing to weaken the insulation.

These sensors allow the user to plan a machine stop for new stator re-wedging and their location is shown in Figure 5.

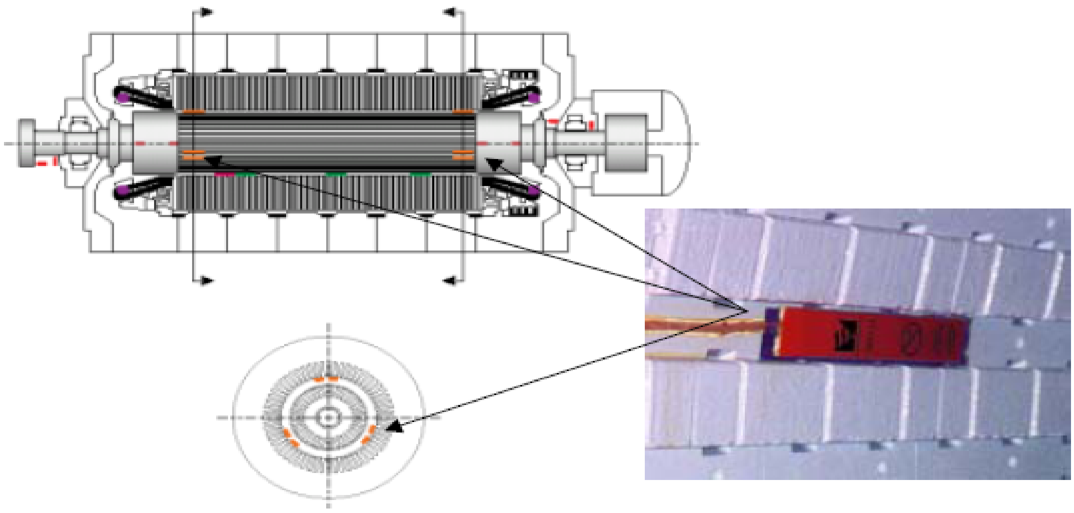

Figure 5: Location of stator bar vibration sensors

4.13. Brush condition of static excitation systems

Brush Condition Monitor: A device to measure the voltage drop between slip rings and brushes for the purpose of monitoring low resistive brush/slip ring condition. Some types of monitor may measure a wider range of parameters such as brush temperature, brush movement, electrical sparking, slip-ring surface orbit together with ambient temperature and humidity.

4.14. Diode failure at brushless excitation systems

Diode Breakdown Detector: A device for detecting failure of diodes in a machine with brushless excitation by identifying irregularities in the field flux pattern. The system has the purpose of monitoring the integrity of the rotor winding particularly in regard to over-temperature as well as the diodes themselves.

Diode Fuse Detector: If a diode of rotating rectifier fails, a fuse in series will be released by short circuit current. The monitoring device identifies the destroyed diode fuse.

4.15. Rotor winding shorted turns

Rotor Interturn Short-Circuit Monitor: A device using a small coil sensor installed at the stator core inside surface in the air gap (flux probe) that detects the radial flux density of rotor windings and records of waveform pattern of magnetic flux density by rotation. The purpose is to determine the presence of rotor winding faults (turn-to-turn shorts) from any irregularity in the induced voltage pattern at the air gap flux probe by digital comparison of flux pattern of both rotor poles. Must be used only one sensor assembled at the bottom part of the stator.

The short-circuit in the rotor can produce thermal unbalance, resulting in increased vibration levels that can be difficult to distinguish when compared to other mechanical problems. For an effective analysis, the results are combined with air gap measurements that allow correlation between flux and air gap for each pole allowing to detect if unbalance is caused by an electric failure as rotor winding faults (turn-to-turn shorts) in the pole or induced by a very small air gap. Both sensors are shown in Figure 6.

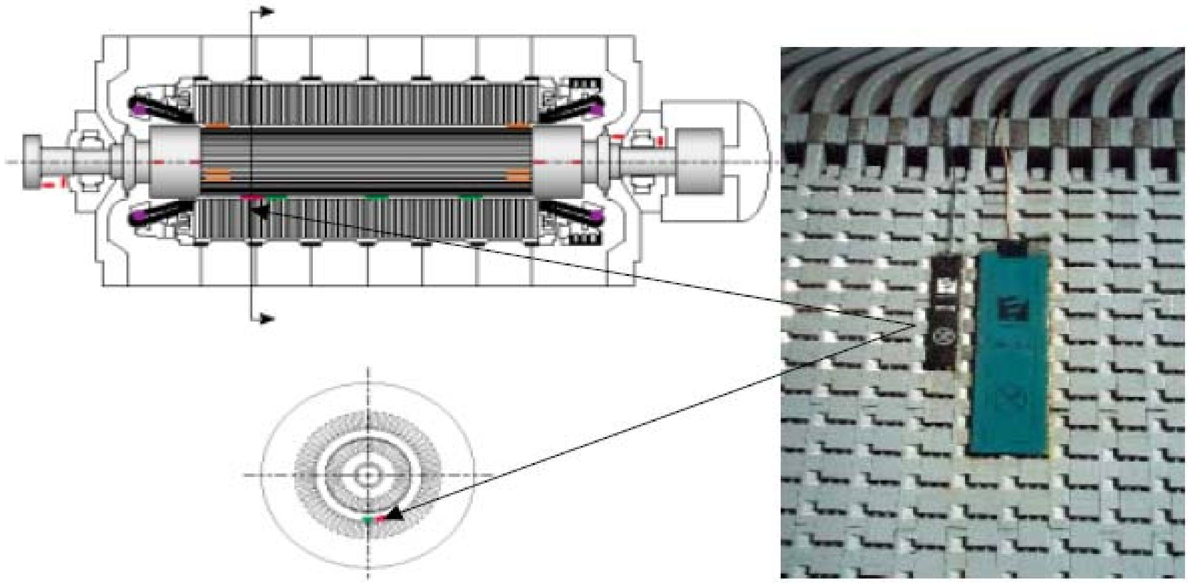

Figure 6: Flux magnetic sensor assembled together with air gap sensor

4.16. Shaft bearing vibration

Bearing Journal Vibration (ORBIT) Analyser: A system of dual probes mounted on each bearing of a turbine generator set for the purpose of diagnosing vibration problems by observing the nature and magnitude of the shaft orbit and mean position.

4.17. Rotor shaft vibration of turbo set (used only by SP)

Shaft Vibration Analyser: A system of proximity probes axially mounted all over the turbine generator set for the purpose of diagnosing vibration problems by observing the nature and magnitude of the shaft orbit and mean position.

4.18. Rotor shaft torsional oscillation (remaining life calculation) (used only by US4, FR, RU)

Shaft Torsional Oscillation Monitor: A device to evaluate shaft fatigue of turbo generator set due to sudden load changes, out of phase synchronization, electrical faults in transmission network etc. Measuring principle: change of permeability due to magnetic-strictional effect at ferromagnetic shaft material under torsional forces.

4.19. Retaining rings failures

Retaining rings failures Monitor: This device uses proximity sensors to regularly monitor the retaining rings for detection of deformations or shape irregularities. The proximity sensors use the same capacitive technology of the stator bar vibration detectors, and are immune to all interferences existing in the area, such as dust, oil, humidity, radio-frequency and electromagnetic.

Retaining rings that are used to repress the centrifugal force at rotor windings end are the more stressed components of a generator and so require extreme care in the project as well as in manufacturing and maintenance. In body-shaped rings can occur a high current circulation during unbalance conditions, driving to damages caused by heat excess. In spindle-mounted rings, they allow a flexibility between the rotor body and the ring, that can drive to insulation failures and cracking the coils in this area, resulting in a very dangerous condition in machines with frequent load cycles and run-up/run-down proceedings.

Figure 7 shows the consequences of a failure in a retaining ring and Figure 8 the location of the capacitive proximity sensors.

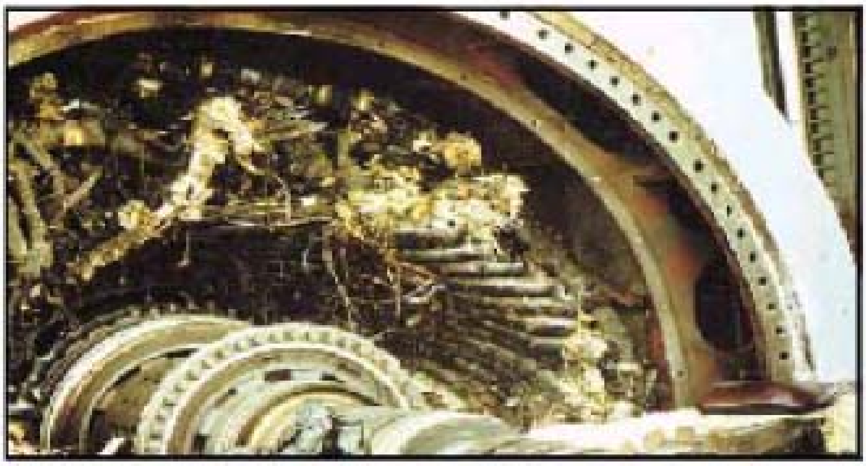

Figure 7: Consequences of a failure in a retaining ring

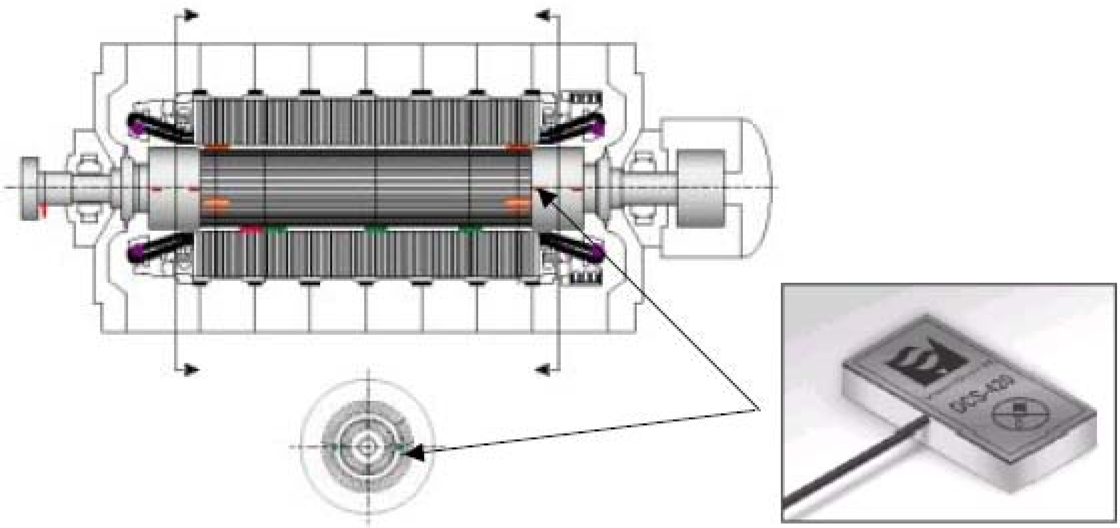

Figure 8: Capacitive proximity sensor to measure retaining rings deformations

4.20. Shaft Torsional Oscillation Monitor:

A device to evaluate shaft fatigue of turbo generator set due to sudden load changes, out of phase synchronization, electrical faults in transmission network etc. Measuring principle: change of permeability due to magnetic-strictional effect at ferromagnetic shaft material under torsional forces.

4.21. Shaft voltage / grounding (AU, SP, US4, FR, RU)

The purpose is to detect any loss of permanent low resistive shaft grounding or loss of integrity in shaft insulation at bearings and exciter set, which can result in bearing babbitt damage due to discharge erosion in soft metals used in the bearing.

(a) *Shaft Grounding Monitor* (US4, FR, RU): A instrument that measures shaft voltages and currents associated with the machine-grounding device.

(b) Shaft Voltage Monitor (AU, SP): A device that controls shaft voltage only. Discharge spikes or reduction of voltage indicate bad shaft insulation.

Other devices that were suggested were:
- I) Rotor Earth Fault Monitor (AU). This is a generator protection device and not a monitoring system and should therefore be skipped
- II) Digital Fault Recording (CA). These systems collect data from many other systems and sensors and preserve data for evaluation in case of generator faults.

5. TYPES OF MONITORING SYSTEMS AND INTERPRETATION OF INFORMATION

Depending on the monitoring device used for on-line measurement and depending on the amount of investment which correlates in most cases with the strategic importance of the unit the following types of monitoring systems are used:

(1) Individual devices or systems installed for each type of possible failure risk to be monitored (used by US1. US2, JP1-3, AU, BR, RO, SP)

(2) Integrated monitoring systems, sometimes having a diagnostic shell, which combine different on-line monitoring modules for a number of different possible failures (used by US1, US2, JP1, JP2, AU, BR, RU, SP)

The design concept of the on-line monitoring systems being used can be categorised as follows:

1. ***display*** the values or the deviations of the surveyed parameters (used by US1- 3, JP1- 3, RU, RO, SP, US 1,2,3,4).
2. ***analyse*** the measured parameters using a technical rule base and generate warnings or alarms about the possibility of a failure to appear (used by RU, US 1234, JP 23, RO, AU, SP).
3. use a ***diagnostic*** knowledge base to perform a prediction of the condition generator or component and display it periodically (used by AU, RO, RU, BR, US 1, JP3).

The information being recorded by data acquisition of the monitoring system is interpreted by:

- Experienced operator
- Specialized personnel like expert/advisory engineers at plant or headquarter
- Technical managers
- Dedicated diagnostic software based on artificial intelligence and knowledge based expert systems (majority)

The distributed systems for a single type of failure are considered more efficient. The system has to permit the connection of different types of signals and the addition of new algorithms for control and diagnosis.

The on-line diagnostic systems performing rule-based predictions and displaying them periodically (trending) are in development for many years. Nevertheless, some believe that the results of automated diagnostic systems should always be cross checked by human experts before actions will be taken at the operating machine.

When the monitoring information is processed by a dedicated diagnostic software, some countries recommended the information be analysed by the specialists in the remote diagnostic center of generator OEM or supplier of monitoring systems, too.

6. OPERATIONAL VALUE AND ALARMS

Information supplied by the monitoring systems is taken into account for adopting intervention decisions or for operational decisions (majority, except US 2,3).

When an alarm appears, decision is made taking into account the possible implications, by: exploitation operator, specialized personnel, technical managers, dedicated software (majority).

7. BENEFITS OF USING ON-LINE MONITORING SYSTEMS

The following benefits of using on-line monitoring systems were mentioned:

- Reduction in off-line testing (only RU, BR, AU, US1)
- Change from time based maintenance to condition based maintenance
- Better management of maintenance
- Improvement in accuracy of diagnosis
- Increase in unit life (only RU, BR, US1)
- Reduction in forced outages
- Prevention of failures
- Better evaluation of operational risk

Comments about the advantages / disadvantages of on-line monitoring systems were given as follows:

Advantages

- advantages are felt in short and long term and during all the equipment life time (BR)
- very accurate results in maintenance stops, reduction in machine stop time, accurate diagnostic, discerning analyses, facilitate information crossing over, easiness in field tests and in commissioning of generating units, as well as on-line evaluation (BR).
- the systems allow the recognition of the fast developing faults, such as the optimal operational regimes can be used till the generator will stop or (and) be repaired (RU).

Disadvantages

- The systems do not allow recognition of the slowly developing faults, in insulation for example, and could not completely replace the inspection at stopped generator (RU).
- There is the risk that the operator be less watchfull, while attempting an alarm signal of the on-line monitoring system. Normally, the operator has to pay attention to the operating parameters all the time. This monitoring equipment must be accurate, reliable, dependable, believable, and trusted (US3).
- Any failure of the instrumentation can produce un-adverted trips or erroneous data analysis (SP).
- The faults of the monitoring systems may lead to the premature stop of the generating unit. Interpretation must be done by specialized personnel, by watching the trends of the data, based on prior experience. The interpretations by different specialists may offer different recommendations. (AU, JP1)

8. FUTURE DEVELOPMENT OF ON-LINE MONITORING SYSTEMS

The given answers at the questionnaire show the following direction in future development of generator on-line monitoring systems.

8.1. Adapted on-line monitoring for all types of generators

It is considered that on-line monitoring systems should be extended to all generators, depending on power, type or size (exception AU, JP1,3)

On-line monitoring may be more justifiable for ‘always-on’ machines producing the larger proportion of the portfolio’s energy (AU).

The small generators could be equipped by simple on-line systems because their stops could be cheaper than the expensive on-line system installation. As for the generators of 100 MW and higher the modern on-line monitoring systems should be installed and operated (RU).

At the small machines a minimum number of parameters has to be monitored (SP, JP3).

The extension of the on-line monitoring at the small machines has to be made depending on the performance, the costs, and the risk of the individual generator (JP1).

All generators could benefit from on-line monitoring. However, the selection of the sensors and monitored parameters have to be based upon value of the investment, in connection with generator size and type, as well as the operational scenario expected for the unit (US4).

8.2. Costs of on-line monitoring system versus benefit

The costs can be justified for the on-line monitoring systems. Justification is dependent on criticality and risk for each case. Prevent one failure and the cost is returned (AU).

Avoiding one failure can justify the monitoring costs for a whole fleet of generators (US1)

Although the costs are justifiable, the generators owners consider they aren't (RO).

These systems can protect the generators against operator's errors and can avoid the imminent problems of the generators (US4).

Need to improve accuracy and to reduce cost so that we may newly introduce the on-line (JP1)

If the maintenance policy is periodic inspection and preventive maintenance, the costs may be high (JP3).

Generally, at least the investment of monitoring instrumentation is recovered by the optimization of outages and by the reduction of failures and the damages.

It should be necessary to evaluate the type of monitoring depending on the size and importance of the generator (SP).

8.3. Can on-line monitoring provide sufficient information for generator condition assessment?

Referring if the present systems provide sufficient information for generator condition assessment, the opinions are different. A part of answers considers the information is enough and other part considers that it is not enough.

Problems such as looseness in the stator winding overhang, loose slot wedges, migration of rotor insulation can only be identified through visual inspection (AU).

Deteriorating conditions can be picked up by vibration of stator end windings and rotor, partial discharge in high voltage stator coils, rotor short circuit detectors etc. that would help prepare for upcoming outages. Predicting final life of a component is still difficult with any accuracy (US4).

The systems can be improved and new systems can be developed, based upon new principles. For example, a monitoring system watching over the shaft torsional oscillation may prevent events such as shaft breaking, together with the generator destruction (RO).

User's needs are to improve the accuracy further and to estimate the equipment life (JP1).

Present system provides information only after the trouble occurred, and does not provide warning level alarm of initial fault. For example, the core monitor indicates after the core was burned. PD monitor does not provides life prediction (JP3).

There is no incentive for supplier of individual system to integrate with other providers (US2).

8.4. Open issues of existing on-line monitoring systems

It is considered that individual generator components, some operational stresses or failure mechanisms are not covered by the actual on-line monitoring systems and improved systems have to be developed.

Continuous on line monitoring of PD at line terminals with correct bandwidth and sensitivity and a reasonably priced end-winding vibration monitoring (AU).

Monitoring system for water penetration into stator winding insulation at direct water cooled stator windings of large turbine generators (FR).

On-line monitoring of incipient core lamination shorts in addition to maintenance tests (US2).

The negative sequence a bit more closely due to overloading the transmission lines as a result of deregulation and profit taking (US3).

Deformation of stator frame, deformation of cross-arm (BR).

Rotor shaft voltage, stator core not large defects, local overheating of stator and field turns due to the cooling decreasing, cracks in the field turns (RU).

Integrate systems to watch over all the vital components of the generators, their stresses and possible failures (RO).

Electrical insulation on the whole and locally (in the slots, in the end zones, at the exit from slots) (JP1).

If life evaluation by stator coil PD monitoring come to realization, time management of stator coil will make remarkable progress (JP3). On the other hand world wide basic research work of the last 30 years on acceptable correlation between PD activity or PD pulse pattern analysis and operational life time of stator winding insulation system has not lead to real success.

9. OTHER COMMENTS

a) Integration among the measures and informations provided by the protection, control and supervisory systems, regulation, auxiliaries systems and the monitoring and diagnosis systems must be evaluated visualizing friendly and reliable interfaces, taking into consideration the interaction of these systems in accordance with the capacity of the power plant (BR).

b) The available tools in the manufacturers monitoring systems will have to be friendly among them and among known communication protocols and following IEC standards (BR).

c) Monitoring systems specific standards should be created during the phases of its development, project, prototype, platform tests, calibration, assembly and operation (BR).

d) Supervision and management of data generated by the monitoring systems must be better evaluated taking into consideration backup, size, tags, consistency and life time (BR).

e) The sampling time, due to the frequency in which the sensors are read, for each surveyed parameter, as well as the sensors capacities must be evaluated and become standardized (BR).

f) The integration of the monitoring system should be better evaluated with regard to (BR):

- the architecture and applicability of the system;
- the management of data base;
- the utilization of dual servers;
- the availabilities in corporative nets and in the web;
- the security of information;
- the executive project to take care of specific customers in agreement with the power plant size;
- the basic and executive model of technical specifications for system acquisition.

g) Upgrade of the systems in development, operation guarantees, and after guarantees must be better evaluated (BR).

h) Comparison tables of all integrated systems among manufacturers have to be presented (BR).

i) The sonorous monitoring systems must be implanted in integrated systems in accordance with the capacity of the power plants (BR).

j) The application of monitoring net of stator and rotor temperatures, heat exchanger, cold air, hot air, pressure and water outflow of the heat exchangers must be evaluated (BR).

10. CONCLUSIONS

The questionnaire has once more proved the world wide opinion that on-line monitoring systems are very useful tool to increase availability of the generator and to reduce maintenance time. Under this view their installation and operational costs are justified.

On-line monitoring can be considered as a risk mitigation tool. It can give an inestimable knowledge about the machines, that allow utilities take the right decisions about maintenance based on the actual generation equipment conditions, instead of the traditional time based approach to maintenance.

Machine age has been shown not to be the determining factor for winding condition. More modern windings do not necessarily have more reliable insulation, implying that time-based maintenance practices may not be optimal for new large machines.

The time to winding failure is normally the result of a deteriorated winding being subjected to an extreme stress such as a lightning strike, out-of-phase synchronization, excessive starts, or system imbalance. As these events are unpredictable, it is impossible to forecast when a failure will occur. However, by monitoring the PD characteristics of a stator winding, it is often possible to determine which machines are more susceptible to failure and therefore which require predictive maintenance.

On-line monitoring systems support predictive maintenance strategy that could allow for better outage scheduling, operating flexibility, better fuel use, improved efficiency, and more efficient spare part management.

Considerable experience from units with continuous monitoring shows that there can be significant benefits for the plant operator. One of the key benefits is that misinterpretation of the measurement data, which can lead to unnecessary and costly downtime of the unit, can be avoided.

Utilisation range has to be analysed in connection with the position and utility of the generator inside the network.

All kinds of on-line monitoring systems will develop in the future and they will trend to integrated systems with a supervisory software shell including different monitoring modules individually chosen by the user. Modern generator monitoring systems include diagnosis and prediction functions together with online access to the remote expert diagnostic center of OEM (Original Equipment Manufacturer).

11. REFERENCES

[1] Fruth, B., Fuhr, J., “Partial Discharge Pattern Recognition – A Tool for Diagnosis and Monitoring of Aging”, CIGRE 1990, Paper 15/33-12.

[2] Stone, G.C., Flyles, Braun, J.M., Kaul, C.L., “A Thermal Cycling Type Test for Generator Stator Winding Insulation”, IEEE Transactions on Energy Conversion, Volume 6, No. 4, Dec. 1991, pp 707 – 713.

[3] Krivda, A., “Automated Recognition of Partial Discharges”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 2, No, 5, October 1995.

[4] Zhu, H., Green, V., Sasic, M. and Halliburton, S., “Increased Sensitivity of Capacitive Couplers for In-service PD Measurement in Rotating Machines”, IEEE Transactions on Energy Conversion, Vol. 14, No 4, December 1999.

[5] Stone, G.C., Boulter, E.A., Culbert, I., Dhirani, H., “Electrical Insulation for Rotating Machines – Design, Evaluation, Aging, Testing and Repair”, John Wiley and Sons, Inc., Publication, 2004.

[6] Hudon, C., Belec, M., “Partial Discharge Signal Interpretation for Generator Diagnostics”, IEEE Trans. on Dielect. and Electr. Insul., Vol 12, No.2, April 2005, pages 297 – 319.

[7] Wendel C., Stephan, C-E, Peters, M., Stein, R., Joho, R., “Automatic PD Pattern Evaluation, as Part of a Condition Based Maintenance Strategy”, CIGRE 2006, Paper A1-213.

[8] A New Conception on on-Line Monitoring and Diagnose of Turbogenerators, Vibrosystm.

[9] Junior, Helio P.A., Levy, A. F.S., Carvalho, A.T., “Estudo sobre a Influência dos Acopladores Capacitivos na Sensibilidade da Medição de Descargas Parciais em Máquinas Elétricas Rotativas”, XX SNPTEE, 22 – 25 Novembro, 2009, Recife, Brasil.

[10] Stone, G.C., “Analysis of Stator Winding Partial Discharge Activity and the Correlation with Insulation Condition”, Seminar on State of the Art in on-Line Monitoring Systems Applied to Rotating Machines”, November, 2009, Brasilia, Brazil.