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State of the Art and Capacity for Robotic Inspection of Turbogenerators

Working Group
A1.23

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Members

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TABLE OF ABBREVIATIONS

CBM	Condition Based Maintenance
CRR	Coil Retaining Ring
ECI	Eddy Current Inspection
ISI	In-Situ Inspection
LAI	Limited Access Inspections
NDE	Non Destructive Evaluation
OEM	Original Equipment Manufacturer
RAC	Remote Access Camera
RIV	Robotic Inspection Vehicle
SCC	Stress Corrosion Cracking
UI	Ultrasonic Inspection

1. EXECUTIVE SUMMARY

Lifetime extension, outage optimization and outage reduction are key objectives for managers of large power plants in liberalized electricity markets. To achieve these goals, critical components such as generators, turbines, boilers and pressure lines have to undergo condition and risk assessment on a continuous basis.

The pressure to maintain low prices while delivering high reliability is forcing utilities to find ways to leverage the most out of their existing generator asset base. Limited resources and the need to focus on prioritized needs is undermining the traditional time based approach to maintenance. Utilities are exploring condition based maintenance and implementation of a preventive/predictive approach using various diagnostic, on-line monitoring and data logging techniques. This has opened up space for new options.

Now there are inspection robots that are able to assess the condition of important components in a fraction of the time as humans, and much more precisely. Thanks to advances in miniaturization, robots are now able to crawl their way into the tiniest structures, and can provide measurement data and video images or treat surfaces in environments long inaccessible to humans.

Another huge advantage of robotic inspection is the fact that they are insensitive to heat, dirt and other adverse conditions. This makes work much safer for the people involved. In short, inspection robots constitute a disruptive technology that massively enhances the competitiveness of service providers in the power generation business.

In-Situ Inspections (ISIs) with the aid of robots provide assessment capability of some generator components without rotor removal. For more than two decades the ISIs has provided steam, gas and nuclear plants with an invaluable robotic tool for strategic outage planning and preventive maintenance.

The ISIs allows the updating of the traditional maintenance system used in rotating electrical machine, in which the rotors are removed for the inspection of the machine.

Working Group task was, with basis on the answers received from the Users in making in-situ maintenance inspections by robots developed by OEMs (Original Equipment Manufacturers), formulate conclusions and recommendations about the experience, so far, obtained with the use of this leading edge technology.

2. METHODOLOGY

Following CIGRE's tradition the data of turbogenerators and power plants were collected by means of a survey made through a questionnaire. Thus, the first task was to establish the questionnaire, get comments from the interested parties and define the final version of the document that was distributed asking for contributions and obtaining information about:

- Lists of turbogenerators covered by the experience of responders, with a brief explanation of relevant manufacturing technologies;
- Effectiveness and limits of different investigation techniques.

The answers to the questionnaire allowed to draw up interesting comparative analyses on different aspects related to this leading-edge technology and to appraisal how has been the Users' experience with robotic inspections and what are their perceptions about the possible advantages versus disadvantages, if any, of adopting this new maintenance system.
Conclusions are presented based on the experience, until now, acquired with robotic inspection by OEMs and Users.

3. DESCRIPTION OF THE TECHNICAL BROCHURE

The present Technical Brochure (TB) is divided in several parts, as follows:

a. Equipment Condition Assessment
b. Considerations about In-Situ Inspection
c. In-situ Inspection Technologies
d. An overview on some current robotic systems
e. Questionnaire answers
f. Conclusions
g. Annexes

4. EQUIPMENT CONDITION ASSESSMENT

There are four methods to determine generators condition assessment:

- Planned maintenance
- Predictive maintenance
- Condition based maintenance
- In-situ inspections

Planned maintenance is based on experience acquired during many years of operation, on the reliability of the equipment, as well as on load demands, weather, personnel availability, coordination with other plants of the same utility. It can be considered to have the lowest cost regarding maintenance procedures, but of high risk for the safety operation of the machine.

Predictive maintenance is based mainly on statistical calculations for programming the schedule of the maintenance. Calculations take into account parameters such as mean time to failure (MTTF) of critical components, e.g. age of the insulation components, and type of insulation (insulation systems), load cycles, and abnormal operation events. It is important to recognize that predictive maintenance, together with planned maintenance, cannot determine in most cases the optimal time to inspect, maintain, and refurbish a specific piece of equipment, in particular something as complex as a large turbogenerator. Planned and/or predictive maintenance has proved to be adequate over many years of operation.

Condition based maintenance (CBM) allows to guide station personnel in determining when to inspect, maintain, and refurbish a generator and other plant equipment. As the name indicates, CBM operations follow a concrete need by a component or apparatus to be refurbished. CBM can only be applied when equipment is monitored by a number of on-line, real-time sensors, as well as offline periodic testing routines. Although requiring an initial higher capital investment in instrumentation, CBM is perceived as providing, in the long run, a more reliable and less expensive operation.

However, there may be problems in the generator, as shown in chapter 5, that are not detected by a Condition-Based Maintenance (CBM) program, through on-line monitoring and diagnostic techniques, unless in-situ inspection supplements the capabilities of on-line monitoring and diagnostics to reduce the risk of a failure.

5. CONSIDERATIONS ABOUT IN-SITU INSPECTIONS

Visual and quantitative inspection techniques play an important role in assessing generator condition. On-line monitoring and diagnostic techniques are limited in detecting potential problems, such as bar movement and vibration, component damage, copper dusting, coil distortion and foreign object damage. Many of these conditions could lead to a major failure of the equipment if left unresolved for a period of time. It is in these areas that in-situ inspection supplements the capabilities of on-line monitoring and diagnostics to reduce the risk of a failure.

In-situ inspection should be used during minor outages as a tool for assessing the generator condition. The inspection results can be used to help plan the generator maintenance at future outages. This information can be used to determine if the rotor will need to be pulled and what components will require maintenance at this or future outages. As long as the generator condition is found acceptable, there would be no additional need to pull the rotor. In-situ inspection techniques can also be used with traditional inspection and tests to provide a complete “major” inspection without rotor removal.

In cases where known generator problems exist, periodic in-situ inspection may allow postponement of rotor removal to a more convenient time by monitoring the problem and minimizing the risk of an in-service failure and resulting damage.

In-situ inspection allows the owner to acquire high quality condition assessment data which minimizes the risk of failures and costs. By lowering the cost, more frequent inspections can be realized, which can facilitate early problem detection and resolution. As a result the cost of maintenance and the equipment reliability are both improved.

6. IN-SITU INSPECTION TECHNOLOGIES

The power generation industry is undergoing major changes requiring power producers, OEMs and insurers to adapt. One way manufacturers have responded to these market changes is through the development of tools that enable in-situ inspections of generators. In-situ inspection offers an acceptable, low cost alternative to traditional field out inspection. The basic systems used to provide the in-situ inspection are:

- Visual Inspection by Robot
- Robot for Stator Wedge Tightness Assessment
- Robot for Detecting Damaged Core Insulation
- Visual Inspection by Remote Access Camera (RAC)
- Stator Capacitance Mapping
- Retaining Ring Scanner

6.1. Visual Inspection by Robot

Visual inspection of the generator is performed by a trained specialist using an inspection robot and can be complemented by a remote access camera (see item 6.4). The robot is a precision crawler carrying two high resolution video cameras that move through the gap between the stator core and rotor. The high resolution video cameras provides the specialist with a clear view of the stator core laminations, stator wedges, field wedges and surface on the inboard ends of the retaining rings.

6.2. Robot for Stator Wedge Tightness Assessment

The Stator Wedge Tightness Assessment may be evaluated using the robot. This test is performed to accurately quantify stator wedge tightness and is used to assess the need for wedge tightening or replacement. Loose wedges and the resulting stator winding movement can cause the insulation of the winding to wear and fret against the stator core iron, causing a premature stator winding damage and failure. A “tight” stator winding can last two or three times as long as a winding that is not firmly held in the stator core. The report’s data can be used for accurate trending of the winding condition and for determining when repairs are needed.

6.3. Visual Inspection by Robot for Detecting Damaged Insulation in the Core

A robot accessory can detect accurately and economically the condition of the stator core lamination insulation. Damaged insulation can result in circulating currents that can lead to core overheating and stator damage or even failure. This evaluation has been proven to be especially valuable on machines where core loosening has been more prevalent.

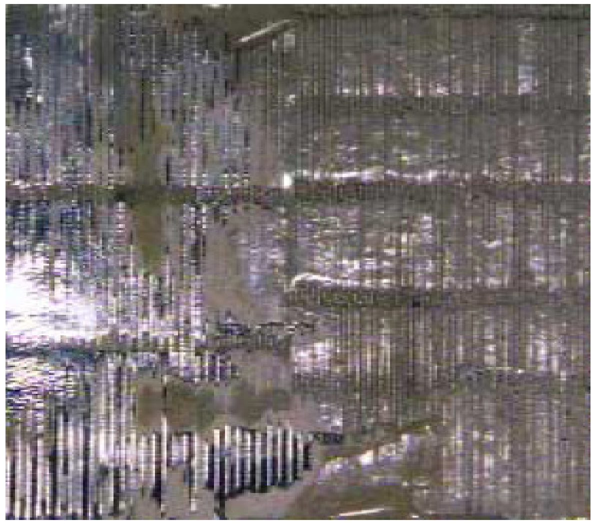

Figure1: Core melting as a result of insulation damage

6.4. Visual Inspection by Remote Access Camera

The RAC is used to perform visual inspection of normally inaccessible areas on the generator. The RAC inspection is an option to Robot visual inspection. It makes use of a miniaturized, remotely actuated video camera to provide a high resolution visual inspection of normally inaccessible areas in the generator, outside of the bore region. These areas include the stator endings; field coil ends turns and stator high voltage terminal connections. This information is combined with that provided by the Robot visual inspection to provide the most through visual inspection possible with the rotor in place.

6.5. Stator Capacitance Mapping

On generators with liquid cooled stator windings/bars a stator capacitance mapping test of the windings/bars is performed. This test requires placing a conductive electrode on the surface of the stator winding/bar groundwall insulation at the location where the winding/bar exits the core slot. A meter is used to measure the capacitance across the insulation between the electrode and the stator winding/bar. Each winding/bar is measured on both ends of the core and statistics analysis is used to identify those windings with higher than normal expected capacitance. High capacitance is a good indicator of moisture in the insulation and has been used successfully to detect stator windings/bars with deteriorated groundwall insulation due to water leaks. Recently was developed a tool enabling the capacitance test to be performed without removing the field from the stator. This tool uses an inflatable electrode, similar to that used with the field removed, and a remote actuator arm for locating the probe. A remote access camera is also used for positioning the probe and identifying its location. This system is being used successfully and provides results similar to those obtained during field out inspections.

6.6. Retaining Ring Scanner

Stress corrosion cracking (SCC) of 18Mn-5Cr retaining rings is a well documented industry-wide concern for generator maintenance. SCC develops on the surface of the material in the presence of moisture and stress, mainly in the retaining ring inner diameter (ID) due to stress concentration and geometry which tends to hold moisture. The initiation time of the cracks is quite long, in general. Nevertheless, once the crack has initiated, crack growth can be quite rapid. The high crack growth rates limit the application of Nondestructive Evaluation (NDE: A technique used for probing and sensing material structure and properties without causing damage) for crack detection. No effort is made to size the cracks once they are detected. Repair or replacement actions are initiated once a crack is detected.
One solution consists on replacing the 18Mn-5Cr alloy by the improved 18Mn-18Cr alloy which has not been susceptible to SCC.

However, for customers who periodically inspect and repair retaining rings, a miniaturized scanner assembly which performs Ultrasonic Inspection (UI) of ring inner diameter (ID) and Eddy Current Inspection (ECI) of ring outer diameter (OD), without removing the field from the stator, can detect corrosion cracking.

7. MANUFACTURERS

There are some manufactures in the market that have developed robotic systems for inspection in turbogenerators. The manufactures that answered the present survey are here designated by the letters A, B, C and D.
Each manufacturer has a specific name for its robotic system. In general, the tasks that the systems are able to perform are somewhat similar and describe each system.

7.1 Manufacturer A: Magic System

The MAGIC SYSTEM consists of Miniature Air Gap Inspection Crawler (MAGIC) Robot, which can be used in turbogenerators with air gap as narrow as 6.35 mm (0.25 inches) to perform robotic inspections for the complete range of small industrial and gas turbine generators, as well as for the large fossil and nuclear driven generators. All MAGIC inspections include a detailed visual examination of some critical areas. For generators with as long as the retaining ring-to-stator entrance gaps greater than 12,7 mm (0,50 inches) MAGIC can also perform stator wedge tightness assessments and core insulation inspections (EL- CID), regardless of manufacturer.

Coupled with other in-situ inspection systems such as remote access camera, retaining ring scanner and stator capacitance mapping, is possible, with a robotic inspection, to evaluate the generator components condition and provide a detailed assessment with minimum disassembly without rotor removal.

7.1.1. Benefits include:

- Reduced inspection cost
- In-situ inspection technologies enable generator testing and inspection while the rotor remains in place
- Early problem detection
- Less risk of collateral damage from disassembly/reassembly
- Reduced inspection time to more than 33% of the inspection time with the field removed
- More time between field pulls
- Periodic monitoring of known conditions

7.1.2. Features

- The MAGIC robot is a precision crawler carrying two high resolution video cameras that move through the gap between the stator core and field, providing visual inspection via digital recordings and still photo documentation is made available to supplement the detailed generator condition report.
- It also evaluates wedge tightness. Test results are used to generate a “wedge tightness map, which clearly shows the wedge tightness within the generator.
- Electromagnetic core insulation damage (EL-CID) can also be detected by the Magic Robot.
- It can be used in turbogenerators with air gap as narrow as 6.35 mm (0.25 inches).
- For generators with the retaining ring-to-stator entrance gaps greater than 12,7 mm (0,50 inches), MAGIC can also perform stator wedge tightness assessments and core insulation inspections (EL- CID), regardless of manufacturer.

Figure 2: MAGIC System

7.2. Manufacturer B: FAST Gen V Inspection System

FAST Gen V technology developed in the 1980´s, has been providing power plant operators with cost effective on-site generator inspections services for over two decades.

A FAST Gen V inspection can be performed in a short scheduled outage, saving approximately one-half of the traditional generator inspection time. It may also considerably reduce the overall time and costs of the outage.

7.2.1. Benefits include:

- Proactive planning of generator maintenance using inspection data for assessments, trending, predictions, and recommendations for future maintenance and unit reliability
- Reduced inspection time of up to 50% due to minimal disassembly
- Increased accuracy and thoroughness of inspection due do powerful digital visual imaging and enhanced capabilities
- Narrated video by experienced generator specialist
- Easy-to-analyze graphical results in a computerized report format
- In-situ technique avoids removing and reinstalling the rotor just performs an inspections and potential associated handling risks.

7.2.2. Features

The FAST Gen V generator inspection service offers expanded capabilities and new flexibility:

- Computer operated, precision robotic system with digital data format
- Carriage design allows manual extraction if required
- Flexible visual system that includes high definition miniature color cameras for video and still images, and brighter, shock proof, solid state illumination
- Completely resigned drive system fits air gaps as small as 20 mm (0.75 in).
- Faster drive speed – four times the torque of FAST Gen III inspection carriage.
- Immediate diagnostic results available on-site for interpretation with off-site service engineering assessment.

This leading edge technology can significantly reduce forced outage time and the predictive maintenance approach can impact future major outages. Inspections can be performed on others OEM generators on a case-by-case basis.

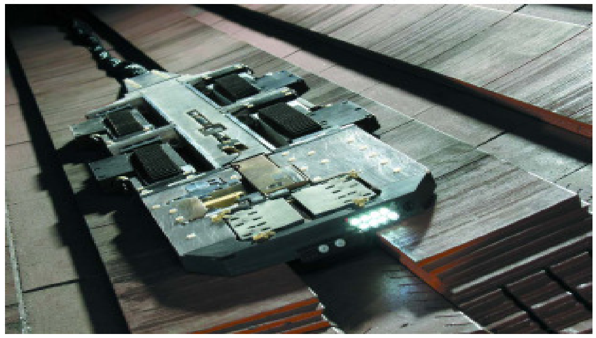

Figure 3: The Wedge Tightness Carriage inspects tightness of the stator wedges with the rotor in-situ or removed, digitally mapping them for non-subjective analysis

Figure 4: A FAST Gen V generator specialist conducts stator, rotor and wedge inspections conveniently on site, featuring narrated video taping plus high resolution photos

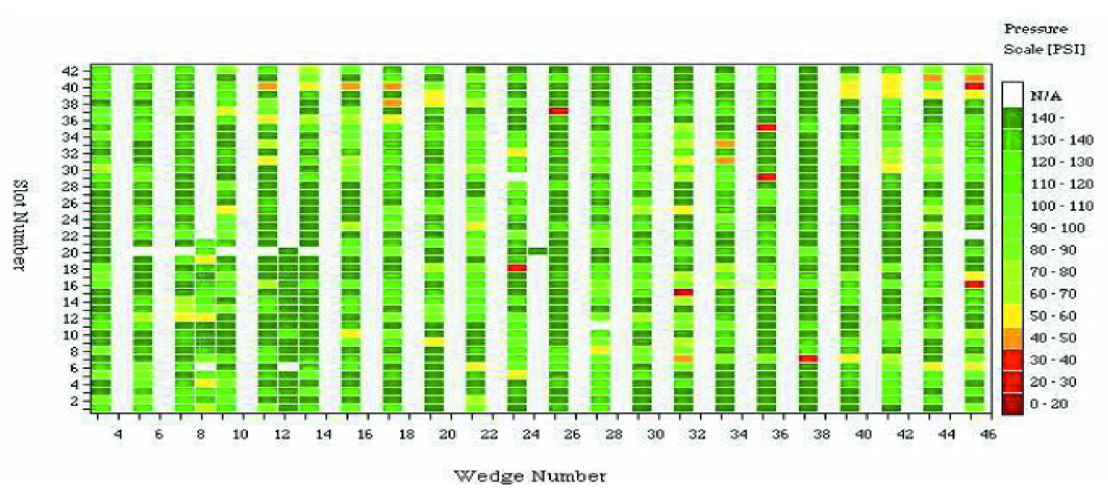

Figure 5: A sample Wedge Tightness Inspection printout shows real-time digital mapping of individual wedges with the green-red scale demonstrating the degree of tightness

7.3. Manufacturer C: Diagnostic Inspection with Rotor in Situ (DIRIS)

The Diagnostic Inspection with Rotor in Situ provides modern robotic instrumentation and tooling to allow fast and reliable remote inspection of the turbogenerator. Fully embedded in a modular diagnostics solution portfolio, DIRIS is a technology offering effective turbogenerator inspections, reducing the risks related to rotor dismantling while giving complete confidence in continued machine operation between major outages.

Due to its advanced design, the DIRIS inspection technology can be use for almost all turbogenerator sizes from different Original Equipment Manufacturers (OEMs) in the industry and utility businesses.

7.3.1. DIRIS enables reliable inspection of:

- Air gap inspection: The DIRIS video probe allows the detection of any foreign objects in the air gap.
- Stator active part surface: The DIRIS video probe allows the detection of hot spots, scratches and flaking paint.
- Stator Wedge tightness: With the DIRIS stator slot wedge assessment, loose wedges can be identified and so the risk of vibration and stator ground faults can be reduced.
- Rotor active part surface: The video probe allows the detection of hot spots, scratches, flaking paint and foreign objects.
- Rotor wedges condition: The video probe allows the detection of wedge movement, pollution and hot spots.
- Balancing Bolt fixation: With DIRIS, rotor balancing bolts can be inspected for looseness to prevent catastrophic damages to the rotor itself, the magnetic core and the stator winding.
- Potential blocking of ventilation ducts and the cooling path: The DIRIS video probe allows the detection of potential blocking of rotor and magnetic core ventilation ducts that might affect the performance of the generator.
- Overheating of the core: The DIRIS can detect short-circuit laminations that may lead to core burning and result in very costly and time-consuming repairs information
- With the rotor in place, one engineer can perform the inspection within as little as two days. This includes installation and removal of the test equipment.

Figure 6: Diagnostic Inspection with Rotor in Situ (DIRIS)

7.4. Manufacturer D: Robotic Inspection Vehicle (RIV)

The Robotic Inspection Vehicle enables remote scanning of the stator core of large generators and motors with or without the rotor in place. Controlled from outside the stator bore, the RIV can carry the EL CID stator core fault test equipment along the stator core, providing easier and more efficient testing of stator lamination insulation. Some power utilities have successfully used the RIV for EL CID testing.

The RIV can also carry other lightweight transducers for stator and rotor inspection such as slot wedge tightness probes and mini-cameras, that can be focused remotely, allowing visual inspection of the generator and rotor for checking the air vents for debris, without removing the rotor.

7.4.1. Features:

- Fits into the air-gap for rotor-in-place testing
- Carries multiple modules: EL CID, Wedge Tightness Detector (optional) and a Mini-Camera (optional)
- Tests faster with reduced human fatigue stress
- Follows a straight line along the stator teeth
- Scans the stator surface with an optional mini-camera
- Auto-stop setting ensures RIV stops at preset distance
- Control unit outside stator core via single multi-core cable for power and signals
- Can be mechanically adjusted for various slot widths
- Curvature adjustment for various core diameters
- Low height (30 mm) allows rotor-in-place testing
- Magnetically self supporting on core surface
- Automatically detects the wedges of the stator teeth to follow a straight line
- Side plates give additional guidance when wedges are recessed or when wedges and coils are removed

7.4.2. Specifications:

	Vehicle
. Height	30 mm – excluding payload
. Overall length	350 mm with chattock holders
. Overall Width	Adjustable from 1 to 300 mm
. Weight	3.0 Kg
. Maximum Payload	2 kg in vertical position
. Slot Pitch	65 to 210 mm
. Distance measurement	Optical encoder wheel, 0 to 9.99 m
. Tractor speeds	nominally, 2,4 or 6 m/mim
. Controls	speed, direction and auto-stop distance
. Outputs	X axis pulses for EL CID
. Power requirement	85-264V 50/60 hz (<50 VA) CAT II
.Operating temperature	0 to +50ºC
. Carrying case dimensions	55x72x30 cm
.Total weight	26,8 Kg
. Standards	EN 61010-1, EN 6132 CE market

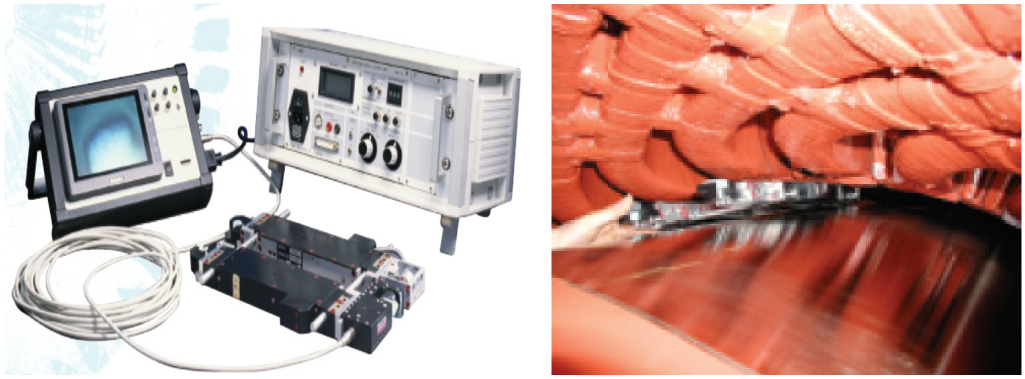

Figure 7: Robotic Inspection Vehicle (RIV)

8. QUESTIONNAIRE ANSWERS

8.1. General Information

The questionnaire was answered by Power Generation Utilities and a Consultant, from four countries. All responses are presented in accordance with the following order and the items unanswered were not included.

A - ISRAEL, Power Generation Utility
B - SPAIN, Power Generation Utility
C - CANADA, Power Generation Utility
D - SOUTH AFRICA, Consultant

8.2. Verification Technologies (Answers)

Q.1. What is the total capacity and number of generation units in your power station?

D: I serve a centralized maintenance organization looking after a number of stations:

Capacity: ~43,000MW, No. of units: ~62.

B: This questionnaire is done to cover the entire turbogenerators fleet of the utility.

Q.2. How many turbogenerators does your plant have?

No answers.

Q.3. What are the characteristics of the biggest turbogenerator in your station?

Power, rpm, stator voltage, power factor, field amperage, cooling medium (stator, field and core)

TAG	MW	Rpm	KV	A	FP	Cooling
A	575	3000	22	17000	0,85	H2/water
D	957	1500	24	---	---	H2/water

Q.4. Where is located the turbogenerator?

B: All fleet is indoor.

A: Some of them are indoor.

8.3. Verification Methodologies

8.3.1. Introduction

Visual Inspection is done by the robot with high resolution video cameras as it moves through the gap between the stator core and field on rubber tractor treads which have axial and transverse motion capability.

It can inspect the field and core surface on units with an air gap of 6.35 mm (0,25") to 12.7 mm (0,5") (Magic Robot) and can navigate around the core gas baffles in special cases.

The cameras provide a clear view of all components inside generator.

The Stator Wedge Tightness Test is used on hard stator insulation systems with flat or piggyback wedges.

Back wedges. It measures wedge tightness by measuring the response of the wedge to a mechanical stimulus (impact). The inspection data is stored in a file and provided with the final report.

Core fault detection is performed by an on-board and a signal processor located in the control system computer, is used to measure, record and report the data.

8.3.2. Answers

Q1. In you business you have had experience with the robotic inspection in turbogenerators?

If the answer is yes it is possible to describe which parts of the turbogenerator were inspected?

A	YES, Air gap area (stator and rotor surfaces including wedges).
B	YES, Stator and rotor. Visual Inspections with air gap inspections robot (MAGIC Robot), wedge map and EL CID tests.
C	YES, Stator core, stator wedges and rotor surface.
D	YES, Stator core, rotor body, wedge test and ELCID test.

Q2. In your opinion what is the advantage of a robotic inspection instead of traditional overhaul inspection?

A	Visual inspection and some test with rotor in-situ. We mainly use LAI during minor outages or as a preparation towards major outages (but not in place of rotor-out major).
B	The main advantage is to avoid disassembling of the field, its cost and risks. Therefore a whole generator visual inspection can be done more frequently. However, in our opinion robotic inspection would not avoid removing the rotor in whole generator lifetime, but it should be considered in maintenance programs, to be scheduled between two major inspections (one major inspection by robotic systems and one removing the field).
C	No requirement to pull the rotor out.
D	Not having to remove rotor – saved 3 weeks on a 200MW machine.

Q.3. What are the advantages of using robotic EL CID inspection?

A	No answer.
B	Main advantage is to avoid remove the field for testing, therefore this test can be done In more regular basis. Also, controlled scanning speed could be other

	advantage. Most part of turbogenerators includes Core Monitor systems, so most hot spot problems in the core should be detected in advance. Any way, predictive maintenance program include EL CID test in major inspections.
C	No requirement to pull the rotor out, data should be comparable to rotor out test.
D	Smooth movement results in smooth traces. Not having to remove rotor

Q.4. The wedge testing using the robotic tools has the same results of a wedge testing using a traditional tool for verification of the wedge movement?

A	Not always. Depends by tester experience and equipment calibration.
B	It is used ADWEL WTD system, same instrument that is mounted in MAGIC systems so if the testing is carry out properly and position of the hammer and sensor are controlled, results should be the same.
C	Not in every case.
D	Yes.

Q.5. What parts of turbogenerators are necessary to remove for robotic inspection?

A	End shields, gas baffles.
B	Upper shields at both sides of the generator.
C	Upper and lower shields, sometimes rotor fan blades.
D	Depends on the design of the machine – sometimes just outer doors and coolers, sometimes much more.

Q.6. What is the minimum gap necessary for introducing the robotic tools?

A	No Answer.
B	At the moment we only have done robotic inspections at hydrogen cooled generators and it had been done by MAGIC Robots. We are analyzing this data for all fleet.
C	The critical point is not air-gap, it is the entrance gap, measured from top of the retaining ring to the core surface. Frequently, end winding design also needs to be taken in account in determination if entry is possible or not. Required entry gap size depends on type of the tool used, but 30 mm seems to be enough for most.
D	Air-gap – 30mm, but the problem is getting the robot past the CRR (Coil Retaining Ring).

Q.7. The assurance companies are considering the robotic inspection valid instead of the traditional overhaul major inspection?

A	No answer.
B	Yes, if it is recommended or accepted by the OEM.

C	No answer.
D	No answer.

Q.8. In case of oil or water leakage inside generator is possible to use robotic toll for cleaning the parts of generators?

A	No. Even more, water leakages are sometimes invisibles to LAI.
B	No answer.
C	No.
D	Don't know.

Q.9. What is the maximum time for a complete robotic inspection?

A	No answer.
B	See manufacturer answers.
C	Depending on scope, 24-48 hours.
D	3-4 days.

Q.10. Is possible to perform a good inspection in all parts of the field using only robotic inspection. What are deficiencies?

A	Under retaining rings is not possible, other tools can be sometime used (boroscope).
B	As we explain before, in our opinion to carry out robotic inspection not avoid removing the rotor in whole generator lifetime, and it should be consider in the maintenance programs. Although image quality of the robotic systems camera is good, it is always better to evaluate degradation mechanism effects in a direct way. Large experience in this system management is needed to make complete visual inspections of the field. Retaining rings Non Destructive Examination (NDE).
C	Most of the inspection vehicles are stator mounted-access to the rotor might be a challenge. Visual inspection of vent holes is possible.
D	No – can't access underneath coil Retaining Rings/overhang.

Q.11. Mark YES or NO according your experience using robotic inspection:

Rotor	A	B	C	D
Mechanical balancing after inspection	N	N	N	N
Rotor alignment after inspection	N	N	N	N
Check movement of seal oil ring	N	-	N	Y
Inspection near Retaining Ring end teeth	N	Y	Y	N

Detection of sparks due partial discharges	Y	Y	Y	Y
Non Destructive Examination tests on Retaining Ring	N	N	N	N
Inspection on cooler gaskets	N	-	N	Y
Inspection on gas seal baffle ring	Y	-	N	N

Q.12. Mark YES or NO if the following investigations are used in your company using robotic inspection

Stator core	**A**	**B**	**C**	**D**
Foreign object damage, hot spots, evidence of movement	**Y**	**Y**	**Y**	**Y**
Migration, cooling passage blockage	**N**	**Y**	**Y**	**Y**
Cracked welds, looseness	**N**	**N**	**Y**	**N**
Looseness, loss, sparking, girth cracks, movement	**N**	**Y**	**Y**	**N**
Wet groundwall insulation	**N**	**N**	**N**	**N**
Bar movement, loose/broken ties, supports, etc. excessive corona activity	**Y**	**Y**	**Y**	**N**
Overheating, looseness, general condition	**Y**	**Y**	**Y**	**Y**
Resistance Temperature Detector (RTD) thermocouple wiring ties, flux probe, general condition	**N**	**Y**	**N**	**Y**
Checking of stator core compactness	**N**	**-**	**-**	**-**
Measurements of self vibrations of stator winding	**N**	**-**	**-**	**-**
Field				
Heating, arcing, foreign object damage	**Y**	**Y**	**Y**	**Y**
Looseness, staking	**N**	**Y**	**N**	**-**
Arcing, migration, cracking	**N**	**-**	**N**	**N**
Wedge contact, arcing, foreign object damage, material cracks, pitting	**Y**	**-**	**Y**	**Y**
Blocked ventilation, damaged insulation, coil distortion, contamination	**N**	**-**	**Y**	**Y**
Testing of main insulation	**N**	**-**	**-**	**-**
Testing of winding turn-to-turn insulation	**N**	**-**	**-**	**-**
General				
Excessive oil or other contamination, foreign object damage, blocked cooling	**Y**	**Y**	**Y**	**Y**

Insulation condition, connection integrity, high voltage bushing condition	**N**	**Y**	**Y**	**Y**

9. CONCLUSIONS

On-line monitoring and diagnostic techniques are limited in detecting potential problems, such as bar movement and vibration, component damage, copper dusting, coil distortion and foreign object damage. Many of these conditions could lead to a major failure of the generator if left unresolved for a period of time. It is in these areas that in-situ inspection (ISI) with robots and other inspection systems, supplements the capabilities of on-line monitoring and diagnostics to reduce the risk of a failure.

A robotic inspection allows detecting:

- Any foreign objects in the air gap.
- In the stator active part surface: Hot spots, scratches and flaking paint.
- Stator loose wedges minimizing the risk of vibration and stator ground faults.
- In the rotor active part surface: hot spots, scratches, flaking paint and foreign objects.
- The rotor wedges condition as detection of wedge movement, pollution and hot spots.
- The looseness in the rotor balancing bolt fixation preventing catastrophic damages to the rotor itself, the magnetic core and the stator winding.
- Potential blocking of rotor and magnetic core ventilation ducts and the cooling path that might affect the performance of the generator.
- Short-circuit laminations that may lead to core burning and result in very costly and time-consuming repairs information.
- With the rotor in place, one engineer can perform the inspection, in general, within as little as two days. This includes installation and removal of the test equipment.

Robotic inspection can provide the following additional benefits:

- Reduced inspection cost
- Enable generator testing and inspection while the rotor remains in place
- Early problem detection
- Less risk of collateral damage from disassembly/reassembly
- Reduced inspection time to more than 33% of the inspection time with the field removed
- More time between field pulls
- Periodic monitoring of known conditions

Coupled with other in-situ inspection systems such as remote access camera, retaining ring scanner and stator capacitance mapping is possible, with a robotic inspection, to evaluate the generator components condition and provide a detailed assessment of the machine conditions.

ISI inspections may be considered as a substitute for rotor out inspections. ISI in addition to maintenance & operations history, and standard tests, provide some of the essential ingredients for an overall comprehensive maintenance program for the machine.

There may be extenuating cases where further investigation may require pulling the rotor after an ISI is performed, based on the need for further inspection and testing of unique situations, however this should be the exception.

Severe findings detected during the robot inspection may require immediate repair, and this will involve developing the rotor-in minor inspection into a major rotor-out outage.

The success of the robotic inspection is highly dependent on the steering ability of the tester and on his experience. A relative small defect may appear very impressive due to the camera zoom.

10. REFERENCES

10.1 – General Electric MAGIC, www.ge-energy.com

10.2 – SIEMENS – FAST GEN V, www.siemens.com/powergeneration

10.3 – ALSTOM - DIRIS, www.alstom.com/power

10.4 – IRIS Power – RIV, www.irispower.com

11. ANNEXES: ANSWERS TO THE QUESTIONNAIRE BY COUNTRY

11.1. Israel

Main activity	☒	1	Power generator
	☐	2	Manufacturer
	☐	3	Research Centers and Universities
	☐	4	Consultant
	☐	5	Other – please nominate:
Address: **Haifa, Israel**			

You may skip answers if not applicable, but we encourage you to participate in all sections where you feel comfortable to share your experience in this survey with other groups.

If you need extra space, feel free to add annex pages.

Background:

Limited Access Inspections (LAI) or robotic inspections provides generator component assessment capability comparable to conventional inspections with rotor removed. Acceptance of LAIs by insurance companies as equivalent rotor-out inspections is not universal. For more than two decades the LAI inspection has provided steam, gas and nuclear plants with an invaluable robotic tool for strategic outage planning and preventive maintenance. This inspection technology enables a safe and through inspection of generator with the rotor in situ and minimal disassembly.

Scope :

Explore the possibility of updating the maintenance systems used in rotating electrical machines replacing traditional maintenance removing rotating field by robotic inspections (LAI) of the machines. We shall take into account two different points of view: the OEMs (Original Equipment Manufacturers) and the Users point of view.

We shall focus on two different questions:

a) How confident are OEM's in using robotic inspection

b) How inclined are the Users to use LAI inspections in generators and what are their perceptions about the possible advantages versus the risk of changing to new maintenance system.

In order to answer both questions, one survey would be carried out including OEMs and the Users. The conclusions and the information gathered in the survey would help establishing the state of the art and capacity of robotic inspection in generators and how receptive Users are in adopting these maintenance systems.

This questionnaire is limited to TURBOGENERATORS

Free text boxes like can be typed into to the extent required to respond to the question.

Double click on check boxes like ☐ and select the "checked" option as required.

QUESTIONS

1.General information

1.1. What is the total capacity and number of generating units in your power station?

Capacity:

No. of units:

1.2. How many turbogenerators does your plant have?

1.3 What are the characteristics of the biggest turbogenerator in your station?

Power, rpm, stator voltage, power factor, field amperage, cooling medium (stator, field and core)

650 MVA, 3000 rpm, 22 kV, 0.85, 17000 A, water and hydrogen cooled

1.4. Where is located the turbogenerator?

Indoor (protected with roof) **some of them**

Outdoor (unprotected with roof) **some of them**

2.Verification Technologies

Visual Inspection is done by the robot with two high resolution video cameras as it moves through the gap between the stator core and field on rubber tractor treads which have axial and transverse motion capability. It can inspect the field and core surface on units with with an air gap as narrow as 6.35 mm. The cameras provide a clear view of normally inaccessible areas in the generator, outside of the bore region. These areas include the stator endings; field coil ends turns and stator high voltage terminal connections. This information is combined with that provided by the robot visual inspection to provide the most through visual inspection possible with the rotor in place.

The Stator Wedge Tightness Test is used on hard stator insulation systems with flat or Piggy Back wedges. It measures wedge tightness by measuring the response of the wedge to a mechanical stimulus (impact). The inspection data is stored in a file and provided with the final report.

Core fault detection is performed by a highly sensitive miniaturized sensing coil, or chattock, placed along the core surface to detect fault currents which will result from core insulation damage. A signal processor located in the control system computer is used to measure, record and report these faults.

Part of the In-situ package is Retaining Ring NDE (Nondestructive Evaluation) equipment, that provides an Ultrasonic Test on the Retaining Ring Inner Diameter and an Eddy Current test on the Retaining Rings Outer Diameter.

On generators with liquid cooled stator windings, Stator Bar Capacitance Testing can be performed without removing the field from the stator. A tool is used which has an inflatable electrode, and a remote actuator arm for locating the probe. The Remote Access Camera, essentially a camera on an extension, is used for positioning the probe and identifying its location. Another device, stator bar clearance/jacking tool can be used to detect radial clearance at the ends of the stator slots by applying a carefully controlled pressure radially on the stator bars and measuring movement.

3. Questions

3.1 In your business you have had experience with the robotic inspection in turbo generators?

☒ - Yes ☐ - No

If the answer is yes it is possible to describe which parts of the turbogenerator were inspected?

Air gap area (stator and rotor surfaces including wedges).

3.2. In your opinion what is the advantage of a robotic inspection instead of traditional overhaul inspection?

Visual inspection and some test with rotor in-situ. We mainly use LAI during minor outages or as a preparation towards major outages (but not in place of rotor-out major outage).

3.3. What are the advantages of using robotic EL CID inspection?

3.4. The wedge testing using the robotic tools has the same results of traditional wedge testing using a tool for verification of the wedge movement?

Not always. Depends by tester experience and equipment calibration.

3.5. What parts of turbogenerators are necessary to remove for robotic inspection?

End shields, gas baffles.

3.6. What is the minimum gap necessary for introducing the robotic tools?

3.7.The assurance companies are considering the robotic inspection valid instead of the traditional overhaul major inspection?

3.8. In case of oil or water leakage inside generator is possible to use robotic toll for cleaning the parts of generators?

No. Even more, water leakages are sometimes invisibles to LAI.

3.9. What is the maximum time for a complete robotic inspection?

3.10. Is possible to perform a good inspection in all parts of the field using only robotic inspection

What are deficiencies?

Under retaining rings is not possible, other tools can be sometime used (boroscope).

3.11. Mark YES or NO according your experience using robotic inspection:

Mechanical balancing of generator rotor after inspection/rewinding	☐ - Yes	☒ - No
Rotor alignment after inspection/rewinding	☐ - Yes	☒ - No
Check movement of seal oil ring	☐ - Yes	☒ - No
Inspection near Retaining Ring end teeth	☐ - Yes	☒ - No
Detection of sparks due partial discharges	☒ - Yes	☐ - No
NDE tests on R. Ring	☐ - Yes	☒ - No
Inspection on cooler gaskets	☐ - Yes	☒ - No
Inspection on gas seal baffle ring	☒ - Yes	☐ - No

3.12. Mark YES or NO if the following investigations are used in your company using robotic inspection

Stator core

Foreign object damage, hot spots, evidence of movement	☒ - Yes ☐ - No
Migration, cooling passage blockage	☐ - Yes ☒ - No
Cracked welds, looseness	☐ - Yes ☒ - No
Looseness, loss, sparking, girth cracks, movement	☐ - Yes ☒ - No
Wet groundwall insulation	☐ - Yes ☒ - No
Bar movement, loose/broken ties, supports, etc. excessive corona activity	☒ - Yes ☐ - No
Overheating, looseness, general condition	☒ - Yes ☐ - No
RTD, thermocouple wiring ties, flux probe, general condition	☐ - Yes ☒ - No
Checking of stator core compactness	☐ - Yes ☒ - No
Measurements of self vibrations of stator winding	☐ - Yes ☒ - No

Field

Heating, arcing, foreign object damage	☒ - Yes ☐ - No
Looseness, staking	☐ - Yes ☒ - No
Arcing, migration, cracking	☐ - Yes ☒ - No
Wedge contact, arcing, foreign object damage, material cracks, pitting	☒ - Yes ☐ - No
Blocked ventilation, damaged insulation, coil distortion, contamination	☐ - Yes ☒ - No
Testing of main insulation	☐ - Yes ☒ - No
Testing of winding turn-to-turn insulation	☐ - Yes ☒ - No

General

Excessive oil or other contamination, foreign object damage, blocked cooling	☒ - Yes ☐ - No
Insulation condition, connection integrity, high voltage bushing condition.	☐ - Yes ☒ - No

If YES describe what tools are used:

Visual, wedge tapping, el-cid, capacitance, clearance measurements.

11.2. Spain

Main activity	☒	1	Power generator
	☐	2	Manufacturer
	☐	3	Research Centers and Universities
	☐	4	Consultant
	☐	5	Other – please nominate:
Address: Madrid, Spain			
You may skip answers if not applicable, but we encourage you to participate in all sections where you feel comfortable to share your experience in this survey with other groups. If you need extra space, feel free to add annex pages.			

Background:

Limited Access Inspections (LAI) or robotic inspections provides generator component assessment capability comparable to conventional inspections with rotor removed. Acceptance of LAIs by insurance companies as equivalent rotor-out inspections is not universal. For more than two decades the LAI inspection has provides steam, gas and nuclear plants an invaluable robotic tool for strategic outage planning and preventive maintenance. This inspection technology enables a safe and through inspection of generator with the rotor in situ and minimal disassembly.

Scope :

Explore the possibility of updating the maintenance systems used in rotating electrical machines replacing traditional maintenance removing rotating field by robotic inspections (LAI) of the machines. We shall take into account two different points of view: the OEMs (Original Equipment Manufacturers) and the Users point of view.

We shall focus on two different questions:

a) How confident are OEM's in using robotic inspection

b) How inclined are the Users to use LAI inspections in generators and what are their perceptions about the possible advantages versus the risk of changing to new maintenance system.

In order to answer both questions, one survey would be carried out including OEMs and the Users. The conclusions and the information gathered in the survey would help establishing the state of the art and capacity of robotic inspection in generators and how receptive Users are in adopting these maintenance systems.

This questionnaire is limited to TURBOGENERATORS

Free text boxes like can be typed into to the extent required to respond to the question.

Double click on check boxes like ☐ and select the "checked" option as required.

QUESTIONNAIRE

1. General information

1.1. What is the total capacity and number of generating units in your power station?

This questionnaire is done to cover the company Turbo Generators Fleet.

Capacity:

No. of units:

1.2. How many turbogenerators does your plant have?

1.3. What are the characteristics of the biggest turbogenerator in your station?

Power, rpm, stator voltage, power factor, field amperage, cooling medium (stator, field and core)

1.4. Where is located the turbogenerator?

Indoor (protected with roof) all fleet is indoor

Outdoor (unprotected with roof)

2.Verification Technologies

Visual Inspection is done by the robot with high resolution video cameras as it moves through the gap between the stator core and field on rubber tractor treads which have axial and transverse motion capability.

It can inspect the field and core surface on units with an air gap of 0.75” to 2.0” (magic) or greater and can navigate around the core gas baffles in special cases.

The cameras provide a clear view of all components inside generator.

The Stator Wedge Tightness Test is used on hard stator insulation systems with flat or Piggy

Back wedges. It measures wedge tightness by measuring the response of the wedge to a mechanical stimulus (impact). The inspection data is stored in a file and provided with the final report.

Core fault detection is performed by an on-board and a signal processor located in the control system computer, is used to measure, record and report the data.

3.Questions

3.1 In your business you have had experience with the robotic inspection in turbo generators?

☒ - Yes ☐ - No

If the answer is yes it is possible to describe which parts of the turbogenerator were inspected?

Stator and rotor. VI Inspections with air gap inspections robot (MAGIC), wedge map and EL CID tests.

3.2 In your opinion what the advantage of a robotic inspection instead of traditional overhaul inspection?

The main advantage is to avoid disassembling of the field, its cost and risks. Therefore a whole generator visual inspection can be done more frequently. However, in our opinion to carry out robotic inspection not avoid to remove the rotor in whole generator lifetime and it should be consider in the maintenance programs, for example it could be scheduled between two major inspections (one major inspection by robotic systems and one removing the field).

3.3 What are the advantages of using robotic EL CID inspection?

Main advantage is to avoid remove the field for testing, therefore this test can be done In more regular basis. Also, controlled scanning speed could be other advantage.

Most part of turbogenerators includes Core Monitor systems, so most hot spot problems in the core should be detected in advance. Any way, predictive maintenance program include EL CID test in major inspections.

3.4 The wedge testing using the robotic tools has the same results of traditional wedge testing using a tool for verification of the wedge movement?

It is used ADWEL WTD system, same instrument that is mounted in MAGIC systems so if the testing is carry out properly and position of the hammer and sensor are controlled, results should be the same.

3.5 What parts of turbogenerators are necessary to remove for robotic inspection?

Upper shields at both sides of the generator.

3.6 What is the minimum gap necessary for introducing the robotic tools?

At the moment we only have done robotic inspections at the manufacturer of H_2 cooled generators and it had been done with MAGIC inspections. We are analyzing this data for all fleet.

3.7.The assurance companies are considering the robotic inspection valid instead of the traditional overhaul major inspection?

Yes, if it is recommended or accepted by the OEM.

3.8 In case of oil or water leakage inside generator is possible to use robotic toll for cleaning the parts of Generators?

3.9. What is the maximum time for a complete robotic inspection?
3.10 Is possible to perform a good inspection in all parts of the field using only robotic inspection. What are deficiencies? As we explain before, in our opinion to carry out robotic inspection not avoid removing the rotor in whole generator lifetime and it should be consider in the maintenance programs. Although image quality of the robotic systems camera is good, it is always better to evaluate degradation mechanism effects in a direct way. Large experience in this system management is needed to make complete visual inspections of the field. Retaining rings NDT
3.11. Mark YES or NO according your experience using robotic inspection: Mechanical balancing after inspection ☐ - Yes ☒ - No Rotor alignment after inspection ☐ - Yes ☒ - No Check movement of seal oil ring ☐ - Yes ☐ - No Inspection near R. Ring end teeth ☒ - Yes ☐ - No Detection of sparks due partial discharges ☒ - Yes ☐ - No NDE tests on R. Ring ☐ - Yes ☒ - No Inspection on cooler gaskets ☐ - Yes ☐ - No Inspection on gas seal baffle ring ☐ - Yes ☐ - No Comments:

3.12. Mark YES or NO if the following investigations are used in your company using robotic inspection

Stator core	
Foreign object damage, hot spots, evidence of movement	☒ - Yes ☐ - No
Migration, cooling passage blockage	☒ - Yes ☐ - No
Cracked welds, looseness	☐ - Yes ☒ - No
Looseness, loss, sparking, girth cracks, movement	☒ - Yes ☐ - No
Wet groundwall insulation	☐ - Yes ☒ - No
Bar movement, loose/broken ties, supports, etc. excessive corona activity	☒ - Yes ☐ - No
Overheating, looseness, general condition	☒ - Yes ☐ - No
RTD, thermocouple wiring ties, flux probe, general condition	☒ - Yes ☐ - No
Field	
Heating, arcing, foreign object damage	☒ - Yes ☐ - No
Looseness, staking	☒ - Yes ☐ - No
Arcing, migration, cracking	☐ - Yes ☐ - No
Wedge contact, arcing, foreign object damage, material cracks, pitting	☐ - Yes ☐ - No
Blocked ventilation, damaged insulation, coil distortion, contamination	☐ - Yes ☐ - No
General	
Excessive oil or other contamination, foreign object damage, blocked cooling	☒ - Yes ☐ - No
Insulation condition, connection integrity, high voltage bushing condition.	☐ - Yes ☒ - No

If YES describe what tools are used:

Visual, wedge tapping, el-cid, capacitance, clearance measurements.

Comments:

Visual, wedge tapping, EL CID.

Clearance measurements at the bottom of the slot or bar jacking test was requested to the manufacturer for 330H generators. The manufacturer indicated that this test was developed for H_2O cooled generator with MICAPAL I or II insulation systems. MECAPAL HT is more susceptible for mechanical damages and therefore it is not recommended. The manufacturer also indicated that this test is today discontinued.

11.3. Canada

Main activity	☐	1	Power generator
	☒	2	Manufacturer
	☐	3	Research Centers and Universities
	☐	4	Consultant
	☐	5	Other – please nominate:
Address: Ontario, Canada			
You may skip answers if not applicable, but we encourage you to participate in all sections where you feel comfortable to share your experience in this survey with other groups. If you need extra space, feel free to add annex pages.			

Background:

Limited Access Inspections (LAI) or robotic inspections provides generator component assessment capability comparable to conventional inspections with rotor removed. Acceptance of LAIs by insurance companies as equivalent rotor-out inspections is not universal. For more than two decades the LAI inspection has provides steam, gas and nuclear plants an invaluable robotic tool for strategic outage planning and preventive maintenance. This inspection technology enables a safe and through inspection of generator with the rotor in situ and minimal disassembly.

Scope :

Explore the possibility of updating the maintenance systems used in rotating electrical machines replacing traditional maintenance removing rotating field by robotic inspections (LAI) of the machines. We shall take into account two different points of view: the OEMs (Original Equipment Manufacturers) and the Users point of view.

We shall focus on two different questions:

c) How confident are OEM's in using robotic inspection

d) How inclined are the Users to use LAI inspections in generators and what are their perceptions about the possible advantages versus the risk of changing to new maintenance system.

In order to answer both questions, one survey would be carried out including OEMs and the Users. The conclusions and the information gathered in the survey would help establishing the state of the art and capacity of robotic inspection in generators and how receptive Users are in adopting these maintenance systems.

This questionnaire is limited to TURBOGENERATORS

Free text boxes like can be typed into to the extent required to respond to the question.

Double click on check boxes like ☐ and select the "checked" option as required.

QUESTIONNAIRE

1.General information

1.1. What is the total capacity and number of generating units in your power station?

Capacity:

No. of units:

1.2. How many turbogenerators does your plant have?

NA

1.3. What are the characteristics of the biggest turbogenerator in your station?

Power, rpm, stator voltage, power factor, field amperage, cooling medium (stator, field and core)

NA

1.4. Where is located the turbogenerator?

Indoor (protected with roof)

Outdoor (unprotected with roof)

NA

2.Verification Technologies

Visual Inspection is done by the robot with high resolution video cameras as it moves through the gap between the stator core and field on rubber tractor treads which have axial and transverse motion capability.

It can inspect the field and core surface on units with an air gap of 0.75” to 2.0” (magic- GE) or greater and can navigate around the core gas baffles in special cases.

The cameras provide a clear view of all components inside generator.

The Stator Wedge Tightness Test is used on hard stator insulation systems with flat or Piggy

Back wedges. It measures wedge tightness by measuring the response of the wedge to a mechanical stimulus (impact). The inspection data is stored in a file and provided with the final report.

Core fault detection is performed by an on-board and a signal processor located in the control system computer, is used to measure, record and report the data.

3. Questions

3.1 In your business you have had experience with the robotic inspection in turbo generators?

☒ - Yes ☐ - No

If the answer is yes it is possible to describe which parts of the turbogenerator were inspected?

Stator core, stator wedges and rotor surface.

3.2 In your opinion what the advantage of a robotic inspection instead of traditional overhaul inspection?

No requirement to pull the rotor out.

3.3. What are the advantages of using robotic EL CID inspection?

No requirement to pull the rotor out, data should be comparable to rotor out test.

3.4 The wedge testing using the robotic tools has the same results of traditional wedge testing using a tool for verification of the wedge movement?

Not in every case.

3.5 What parts of turbogenerators are necessary to remove for robotic inspection?

Upper and lower shields, sometimes rotor fan blades.

3.6 What is the minimum gap necessary for introducing the robotic tools?

The critical point is not air-gap, it is the entrance gap, measured from top of the retaining ring to the core surface. Frequently, end winding design also needs to be taken in account in determination is entry possible or not.

Required entry gap size depends on type of the tool used, but 30 mm seems to be enough for most.

3.7 The assurance companies are considering the robotic inspection valid instead of the traditional overhaul major inspection?

NA

3.8 In case of oil or water leakage inside generator is possible to use robotic toll for cleaning the parts of generators?

No.

3.9 What is the maximum time for a complete robotic inspection?

Depending on scope, 24-48 hours…

3.10 Is possible to perform a good inspection in all parts of the field using only robotic inspection.

What are deficiencies?

Most of the inspection vehicles are stator mounted-access to the rotor might be a challenge. Visual inspection of vent holes is possible.

3.11. Mark YES or NO according your experience using robotic inspection:

Mechanical balancing after inspection	☐ - Yes	☒ - No
Rotor alignment after inspection	☐ - Yes	☒ - No
Check movement of seal oil ring	☐ - Yes	☒ - No
Inspection near R. Ring end teeth	☒ - Yes	☐ - No
Detection of sparks due partial discharges	☒ - Yes	☐ - No
NDE tests on R. Ring	☐ - Yes	☒ - No
Inspection on cooler gaskets	☐ - Yes	☒ - No
Inspection on gas seal baffle ring	☐ - Yes	☒ - No

Comments:

3.12. Mark YES or NO if the following investigations are used in your company using robotic inspection

Stator core

Foreign object damage, hot spots, evidence of movement	☒ - Yes	☐ - No
Migration, cooling passage blockage	☒ - Yes	☐ - No
Cracked welds, looseness	☒ - Yes	☐ - No
Looseness, loss, sparking, girth cracks, movement	☒ - Yes	☐ - No
Wet groundwall insulation	☐ - Yes	☒ - No
Bar movement, loose/broken ties, supports, etc. excessive corona activity	☒ - Yes	☐ - No
Overheating, looseness, general condition	☒ - Yes	☐ - No
RTD, thermocouple wiring ties, flux probe, general condition	☐ - Yes	☒ - No

Field

Heating, arcing, foreign object damage	☒ - Yes	☐ - No
Looseness, staking	☐ - Yes	☒ - No
Arcing, migration, cracking	☐ - Yes	☒ - No
Wedge contact, arcing, foreign object damage, material cracks, pitting	☒ - Yes	☐ - No
Blocked ventilation, damaged insulation, coil distortion, contamination	☒ - Yes	☐ - No

General

Excessive oil or other contamination, foreign object damage, blocked cooling	☒ - Yes	☐ - No
Insulation condition, connection integrity, high voltage bushing condition.	☒ - Yes	☐ - No

If YES describe what tools are used:

visual, wedge tapping, el-cid, capacitance, clearance measurements.

Comments:

Visual inspection, wedge tapping and EL CID test.

11.4 South Africa

Main activity group: (Please check)	☐	1	Power generator
	☐	2	Manufacturer
	☐	3	Research Centers and Universities
	☒	4	Consultant
	☐	5	Other – please nominate:
Address: Johannesburgo, South Africa			
You may skip answers if not applicable, but we encourage you to participate in all sections where you feel comfortable to share your experience in this survey with other groups. If you need extra space, feel free to add annex pages.			

Background:

Limited Access Inspections (LAI) or robotic inspections provides generator component assessment capability comparable to conventional inspections with rotor removed. Acceptance of LAIs by insurance companies as equivalent rotor-out inspections is not universal. For more than two decades the LAI inspection has provides steam, gas and nuclear plants an invaluable robotic tool for strategic outage planning and preventive maintenance. This inspection technology enables a safe and through inspection of generator with the rotor in situ and minimal disassembly.

Scope :

Explore the possibility of updating the maintenance systems used in rotating electrical machines replacing traditional maintenance removing rotating field by robotic inspections (LAI) of the machines. We shall take into account two different points of view: the OEMs (Original Equipment Manufacturers) and the Users point of view.

We shall focus on two different questions:

e) How confident are OEM's in using robotic inspection

f) How inclined are the Users to use LAI inspections in generators and what are their perceptions about the possible advantages versus the risk of changing to new maintenance system.

In order to answer both questions, one survey would be carried out including OEMs and the Users. The conclusions and the information gathered in the survey would help establishing the state of the art and capacity of robotic inspection in generators and how receptive Users are in adopting these maintenance systems.

This questionnaire is limited to TURBOGENERATORS

Free text boxes like can be typed into to the extent required to respond to the question.

Double click on check boxes like ☐ and select the "checked" option as required.

QUESTIONNAIRE

1.General information

1.1 What is the total capacity and number of generating units in your power station?

I serve a centralized maintenance organization looking after a number of stations:

Capacity: ~43,000MW

No. of units: ~62

1.2 How many turbogenerators does your plant have?

~62

1.3 What are the characteristics of the biggest turbogenerator in your station?

Power, rpm, stator voltage, power factor, field amperage, cooling medium (stator, field and core)

957MW, 1500rpm, 24kV, H2/water

3.8 Where is located the turbogenerator?

Indoor (protected with roof) Indoor

Outdoor (unprotected with roof)

2.Verification Technologies

Visual Inspection is done by the robot with high resolution video cameras as it moves through the gap between the stator core and field on rubber tractor treads which have axial and transverse motion capability.

It can inspect the field and core surface on units with an air gap of 0.75” to 2.0” (magic- GE) or greater and can navigate around the core gas baffles in special cases.

The cameras provide a clear view of all components inside generator.

The Stator Wedge Tightness Test is used on hard stator insulation systems with flat or Piggy

Back wedges. It measures wedge tightness by measuring the response of the wedge to a mechanical stimulus (impact). The inspection data is stored in a file and provided with the final report.

Core fault detection is performed by an on-board and a signal processor located in the control system computer, is used to measure, record and report the data.

3. Questions

3.1 In your business you have had experience with the robotic inspection in turbo generators?

☒ - Yes ☐ - No

If the answer is yes it is possible to describe which parts of the turbogenerator were inspected?

Stator core, rotor body, wedge test and ELCID test

3.2 In your opinion what the advantage of a robotic inspection instead of traditional overhaul inspection?

Not having to remove rotor – saved 3 weeks on a 200MW machine

3.3. What are the advantages of using robotic EL CID inspection?

Smooth movement results in smooth traces

Not having to remove rotor

3.4 The wedge testing using the robotic tools has the same results of traditional wedge testing using a tool for verification of the wedge movement?

Yes

3.5 What parts of turbogenerators are necessary to remove for robotic inspection?

Depends on the design of the machine – sometimes just outer doors and coolers, sometimes much more

3.6 What is the minimum gap necessary for introducing the robotic tools?

Airgap – 30mm, but the problem is getting the robot past the CRR

3.7 The assurance companies are considering the robotic inspection valid instead of the traditional overhaul major inspection?

N/A

3.8 In case of oil or water leakage inside generator is possible to use robotic toll for cleaning the parts of generators?

Don’t know

3.9 What is the maximum time for a complete robotic inspection?

3-4 days

3.10 Is possible to perform a good inspection in all parts of the field using only robotic inspection. What are deficiencies?

No – can't access underneath CRRs/overhang

3.11. Mark YES or NO according your experience using robotic inspection:

	Yes	No
Mechanical balancing after inspection	☐	☒
Rotor alignment after inspection	☐	☒
Check movement of seal oil ring	☒	☐
Inspection near R. Ring end teeth	☐	☒
Detection of sparks due partial discharges	☒	☐
NDE tests on R. Ring	☐	☒
Inspection on cooler gaskets	☒	☐
Inspection on gas seal baffle ring	☐	☒

Comments:

3.12. Mark YES or NO if the following investigations are used in your company using robotic inspection

Stator core

	Yes	No
Foreign object damage, hot spots, evidence of movement	☒ - Yes	☐ - No
Migration, cooling passage blockage	☒ - Yes	☐ - No
Cracked welds, looseness	☐ - Yes	☒ - No
Looseness, loss, sparking, girth cracks, movement	☐ - Yes	☒ - No
Wet groundwall insulation	☐ - Yes	☒ - No
Bar movement, loose/broken ties, supports, etc. excessive corona activity	☐ - Yes	☒ - No
Overheating, looseness, general condition	☒ - Yes	☐ - No
RTD, thermocouple wiring ties, flux probe, general condition	☒ - Yes	☐ - No

Field

	Yes	No
Heating, arcing, foreign object damage	☒ - Yes	☐ - No
Looseness, staking	☐ - Yes	☐ - No
Arcing, migration, cracking	☐ - Yes	☒ - No
Wedge contact, arcing, foreign object damage, material cracks, pitting	☒ - Yes	☐ - No
Blocked ventilation, damaged insulation, coil distortion, contamination	☒ - Yes	☐ - No

General

	Yes	No
Excessive oil or other contamination, foreign object damage, blocked cooling	☒ - Yes	☐ - No
Insulation condition, connection integrity, high voltage bushing condition.	☐ - Yes	☒ - No

If YES describe what tools are used:

Visual, wedge tapping, el-cid, capacitance, clearance measurements.

Comments:

Visual, wedge tester, ELCID