Large turbo generator robotic inspections and testing

Turbo generators operate with very high load factors and are constantly exposed to the high electromagnetic stresses found in high voltage systems and are simultaneously exposed to extremely high mechanical torque, vibrations and centripetal forces transferred from the large high speed steam turbine rotors. Despite their robust design, the combination of all these factors influences the life expectancy and reliability of these enormous machines.

It comes as no surprise therefore that these machines require a strict periodic maintenance plan. In addition to the electrical, magnetic and mechanical forces, they also operate at very high current densities requiring specialised cooling for the removal of heat produced by the I²R losses. This cooling involves the use of pressurised hydrogen gas to remove the heat from rotor windings and stator cores, and chemically controlled pure demineralised cooling water to remove the heat from the high voltage stator windings.

Periodic maintenance plans are divided into minor and major maintenance interventions. Minor interventions normally do not require the removal of generator rotors from the stator whereas major interventions require a complete mechanical strip down of the generator to allow access for all the required maintenance and testing to be performed.

A typical large turbo generator maintenance schedule will involve the following:

Every third year of operation the machine requires a minor maintenance intervention which should consist of a visual inspection without removal of the rotor from the stator.

Every sixth year of operation the machine requires a major maintenance intervention consisting of:

- Rotor removal
- Removal of cooling liquid from stator bar cooling channels
- Leak testing of stator bar liquid cooling system
- Leak testing of stator frame gas cooled system
- Flow measurements of stator bar cooling circuits to detect blockages
- Visual inspection of stator windings, stator core, stator slot wedges, stator frame, stator phase connections, etc.
- Stator slot wedge tightness tests
- Stator core electromagnetic core imperfection detection (El CID) testing
- Rotor coil retaining ring crack testing using ultrasonic scanning equipment
- Visual inspection of rotor body balance weights
- General inspection of stator air gap for foreign objects, lubrication oil contamination and flaky paint.
- Electrical testing of stator and rotor windings

The following maintenance tasks traditionally require the rotor to be removed from the stator:

- Visual inspection of stator windings, stator core, stator slot wedges
- Stator slot wedge tightness tests
- Stator core El CID testing
- Rotor coil retaining ring crack testing using ultrasonic scanning equipment
- Visual inspection of rotor body balance weights

Every ninth year of operation the machine requires a minor maintenance intervention which should consist of a visual inspection without removal of the rotor from the stator (similar to the third year scope of work).

Every twelfth year of operation the machine requires a major maintenance intervention which is the same scope of work as for the sixth year maintenance intervention with additional work as follows:

- Stator slot wedge retightening
- Stator bar cooling hose connection rubber O-ring replacement
- Rotor electrical connection (stalk bolt) gas seal replacement
- Possible high speed balancing of generator rotors

As can be seen from these normal maintenance programmes, certain routine planned maintenance tasks require the removal of the generator rotor. This task is very costly due to the specialised manpower and equipment involved and the risks are significant. It is a major rigging exercise to remove these very large and heavy rotors (80 t rotors in two-pole generators and 160 t rotors in four-pole generators) from the internals of a high voltage stator that is very sensitive to mechanical damage due to the high forces experienced in service. Any mistake during the rigging operation can cause damage to the stator and rotor resulting in repair costs and production down time worth hundreds of millions of rand.

Therefore, significant cost savings, as well as the reduction of risk, can be achieved by eliminating the need to remove the generator’s rotor during some of the major interventions.

Generator robotic inspections

Developments in strong light-weight materials, advanced control systems as well as micro-electronics, has made it possible to develop industrial equipment

Fig. 1: Large two pole generator rotor installed in a generator stator.
which can be used in small spaces, able to reach over extended distances for the purposes of doing specialised testing and inspections in areas which were previously inaccessible without removing the generator rotor. Taking into account that turbo generators have limited space between the stator and rotor of between 30 to 80 mm, and a core length of up to 8 m, all of which requires detailed inspection and advanced testing, it is clear that very small, sophisticated yet robust equipment is required.

Robotic equipment makes the following tests and inspections possible in generators without removing the rotor:
- Visual inspection using various angled and angle controllable high resolution cameras and high intensity lighting
- Stator wedge tightness assessment using built in wedge tappers
- Detecting damaged core insulation with built in El CID test equipment
- Visual Inspection using a remote access camera (RAC)
- Stator capacitance mapping for the detection of wet insulation
- Coil retaining ring ultrasonic scanner

By performing robotic inspections while the generator rotor is still in position, the elimination of routine rotor removals every six years is possible (so long as the tests and inspection do not reveal a defect which requires the rotor to be removed for repair). This can lead to significant cost savings through the life of the plant. Outage planning can also be more predictable as the planned scope of work is more accurately known, and therefore more controllable.

The benefits from doing robotic inspections are as follows:
- Reduced inspection costs
- Generator testing and inspection can be done while the rotor remains in place
- Early problem detection
- Less risk of collateral damage from disassembly/reassembly
- Reduced inspection time to less than 33% of the inspection time with the rotor removed
- Longer production intervals between rotor removals
- Periodic monitoring of known conditions, as robotic inspections can also be performed during shorter more frequent outage interventions

A robotic inspection allows detection of:
- Hot spots, damage, flaking paint and foreign objects in the stator and rotor active parts.
- Loose stator wedges, as detection of wedge movement, pollution and hot spots is possible.
- Looseness of rotor balancing bolt fixation will be noted, thereby preventing catastrophic damage to the rotor itself, the magnetic core and the stator winding.
- Potential blocking of rotor and magnetic core ventilation ducts and the cooling path which might affect the premature deterioration of the insulation systems.
- Short-circuited core laminations that could lead to the core overheating and result in very costly and time-consuming repairs.
- With the rotor in place, two engineers can perform the inspection, in general, within two days, this includes installation and removal of the test equipment.

Conclusion

Depending on what additional test equipment is mounted on the inspection robot, various tests can be performed on the generator. Most testing was until recently only possible by removing the generator rotor. Adding a remote access camera, coil retaining ring scanner, core imperfection testing equipment and stator capacitance mapping equipment, it is possible to evaluate specific generator components condition and provide a detailed assessment of the machine condition.

Adding these robotic inspections and testing possibilities to the conventional on-line monitoring and diagnostic techniques such as end winding vibrations, stator core and stator bar temperature monitoring and online partial discharge measurements, more effective mean-time-to-failure prediction and future outage planning is possible. By having relevant information available about the generator’s operational condition combined with actual visual inspection and test data, the need to remove generator rotors during major outages can be reconsidered. Rotor removal need then only be done when definite problems are detected during robotic inspections and testing, which can potentially result in significant cost savings as well as major risk reduction to the plant.

Reference


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