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Inspection and Repair of Stator Winding Slot Wedging

Joe Kapler, Rotating Machine Expert

The stator winding in rotating electrical machines such as large turbo generators must be supported against the electromagnetic forces produced by the service load current. The load related forces consist of continuous cyclic forces at double system frequency (120 Hz in 60 Hz systems) and of low cycle thermal differential expansions from load changes. Against these forces one section of the stator windings is supported in the slots of the magnetic core and the other by a comprehensive end winding support structure. The purpose of all the supports is prevention of the winding against high vibration and against rubbing at support interfaces. High vibrations may lead to fatigue cracking of the copper conductors, the rubbing abrades the insulation. Experience has shown that both conditions can lead to rapid and severe winding damage and winding failures. This is a leading cause of stator winding failure in large turbo generators.

In the slot section, the forces on coils or bars develop from interaction between the flux crossing the slot and the load current in conductors. The force directions are tangential, pressing against the core teeth, and radial. The dominant radial forces are proportional to the load current squared and are pulsating against the wedges at twice system frequency, or about 10 million cycles per day. Continuous impacting of the winding on the wedges can cause gradual weakening of the wedge restraint, leading to loose wedges and possible winding motion against the laminated (and abrasive) steel teeth. The resulting continuous insulation abrasion can then lead to the winding failure. The detection of loose wedging is, therefore, an indicator of possible insulation damage from winding vibration. There is a history of winding failures caused by winding vibration in slot sections, because of the lack of inspections and needed repairs to the slot wedging.

The wedging design has changed greatly over time as the current magnitudes have increased with the rise in machine power ratings. Wedges are made from non-magnetic laminates based on phenolic (in older machines) or epoxy resins. They are secured in grooves in the core teeth and packed to exert a radial pressure on the coils or bars in the core slots. The wedge pressures must be sufficient to overcome the winding radial forces at rated current as well as at high inrush currents present during sudden short circuits or line fault events. In higher rated hydraulic and turbine generators, the wedging systems frequently contain top and/or side ripple springs along with tapered sliders to obtain high compression with flexible follow-up and uniform distribution.

Despite extensive efforts during manufacture to provide long term stable wedging, experience shows that the wedge pressure in service does gradually diminish and can lead to winding insulation degradation. It is, therefore, necessary to monitor the wedge pressure in service, and inspect and restore the pressure at regular intervals during maintenance outages. On-line monitoring for slot partial discharges may provide an indication of the early stage of insulation degradation from winding movement in slots due to developing looseness in the wedging. The maintenance inspection involves visual inspection for signs of dusting and/or greasing along the wedges and the wedge tapping test can be used to quantify the degree and the extent of the slackness.

Visual inspections and manual wedge tapping were traditionally done during major maintenance outages with the rotor removed from the bore. The signs of dusting and greasing (in presence of oil), indicates that the winding relative motion in slots is already occurring and abrading the insulation. In such a case a partial or a full re-wedging is needed immediately, or should be scheduled within a short time, preferably within six months.

The manual wedge tapping is done by striking each wedge at several locations with a one pound hammer and listening to the acoustic response. A clear metallic sound or a dull response distinguish tight from lose wedges. This test is somewhat subjective, depending on the judgement of the tester. It requires some experience, but this can be acquired quite readily. A wedge tapping map is produced for the assessment of the wedging condition and need for any corrective action.

Automatic wedge inspection and tapping devices have been developed and are available from OEMs and independent providers such as Qualitrol-Iris Power.

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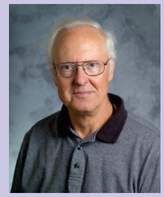
They generally produce more accurate and repeatable results, including maps for future reference and trending of the wedging condition. One advantage of these devices is that they can be used for inspections in outages without the removal of the rotor. In many generators they can be inserted in the air gap between the rotor and stator and remotely controlled to travel from wedge to wedge and around all stator slots. The wedge tightness acceptance criteria have been developed based on the assessment of the risk of probable winding motion in the slots. The generally good acceptance criteria, applied by many users, are:

- No loose end wedges
- No more than 25% loose wedges in any slot
- No more than two or three loose wedges in a row, depending on the wedge length
- No more than 25 to 30% of all wedges loose

From these criteria, decisions can be made to re-wedge individual wedges, individual rows of wedges or a complete stator winding re-wedge.§



Joe Kapler is a Rotating Machines Specialist at Iris Power LP. Before joining Iris Power, Joe was Supervising Design Engineer at Ontario Hydro (now called Ontario Power Generation) for large steam turbine-generators, exciters, electric motors and associated auxiliaries. Joe's unit was responsible for development of purchasing specifications for generators at large fossil and nuclear power plants in Ontario, design reviews during generator manufacturing cycle and generator acceptance testing before delivery and during commissioning. Joe also provided engineering services to station operating staff for failure risk analysis, conducting equipment reliability assessment, equipment repairs and maintenance strategies. Prior to emigrating to Canada, Joe worked as a generator design engineer at Brown Boveri, later part of ABB, in Switzerland. Joe is a Registered Professional Engineer in the Province of Ontario, Canada.

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Qualitrol-Iris Power—3110 American Dr.—Mississauga—Ontario—Canada—L4V 1T2
Telephone: 905-677-4824; Fax: 905-677-8498; Email: sales.iris@qualitrolcorp.com; www.irispower.com—www.qualitrolcorp.com