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DIAGNOSTIC NEWS

The Newsletter on Monitoring the Reliability of Electrical Equipment

New Stator Windings Using Thinner Groundwall Insulation

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BY: GREG STONE

Even with the recent turndown in demand for gas turbine generators, the market for new motors, hydrogenerators and air-cooled turbine generators remains fiercely competitive. Thus manufacturers of such machines continue to strive to reduce manufacturing costs, to gain competitive advantage.

One of the best ways of reducing costs is to make the groundwall insulation thinner than normal, that is, reduce the insulation thickness. GE has calculated that a 20% reduction in the groundwall insulation thickness, with all other parameters held constant, can reduce the overall cost of a motor or hydrogenerator by 20% - yielding a tremendous competitive edge. By reducing the groundwall thickness, one can use less copper to achieve the same temperature rise (a thinner insulation allows the heat from the copper I^2R losses to be conducted to the stator core more effectively). The smaller copper crossection, together with the thinner groundwall, enables the slots in the stator core to be narrower. This in turn allows the depth (radial size) of the core to be smaller for structural support reasons. The result is that the initial reduction in groundwall thickness translates into less copper, less insulation and less steel being required, for the same stator power rating and temperature rise. Since the cost of a machine is largely proportional to the weight of the materials used, overall manufacturing costs are reduced.

Of course reducing the insulation thickness will increase the electrical stress across the insulation. 30 years ago, it was common for many groundwalls to be designed to operate at an average stress of 2 kV/mm (this is the rms phase-to-ground voltage divided by the thickness of the insulation between the copper and the surface of the coil.) In the 1980s, many manufacturers had adopted a design stress of 2.5 to 3 kV/mm. Today, some machines are designed to operate at as high a stress as 5 kV/mm.

Manufacturers who have taken this path, have had to ensure that the increased electric stress will not reduce winding life - 30 years for most users. To validate a new design, the manufacturers use a voltage endurance test on either complete bars or coils, or specially made short segments of coils. The test protocol is IEEE 1043 or similar. With careful design and

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Humidity May Have an Important Effect on Partial Discharge Levels

BY: GREG STONE

On-line partial discharge (PD) testing has been used for decades to help maintenance personnel detect stator winding insulation problems in motors and generators. Specifically, the test can find loose, overheated, and contaminated windings, well before these conditions lead to failure. As a result, on-line PD testing has become an important tool for planning machine maintenance. The test has also found use in determining the effectiveness of any repair work. With the advent of electrical noise separation technology developed in the 1970s and 1980s by Iris staff, reliable on-line PD testing and basic interpretation was made possible by plant engineering staff with moderate training. The result has been the widespread application of the Iris PDA and TGA tests on machines throughout the world.

A tremendous amount of data has been collected with these on-line monitoring systems. It has become clear over the years that motor and generator-operating parameters such as voltage, hydrogen pressure (if applicable), winding temperature and load can sometimes influence the PD activity. This creates both a problem and an opportunity. The problem is that to determine if the insulation is deteriorating over time, variations in the machine operating conditions during PD data collection must be considered. The opportunity is that by observing the influence of operating parameters on the PD activity, it is sometimes possible to identify the root cause of any insulation problems. This then allows the maintenance engineer select the most effective repairs before the motor or generator is removed from service.

Over the past few years, it has become obvious that under certain circumstances the humidity (or perhaps the moisture content) can also affect the PD activity, in addition to load, temperature, etc. It is important for PD test users to be aware of the effect of humidity on the test results. The following gives a few examples of this 'humidity effect'.

Case Study 1

A MotorTrac continuous PD monitor installed on a 4.1 kV motor in PP&L's Susquehanna power plant, measured unexplained swings of PD throughout the day on a motor that was operating at a fixed load and voltage. The customer, Joel Fallbright placed a humidity monitor in the environment of the motor. Figure 1 shows that over a 24-hour period there is an excellent inverse correlation between the PD activity, expressed by Qm and NQN, and relative humidity. That is as the relative humidity increases from 32% to 54%, the peak PD magnitude (Qm) drops from 200 mV to 100 mV, over a 5-hour period. In subsequent testing using a portable TGA-B instrument, it was apparent that the PD was occurring in the endwinding area between phase A and B, since the PD was phase shifted +30° in A phase and -30° in B phase from the normal phase position in the AC cycle for PD occurring in the stator

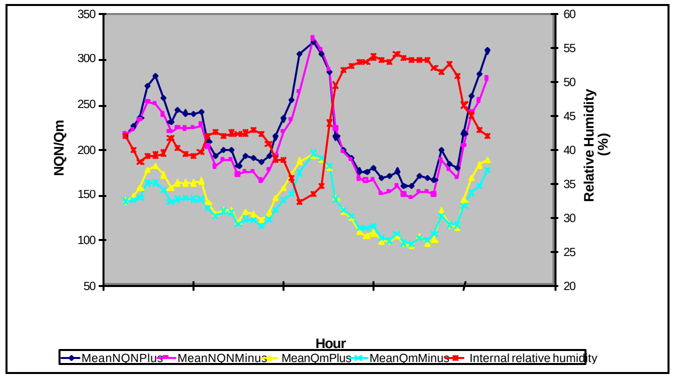

Figure 1: Impact of humidity on PD activity over a 24-hour period in a 4 kV utility cooling water motor with known endwinding contamination problems

slot. In a later visual inspection of the winding, the endwindings of this vertical motor were found to be soaked in oil from a bearing oil leak. In addition, a heavy layer of dead insects covered the endwinding. Such contamination is known to produce electrical tracking in the endwindings of coils connected to the phase terminals. Thus for this motor at least, it appears that lower humidity causes the endwinding electrical tracking to accelerate.

Case Study 2

Figure 2 shows the relationship between PD and humidity in a different motor on the gulf coast of the USA. No continuous humidity sensor was available near the motor. Instead the humidity was taken from the database of a nearby US weather service monitor. Only discrete humidity data was available. This example is much less clear than the one discussed above, but it seems that as the humidity increases the PD also increases. This is opposite to the effect in Case Study 1.

However, the results may be confounded with changes in load and temperature. A visual inspection has not been possible yet, so the root cause of the PD has yet to be confirmed, but the PD patterns indicate the root cause is slot discharge within the slot. The implication from both case studies is that humidity may either increase or decrease the PD.

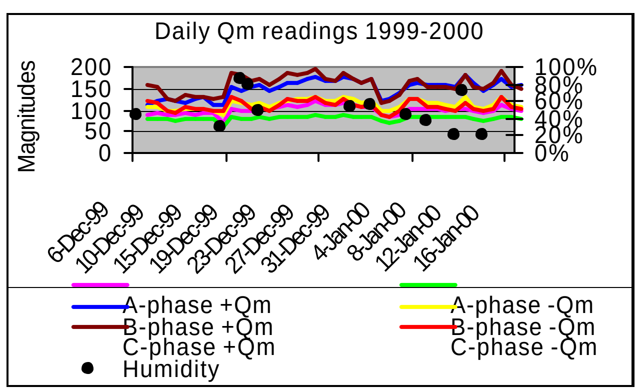

Figure 2: PD activity vs. humidity in an operating 9000 HP, 4.1 kV refinery motor over a 5-week period

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Growth in Field Service

Ian Culbert
Ian received 2nd Class Honors Degree in Electrical Engineering from Dundee Technical College, Dundee, Scotland in 1965. A year later, he joined Parsons Peebles, Edinburgh, Scotland as an induction motor designer. In 1974, he emigrated to Canada to work for Reliance Electric, Stratford Ontario as a senior induction motor designer. Ian joined Ontario Hydro (now Ontario Power Generation Inc.) in 1977, as a specialist providing technical support to power station project engineering, operations and maintenance staff on all types of motors and standby generators. At the end of March 2002, Ian retired from Ontario Power Generation and joined IRIS as a Machine Specialist. He has co-authored a number of papers on the maintenance and testing of rotating machine insulation systems.

David Burr, Ian Culbert, New Recruit, Kevin Rowe, and Paul Sprunt

Paul Sprunt
Before joining Iris, Paul spent thirty years in the natural gas pipeline industry with TransCanada PipeLines and three years in automotive manufacturing with The Crown Group. Paul had extensive involvement with the Ontario Electrical League at both the local and provincial levels.

Kevin Rowe
Hailing from Espanola, Kevin joined Iris after 18 years in the telecom industry, a background in technical training and a familiarity with networks.

David Burr
David James Burr, originated from Tweed, Ontario and is a graduate of St Lawrence College/Kingston Campus. His former position was an electronics-engineering assistant with ESG Canada Inc. located in Kingston, Ontario. ESG Canada is a world leader is the design and manufacturing of micro seismology and acoustic emissions monitoring systems. David's background includes design, manufacturing, testing, field installation and technical field service.

Welcome to the Iris team, we look forward to working with each of you!

IRMC 2002

San Antonio, Texas was the location for this year's Iris Rotating Machine Conference. The attendees were extended a warm Texan welcome by everyone. The historical Menger Hotel provided a relaxed down home venue rich in history and atomosphere. In spite of the heat, the delegates found time to visit the Alamo and dine in one of the many restaurants along the Riverwalk. The program was divided into two training sessions and two technical sessions, breakout sessions and a walk-in clinic. As is customary, the training sessions were full; customers exchanged information and solutions to various problems in the usergroup meetings and at the walk-in clinic machines were given a clean bill of health. These sessions are a great opportunity to learn all about condition-based maintenance and Partial Discharge theory for both new and seasoned users of the technology.

We would like to thank all the authors for their time and effort in presenting very informative technical papers; the session chairs for maintaining the flow of the program; and most of all thank you to all those who attended.

Keep an eye on the website for details on next year's conference. Anyone interested in presenting a paper next year, please email kzarb@irispower.com.

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Implications for PD Testing

The above case studies, as well as some laboratory testing performed at Iris, seems to indicate that the humidity effect on PD will be strongest for stators with endwinding surface PD problems. Thus if a machine is known to have high PD, the humidity effect may be used to help confirm that a PD source is in the endwinding. When testing over a few days with large swings in humidity while the machine is operating at constant load, temperature and voltage, if the PD inversely correlates with humidity, the PD source is likely to be endwinding PD, rather than overheated or loose windings. This is practical information, since it helps maintenance personnel determine the severity of the problem, the nature of the maintenance required, and the outage duration required to correct the problem.

Unfortunately, this humidity effect does make it more difficult to detect increasing deterioration due to endwinding PD by just trending the PD over time. Whenever PD tests are done, and high PD is measured (compared to the Iris database), then users should note the humidity for future reference.

UPCOMING EVENTS

Conferences & Tradeshows

Jul 13: **IEEE**, Acapulco, MX

July 29-Aug 2: **HydroVision**, Portland, OR

Aug 20-23: **EPRI**, St. Louis, MO

Conferences & Tradeshows continued

Sep 2-5: **CIGRE**, Paris, France

Oct 20-14: **CEIOP**, Cancun, MX

Nov 4-7: **Hydro2002**, Kiris, Turkey

Courses

Oct 1-4: **Hydrogenerator Maintenance Course**, Spokane, WA

Nov 20-22: **Partial Discharge Course**, New Orleans, LA

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manufacture, the new designs have been shown to pass the usual criteria for acceptance.

However, it is apparent that some problems can occur when the practical 'thin groundwall' stators are put into service. These include:

- greater tendency for electrical tracking of the endwinding
- greater sensitivity to manufacturing problems - for example smaller wrinkles in the tapes may lead to substantial partial discharge activity
- premature degradation of the semiconductive (slot) coating or stress relief (silicon carbide) coating in the endwinding.

The first of these is not apparent in laboratory voltage endurance tests. Electrical tracking will only occur if there is partly conductive contamination on the endwindings of the coils. Since the insulation is thinner than for older designs, the capacitance of the insulation in the endwinding area will be higher. This leads to higher capacitive currents that will flow over the surface of coils in the endwinding area. At discontinuities in the conductive path, discharging will occur, which results in carbonized electrical tracks over the surface. With time, such tracking can lead to phase-to-phase failure. Although electrical tracking is a well-known phenomenon in contaminated windings, the thin wall designs tend to deteriorate much faster. Thus stator winding cleanliness is a critical requirement for modern air-cooled designs. The problem can become even more intense if the separation between coils in the endwinding is not increased from normal designs.

Secondly, there seems to be a greater sensitivity to minor manufacturing flaws with the thin wall designs. Although voltage endurance testing may have shown that well-made coil insulation will have an acceptable life, in mass produced coils and bars it is inevitable that some wrinkling of mica paper tapes or imperfect impregnation of the tapes with epoxy will occur. If these deficiencies result in voids within the insulation, then the likelihood of partial discharges within the groundwall is increased. This is because the electric stress within a void is proportional to the dielectric constant of the epoxy mica times the average ambient electric stress (up to 5 kV/mm in some thin wall coils). Thus it is even more important to ensure that the quality is high in thin wall stators by performing off-line PD or tip-up tests in the modern designs.

Finally, there seems to be a resurgence of problems associated with the semicon and grading coatings in the thin wall stators. In the 1970s and 1980s, a signficant percentage of air-cooled stators had partial discharge and ozone problems associated with pre-mature degradation of the stress control coatings in the slot or adjacent to the slot (the so-called white powders and white bands). With improved QC of the semicon and grading coatings, these problems largely disappeared in the 1990s. However, the thin groundwall has higher capacitance (as described above), which increases the 50/60Hz current through the surface coatings, increasing the rate of oxidation. In addition, even small microvoids just under the coatings have a tendency to experience PD, also resulting in coating destruction. The result is that manufacturing QC of the coatings is even more critical if PD is to be avoided.

The trend to designing stator windings to operate at ever-higher electric stress will result in less expensive motors and generators for machine users, or the ability to significantly increase the power output for a rewind. However, everyone should be aware that there is a 'price' in the form of increased quality control on the part of manufacturers, and an even greater need for users to keep the windings free of partly conductive contamination.

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