

Inside this Issue:

Off-Line Diagnostic Testing of Stator Winding Insulation	1,2,3
Hazardous Area Certifications for On-Line Monitoring Systems	3
Blake Lloyd Elected IEEE Fellow	4
IRMC 2016	4

**UPCOMING EVENTS
2016**

501 F&G User Group Meeting	Feb 22 San Antonio, TX
WTUI—Western Turbine Users Meeting	Mar 20-23 Palm Springs, CA
IRMC	June 13-16, Scottsdale, AZ
Hydro Vision	June 25-28 Minneapolis, MN

OFF-LINE DIAGNOSTIC TESTING OF STATOR WINDING INSULATION

By: Howard Sedding

Many end users, manufacturers and service organizations now routinely employ some form of on-line monitoring technology, e.g., partial discharge (PD), as a significant component of a predictive or condition-based maintenance program. The widespread and increasing use of such methods has led to some in the industry questioning the value of performing off-line diagnostic testing to assess stator winding insulation condition if they have on-line monitoring. Traditionally, many utilities would take the opportunity during major outages to do one or more of these off-line tests, however, due to economic pressures, the interval between such outages has significantly increased. In the past, the frequency of outages in which the rotor was removed was about five to six years; however, currently intervals of 10 – 12 years have become common. Further, many plant managers are reluctant to permit electrical testing because of concerns that such testing may damage the winding even though the applied voltage used in the vast majority of tests is limited to the nominal line-to-ground operating voltage. Below, we shall discuss the role that off-line tests have to play, the commonly used tests and their appropriate application. Only those tests that are covered by IEEE or IEC standards are discussed and ac and dc hipots are precluded because these are go/no-go tests with relatively little diagnostic value.

Insulation Resistance & Polarization Index

An insulation resistance measurement is one of the most basic and commonly employed tests used in the industry. The test involves applying prescribed dc voltage across the groundwall insulation and, on the basis largely of the leakage current, the resistance value after one minute of

voltage application is derived. The polarization index is obtained by taking a further insulation resistance measurement at 10 minutes and dividing this value by that measured after 60 seconds. These tests are governed by IEEE 43 that specifies, among many factors, the appropriate applied voltage (dependent on the rated voltage of the machine) as well as acceptance criteria for insulation resistance and polarization index. Until recently, there was no equivalent IEC standard for this type of testing, however, this situation will change in 2016 or 2017 with the impending publication of IEC 60034-27-4. Typically, these tests are used either to determine that the stator winding is fit to undergo further diagnostic testing involving high voltages or to verify a ground fault in the event of an alarm or trip. While the diagnostic content of an insulation resistance test has been considered limited due to sensitivity to surface leakage currents, the latest version of IEEE 43 does include guidance



Off-line testing of a stator winding

Continued on page 2...

OFF-LINE DIAGNOSTIC TESTING OF STATOR WINDING INSULATION

Continued from page 1...

on more sophisticated methods of interpretation that may provide insight into the bulk condition of the insulation. If the machine is shut down for maintenance, this test is strongly recommended.

Capacitance & Dissipation Factor

Capacitance and dissipation factor measurements have been routinely used by manufacturers for decades as a means to assess the quality and uniformity of individual stator bars and coils. Dissipation factor testing belongs to the broad range of measurements of dielectric loss and is also commonly referred to as the tan delta or power factor test. Power factor is the cotangent of the loss angle (delta) whereas dissipation factor represents the tangent. At low values of loss angle, the tangent and cotangent are virtually the same. The higher the dielectric loss in an insulating material, the higher will be the dissipation factor. Defects in an insulation system, such as voids and delamination, result in PD which is a loss mechanism. Thus, dissipation factor measurements may be used to determine the void content of an insulation system. Unlike a PD test, dissipation factor also incorporates information about the bulk insulation system. Thus, there may not be an exact correlation between the results obtained from PD and dissipation factor tests. Often the dissipation factor is obtained at two different voltages, e.g., at 25% and 100% of the nominal line-to-ground operating voltage, to derive the dissipation factor tip-up. At the lower voltage the insulation system is assumed to not be subject to PD. Thus, the tip-up is used as a means to differentiate between effects due to the bulk and defects such as voids. This testing is governed by IEEE 286 and the recently published IEC 60034-27-3. Both documents provide guidance on performance of the test; however, the IEC standard also includes acceptance criteria, for individual stator bars and coils, which to some are controversial. Due to the complications caused by the stress grading components in machines rated 6.6 kV and above, no such criteria are available for measurements performed on complete stator windings. Thus, with the widespread availability of either on-line or off-line PD testing, this

test is becoming less popular as a maintenance test.

Partial Discharge

Off-line partial discharge measurements are employed to provide information on the void content of the insulation system. Unlike a dissipation factor measurement which spatially averages the test result, a PD test is sensitive to those voids with the largest dimensions (which are those of most concern). Where an on-line or off-line PD test indicates anomalously high PD magnitudes, corona (or TVA) probe testing may be deployed to aid in identifying the location of this activity. Partial discharge testing is also useful to uncover other defects such as surface contamination and inadequate clearances between phases. The identification of such issues which occur in the endwinding regions of machines are significantly aided by employing additional techniques such as corona (ultra-violet) cameras, corona probes and ultrasonic probes. Extensive guidance on off-line PD test methods is given in IEEE 1434 and IEC 60034-27. Comparing on-line PD testing to its' off-line counterpart, there are many advantages to performing the test with the machine operating. Among these are:

- the voltage distribution is correct,
- the stator winding is at elevated temperature,
- and, the coil/bar forces are present.

In short, there are a number of defect mechanisms, e.g., loose windings, that cannot be detected using an off-line PD test. Further, often the results from off-line measurements have to be treated with some caution because they may be pessimistic relative to the operating condition. For example, off-line PD testing of hydrogen-cooled machines is almost invariably done in air at atmospheric pressure which produces much higher PD. However, if one takes the view that these results would be worst case, then the data thus obtained still have value. A significant advantage that off-line PD testing provides is that the test operator has control of the applied voltage. Consequently, despite the always present background electrical interference (which is a significant problem for on-line testing), the PD

Continued on page 3...



Hazardous Area Certifications for On-Line Monitors

Many motors, and some generators, operate in areas where there may potentially be atmospheres containing flammable gases. If a spark occurs, these gasses may be ignited, starting a fire or initiating an explosion. The main concern for hazardous gases is in petrochemical plants, but there may also be risks in mines, food processing plants where fine dusts are present, and in some jurisdictions, hydrogen-cooled turbine generators are considered at risk.

To minimize the danger of fires and explosions, government regulators require that the motors and all associated equipment in hazardous, or potentially hazardous, areas be certified for the application. Generally, this means the equipment cannot produce a spark or a hot enough surface that it could ignite the gas; or, if it can produce a spark, the equipment must be ventilated (purged) with a non-flammable gas such as air or nitrogen. A massive body of regulations has grown around this topic, and the regulations tend to be different for each country. To certify that equipment will not ignite a spark, third party testing organizations assess the equipment for compliance to the regulations (e.g. UL, CSA, DNV -GL, etc.).

In the past, equipment suppliers, like Iris Power, would have to have monitoring equipment modified for each country and tended to have third party certifiers for each country. In the past 5 years, there has been

some effort to make the regulations more consistent between countries, and have mutual recognition of third party testing. We are still a long way from having one set of regulations, and requiring only one set of testing that is recognized everywhere. However, the International Electrotechnical Commission's (IEC) Ex initiative is a move in this direction. This initiative started with the IEC's creation of a series of test requirements (IEC 60079 series) that has been adopted by many countries around the world. Many third party testing companies have now been authorized by IEC to issue certifications after successful passing of the required tests. Many countries will accept these third party tests.

Since many motors are installed in hazardous areas or potentially hazardous locations, Iris Power has been obtaining certifications for the relevant on-line monitors for over 20 years. In particular, our PDTracII on-line PD monitor for motors, including the sensors and the electronics, has been certified for hazardous areas in North America, Europe, Russia and Brazil, amongst others. Other Iris Power products that can be certified for hazardous areas include flux probe sensor kits, Stator Slot Coupler kits (for large steam or gas turbine generators) and the EVA (fiber optic accelerometer) kits.

If you have any questions about the details of the certification for each product, please contact your application engineer. §

OFF-LINE DIAGNOSTIC TESTING OF STATOR WINDING

Continued from page 2...

activity (if present) can normally be observed as the applied voltage is varied. Further, the discharge inception and extinction voltages can be measured, which provide further insight on whether the PD activity is likely to be an issue during operation.

Summary

While experience, to date, indicates that on-line condition monitoring methods such as PD are effective in providing information on stator winding insulation condition, off-line testing still has a significant role to play. In addition to verifying the results of on-line testing, off-line diagnostic tests, especially when more than one technique is used, provide additional information on which to base maintenance decisions. §



2016 Training Schedule

ELCid Course	Mar 8-10 Toronto, Canada
Partial Discharge Course	Apr 12-14 Houston, TX
ELCid Course	Aug 16-18 Toronto, Canada

Blake Lloyd Elected IEEE Fellow



Blake Lloyd, a co-founder of Iris Power and its Director of Development, was elected a Fellow of the Institute of Electrical and Electronic Engineers (IEEE) in late 2015. IEEE is the world's largest technical society with over 400,000 members. Blake was elected for his technical contributions to rotating machine condition monitoring technology. Only 0.1% of IEEE members are elected to the Fellow grade each year so this is a clear recognition of Blake's contributions to rotating machine technology. Prior to founding Iris, Blake worked for the Research Division of Ontario Hydro, where he was involved, amongst other

things, in determining the effect of circuit breaker switching surges on motor windings, partial discharge measurement technology, and expert systems for diagnosing machine winding condition. Since joining Iris he led the research project to develop the world's first continuous on-line partial discharge monitoring system. This technology has now been installed on over 1500 machines. He also developed the HydroX expert system for diagnosing the condition of hydrogenerators, which is sold by GE under license as part of its System One diagnostic system. Blake has also lead the project to develop Iris's integrated monitoring product – GuardII – which can monitor all critical winding functions on a single platform. Blake has been a main author on over 55 technical papers, some of which were voted best paper. One notable paper, on a new technology for detecting shorted turns in turbine generator rotor windings, won the IEEE Power and Energy Society's Best Paper Award in 2014. Mr. Lloyd has a BSc in electrical engineering from the University of Waterloo in Canada, and is a Professional Engineer in Ontario, Canada.

Blake joins Qualitrol – Iris Power's Greg Stone in being elected a Fellow of the IEEE. Other Iris staff who have been recognized by their IEEE peers for technical contributions include Mladen Sasic, Dr. Howard Sedding and Resi Zarb, who are all senior members of IEEE.

Also of note, Clyde Maughan was elected a Fellow of the IEEE in late 2015. Mr. Maughan spent the first half of his career at GE where he was part of the team that developed the very first epoxy mica insulation system – by far the most prevalent insulation system used on motors and generators rated 3.3 kV and above. For the second half of his career, he has been a forensic expert in generator failures and a prolific educator of engineers on the causes of machine failure. Clyde has been a frequent contributor to the Iris Rotating Machine Conference.

We congratulate Blake and Clyde on their election as IEEE Fellows.§

Iris Rotating Machine Conference

The 18th Annual Iris Power Conference was held in Nashville, TN last June. Attendees from the US and Canada were joined by participants from Japan, Ireland, South Korea, Finland, Sweden, Brazil, Italy, Isreal, South Africa, and Switzerland to make this, once again, a very successful conference for endusers of motors and generators.

Mark your calendars for IRMC 2016 which will be held in Scottsdale, Arizona the week of June 13-16! Attendees presenting a paper at the IRMC receive free registration.

If you have a topic to present, please contact Karen Howard,

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