Online Monitoring of Motor Stator Insulation Condition

Industrial motors (Figure 1) drive many of the world’s most critical assets. From oil and gas upstream and downstream installations to combined-cycle and nuclear power plants, three-phase ac motors are a constant presence in our industrial facilities. Whether the driven asset is a main air blower or wet gas compressor at an onshore refinery, a product export pump on an offshore platform, or a pump for boiler feedwater or reactor coolant at a power generation station, these motor driven assets are critical to the viability of your operation, and to the success of your business.

The Big Question
When motors fail, how do they fail?

The Consistent Answer
For medium-voltage (greater than 4 kV) motors, industry surveys consistently point to one answer: stator insulation failure.

Unlike purely mechanical rotating assets, motors incorporate fundamental electrical characteristics, with insulated stator windings and laminated iron armature and field cores to create rotating magnetic fields and convert them to useful torque.

Predictably, when medium voltage motors eventually fail, the weakest link is the winding insulation. Many motors already have condition monitoring systems that will detect rotor failures (which make up 13% of total failures) and bearing failures (which are another 13% of total failures). However, until recently, no reliable on line technology has existed to address the main failure mode, stator winding insulation failure - which accounts for fully 66% of motor failures (Figure 2).

Knowing how motors will eventually fail helps point us to a monitoring solution. If only a technology existed that would allow owners and operators to track the insulation degradation over time, reliably and without needing to remove the motor from service, this would be a useful tool. Outages or downtime could be scheduled more effectively, unplanned events could be avoided, overall reliability would increase, and safety would improve.

For many years, industrial motor owners and operators have had to rely on one of the two following technologies to characterize the condition of the motor stator insulation. As you will see, neither of these methodologies is optimal.

Motor Failures

![Graph showing motor failure modes.]

FIGURE 2: Identified failure modes from a multi-year survey of monitoring and diagnostics statistics of electrical machines and drives (Reference 2).

Offline Portable Motor Testing Instrumentation
Several companies offer offline testing equipment that can give a reasonable characterization of the stator insulation condition. Unfortunately the motor and driven machines must be shut down, removed from service and "locked out" for safety before testing can proceed. Many motor operators cannot afford this interruption to their process or business more often than once every 2 to 5 years or even longer. Testing at such a lengthy interval is of minimal value at best. The motor may be close to failure (or have already failed) by the time a scheduled test occurs.

Additionally, this testing is performed at ambient temperatures, so it cannot give a true
characterization of the insulation condition while running under load at normal operating temperature. Worse-yet, several of the most valuable offline tests use low-current, high-voltage methods that actually degrade the insulation and contribute to early failure. When a motor with such a history eventually fails, the offline testing very likely contributed to the failure it was intended to prevent! Industry has had to rely on this technology because no reliable on line test was available.

**Online Partial Discharge (PD) Testing**
Another method that has been used is an on line technology called Partial Discharge monitoring. As insulation degrades over the life of the motor, very brief small discharge pulses occur through the insulation (often in voids within the dielectric). The PD monitoring system detects the increasing frequency of the discharges as the insulation deteriorates. Some systems also use ultrasonic acoustic sensors to listen for these discharges and plot the approximate location in an attempt to predict where and when the insulation will fail and hence when the motor will fail. While partial discharge technology does perform an on line measurement, the technology relies heavily on complex algorithms and modeling for its prediction.

Partial Discharge monitoring has met with limited success due to the unreliability of the algorithms to predict where the failure in the insulation will occur. Often equipment operators have had Partial Discharge equipment that predicts a particular motor failure, only to find that the motor continues to operate trouble-free for several years past the point it was predicted to fail. Clearly, industry needs a better set of tools to ensure the reliability of their operations and the viability of their business.

Motor Stator Insulation Monitor (MSIM) The Bently Nevada Motor Stator Insulation Monitor (Figure 3) is an on line monitoring system that provides the industry’s only continuous, direct measurement of stator winding capacitive and resistive leakage currents, offering the only credible online indication of motor insulation integrity using direct leakage current available outside of a laboratory.

This system was developed over several years in conjunction with the GE Global Research Center and has been designed for compatibility with the Bently Nevada 3500 Machinery Protection System (Reference 3). It is likely that the 3500 system is already installed in your facility on your most critical motor-driven equipment, making for an economical upgrade path if you decide to add MSIM capability. The system is also fully compatible with our System 1 software for long-term trending and diagnostics, either onsite or remotely.

**MSIM System Benefits**
The MSIM’s technology enables you to monitor stator insulation condition continuously, eliminating surprises and providing valuable lead time for planning any required outages and repair activities. Shutting down the process in a controlled manner reduces the upsets that often result from an emergency trip. The system delivers several important benefits:
- Depends only on the configuration of the motor (6-lead external termination required) and is independent of the OEM.
- Works with induction and synchronous motors, with supply voltages up to 7.5kV and either 50 Hz or 60Hz power supply (not compatible with DC motors or variable frequency drives).
- Continuous, online insulation integrity measurement does not require the motor to be removed from service for (potentially damaging) testing.
- Directly measures resistive and capacitive leakage
• Current to provide Dissipation Factor IDFI measurement.
• Provides motor stator temperature measurement.

**3500 System Integration**

Because the MSIM leverages our existing 3500 series monitoring system technology, it provides additional "infrastructure" benefits:
• MSIM integrates with existing 3500 system, together providing protection and condition monitoring for both the drive motor and the driven machine.
• Accommodates MODBUS communications parameters for integration with your DCS.
• Configurable alarm setpoints (Alert & Danger) for all variables.
• Drives 3500 relay output for local annunciation.
• Local Display available as standard 3500 system options.
• Compatible with System 1* Optimization and Diagnostics Platform.
• Uses existing 3500 system training, reducing training investment.

**Applications**

Motors that can most obviously benefit from application of the MSIM technology are those that are classified as being highly critical to your business. Any situation where motor failure could cause a serious detrimental effect on your operation, whether it is to reliability, safety, production or environmental compliance, would be candidate for application of an MSIM system. While it is impossible to determine the actual criticality of a motor to a business without analysis, a few typical examples of highly critical motor applications are listed here.

**Oil & Gas Upstream (offshore and onshore)**
• Main Process Compressors
• Combustion Air Compressors
• Water Injection Pumps
• Export Pumps

**Oil & Gas Downstream**
• Main Air Blower
• Plant Air Compressors
• Wet Gas Compressors
• Feed Gas Compressors
• Recycle Compressors
• Regeneration Compressors
• Reciprocating Hydrogen Compressors

**Power Generation**
• Boiler Feedwater Pumps
• Boiler Circulation Pumps
• Reactor Coolant Pumps

**Field Deployment**

The MSIM system has been deployed successfully at several power generating stations in the USA (Figure 5). Extensive field testing on Boiler Feedwater Pump drive motors at these facilities has verified that motor insulation degradation CAN be detected on line and trended to give operators and owners direct line of sight to machine condition and early warning of motor failures for their critical machinery, with very high confidence factors.

**Technology Overview**

The MSIM system consists of three voltage and three current sensors, a dedicated 3500 monitor and I/O module, and optional System 1 or DCS connectivity. In many ways the installation is very similar to other 3500 system installations.

The key to how the MSIM works is the HSCT technology (Figure 41). The HSCT directly measures the very small leakage current in the milliamp (mA) range in the presence of the normal running current of hundreds of amps.

The 3500 interface module conditions and converts the HSCT sensor signal to the direct OF measurement.

In addition to the HSCT, the MSIM monitor uses High Voltage Sensors (HVS) with interface modules, along with motor stator temperature IRTDs or thermocouples) as inputs to the system.

**FIGURE 4: Photo inside motor termination vault. One HSCT is installed on each phase of power leads to the motor. Note: The HSCTs need to sense current in both conductors of each phase, so the MSIM system works with externally-terminated wye (star) connected stators, but not with internally-terminated or delta connected stators.**

**FIGURE 5: Field installation at a power generating station. The aluminum-cased HSCT transducers are behind the normal protection CT transducers (with brown molded plastic cases) in this photo.**
Test Data
We tested the MSIM system in a controlled laboratory setting to monitor actual insulation deterioration of stator windings. (Figure 6) shows test results for a motor that was subjected to severe stress in order to "age" the stator winding over a highly-accelerated time frame. This allowed the testing to proceed over the course of a few hours instead of several years.

References
1. GE Motors Pegasus MHV Medium Voltage AC Induction Motors brochure, GEA-12310C.

For More Information
Contact your local GE Representative or find us online:
View and download references at our Motor Stator Insulation Monitor page:
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FIGURE 6: Online leakage current trend showing the final hours of motor life before full insulation failure. The capability to directly measure very small leakage currents in the presence of very high operating currents is unique to the MSIM system.

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Source: Jan.2014 • No.1 • Vol.34 ORBIT 15
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