Sustainable Shaft Grounding Ensures Reliability of Energy-Saving VFDs in Data Center HVAC Systems

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As reported in previous issues of this magazine, the use of variable frequency drives (VFDs), also known as inverters, can reduce the cost of cooling data center computer servers. By optimizing the power usage of HVAC fans or pumps, VFDs can provide substantial energy savings. But if the increased efficiency is not sustainable, those savings vanish.

Currents induced by VFDs on motor shafts can wreak havoc with motor bearings, dramatically shortening motor life and causing costly repairs and/or downtime. To mitigate these currents and realize the full potential of VFDs, effective, reliable shaft grounding is essential.

In flow control applications, the potential for increased efficiency with VFDs is especially dramatic. Many centrifugal fans and pumps run continuously, but often at reduced loads. Because the energy consumption of such devices correlates to their flow rate cubed, motors that drive them will use less power if controlled by a VFD. In fact, if a fan's speed is reduced by half, the horsepower needed to run it drops by a factor of eight. In light of this, throttling mechanisms that restrict a motor's work seem old-fashioned and wasteful. In applications where constant torque is needed for more accurate process control (reciprocating compressors, conveyors, mixers, etc.), VFDs can be programmed to prevent motors from exceeding a specific torque limit.

In direct-expansion (DX) air-conditioning systems, VFDs control the speed of fan motors in air handling units. In chilled-water air-conditioning systems, they control the speed of pump motors. In either case, downtime at a data center could be disastrous.

More and more frequently, owners of data centers are being asked to sign service-level agreements promising customers financial compensation if the center's operation drops below 99.9999% reliability. Known as "the six nines of reliability," this level allows only 31.5 seconds of downtime per year! To complicate matters, today's high-density blade servers have multiple processors, each requiring careful attention to its optimal operating temperature ranges.

Of course, the single most important fail-safe system is backup power generation and an uninterruptible power supply (UPS) system with redundant bussing. Having dealt with the threat of outages, many data centers have installed various "bells and whistles" to allay other reliability concerns. For example, sensors mounted on server racks provide continuous feedback to VFDs for automatic fine-tuning of air temperatures and flow rates. With the confidence that cooling and air flow will be kept to minimum necessary levels and the money saved by eliminating excess power use, a data center can install more servers, or perhaps simply enjoy higher profits.

The next item requiring an owner's or operator's attention would be heading off failures of HVAC fan motors. Even if such failures were limited to one or two motors and the data center's redundant air-handling system could compensate for the loss, most facility managers would prefer to take steps to prevent the problem in the first place.

Hard to predict and often overlooked, VFD-induced shaft currents cause cumulative damage to a motor's bearings, even in motors marketed as "inverter-ready." Because the problem is best addressed in the design stage of a system, the best solution arguably would be a motor with built-in bearing protection, available at a reasonable cost. Minimal, voluntary standards issued by the National Electrical Manufacturers Association (NEMA) for IGBT-inverter-controlled motors rated for 600 volts or less state that such motors should be designed to withstand repeated surges of 1600 volts (or 3.1 times the motor's rated voltage) and rise times of 0.1 microsecond. However, since no one enforces these standards and testing is problematic, motor manufacturers are free to make whatever claims they like, and most models boasting extra protection from VFD currents have beefed-up insulation for the windings, not for the bearings.

Fortunately, the problem can be mitigated by retrofitting previously installed motors. Whether a VFD-controlled motor is being used to run an air-conditioning fan in a "green" building or to run a conveyor on an energy-efficient assembly line, shaft grounding is a cost-effective way to achieve sustainability.

A Closer Look at Bearing Damage

Short of dismantling the motor, there are two main ways to check for bearing damage — measuring vibration and measuring voltage. Neither method is foolproof. By the time vibration tests confirm it, bearing damage is usually far advanced. Likewise, the main benefit of voltage tests may be the relief they provide if the results indicate no shaft voltages. If a baseline voltage measurement is taken right after a VFD is installed, subsequent monitoring may provide early warning of harmful current loops.

Shaft currents can be measured by touching an oscilloscope probe to the shaft while the motor is running. These voltages repeatedly build up on the rotor to a certain threshold, then discharge in short bursts along the path of least resistance, which all too often runs through the motor's bearings.

Serious, cumulative electrical bearing damage can be attributed to high peak voltages and extremely fast voltage rise times associated with the high switching frequencies of modern pulse-width-modulated VFDs. Discharges through bearings can be so frequent that before long the entire bearing race wall becomes riddled with fusion craters known as frosting. Since many of today's motors have sealed bearings to keep out dirt and other contaminants, electrical damage has become the most common cause of bearing failure in VFD-controlled AC motors.

In a phenomenon known as fluting [Figure 1], a VFD's operational frequency causes concentrated pitting at regular intervals along the race wall, forming washboard-like ridges. Fluting can cause excessive noise and vibration that forewarn of imminent bearing failure.

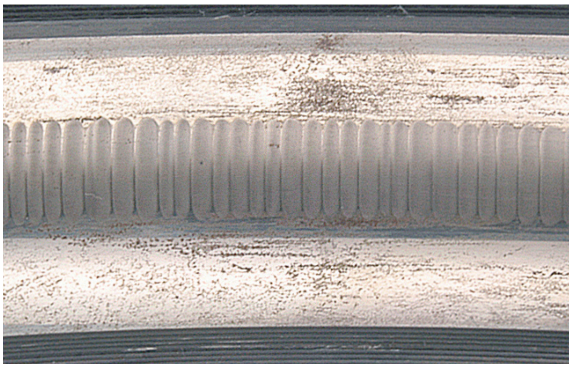

Figure 1: Pitting of a bearing race wall at regular intervals leads to a phenomenon called fluting.

The Search for a Solution

Motor failures caused by VFD-induced shaft currents result in hundreds of thousands of hours of unplanned downtime every year in the United States alone. In addition, these failures affect the performance and mean time between failure (MTBF) of the original equipment systems in which the motors are used. In some production applications, even a momentary stoppage due to motor failure can cost more than $250,000, excluding the cost of repairing/replacing the motor. Clearly, there is a need for a device that mitigates bearing damage from VFD-induced shaft currents.

NEMA Standard MG1 Part 31 ("Definite-Purpose Inverter-Fed Motors"), Section 4.4.3 (to be addressed by Construction Specifications Institute specification 23 05 13 for HVAC motors), recommends bearing insulation at one end of the motor if the NEMA-motor-frame size is 500 or larger and the peak shaft voltage is greater than 300 millivolts. In these larger motors, bearing damage may be due in part to magnetic dissymmetries that result in circulating end-to-end shaft currents.

For smaller motors, the same standard recommends insulating both bearings with high-impedance insulation or installing shaft grounding brushes to divert damaging currents around the bearings. For these motors, a VFD can generate high-frequency common mode voltage, which shifts the three-phase-winding neutral potentials significantly from ground. Because the damaging voltage oscillates at high frequency and is capacitively coupled to the rotor, the current path to ground can run through either one bearing or both.

The NEMA standard is quick to point out that bearing insulation will not prevent damage to connected equipment. When the path to the bearings is blocked, the damaging current seeks another path to ground. That other path can be through a pump, gearbox, tachometer, encoder, or break motor, which consequently can wind up with bearing damage of its own.

While conventional metal grounding brushes do provide alternate paths to ground, unfortunately they also corrode, collect dirt, and wear out, thus requiring regular maintenance.

The ideal solution would be a low-cost, maintenance-free device that safely redirects shaft currents along a very-low-impedance path from shaft to ground (protecting connected equipment as well as bearings). This device could be installed by the motor manufacturer or retrofitted in the field in virtually any VFD application. One device that meets all these criteria is the AEGIS™ SGR Bearing Protection Ring [Figure 2] from Electro Static Technology, a relatively recent invention that overcomes the problems of conventional grounding brushes. The ring works with virtually no friction or wear and is unaffected by dirt, grease, or other contaminants. A few manufacturers have introduced motors with bearing protection rings already installed, but at this writing such motors are the exception, not the rule.

Figure 2: The AEGIS™ SGR Bearing Protection Ring

For too long, the importance of grounding to protect motor bearings has been underestimated. To minimize harmful currents and realize the full "green" potential of VFDs, an economical, long-term method of shaft grounding is a must. Until all OEM motors marketed for use with VFDs are truly "inverter-ready," retrofitting them with shaft grounding is the best approach.

The AEGIS™ SGR Bearing Protection Ring can be installed easily with either brackets or conductive epoxy. Currently the most effective and universally applicable solution to the problem of VFD-caused bearing damage, it ensures sustainability of VFD energy savings and an exceptionally high return on investment.

ÆGIS™ SGR BEARING PROTECTION RING

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