Burned Out Motors and Variable Frequency Drives

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MECHANICAL AND ELECTRICAL ENGINEERS

Overview

A client called me in one day after one of their cooling tower motors burned up. It turns out that this was not the first time it had happened, and the circuit also had a history of nuisance tripping on ground fault. Not overly fond of the cost to rewind a 75 horsepower motor, the client asked me to get to the bottom of the problem.

Upon more research, I learned that the 480 volt motor is located approximately 500 feet away from a variable frequency drive (VFD). The drive manufacturer said that this condition was caused by "reflecting waves" from the VFD.

VFD Technology

Variable frequency starters are one aspect of a much larger trend toward harmonically rich equipment installed in power distribution systems. Other equipment ranges from items as simple as desktop computers with switch-mode power supplies to more complicated UPS systems with large rectifier inputs. In all cases, the instantaneous switching of solid-state based components wreaks havoc on power distribution systems that manifests itself in various ways. Motor burnouts are one such example of the kinds of problems seen whenever there is equipment that causes harmonics on the system.

Reflecting waves on VFD circuits is a fairly common problem where the motor and the VFD are far apart from each other and resistance can go close to zero at a particular frequency. If it does, voltage or current can skyrocket. Since a VFD circuit is rich with harmonic voltage frequencies, and there is a fair amount of resistance and capacitance with long leads, there is a dramatic increase in the likelihood that resonance may occur. The end result is the VFD nuisance tripping off on one of the safeties, and the motors failing due to insulation failure of the windings.

The Resonance Phenomenon

A good way to understand resonance is to take one end of a clothesline, tie the other end to a tree, and shake the line at a certain rate until you see standing waves, or resonance. Change the length of the line (i.e. the resistance), and in order to achieve standing waves, you may have to shake the line at a different rate (i.e. frequency). You can shake the line at some multiple of the standing wave and still get resonance, but at a different frequency. If you shook the line with more intensity (i.e. raising the voltage) but kept the rate of shaking the same, the waves would get stronger until theoretically the tree would be ripped out of the ground - the equivalent of a motor burning out.

Potential Solutions

There are ways to mitigate the problem of resonance once it occurs. Line reactor-type filters improve a generic set of problems by reducing the utility line transients into the VFD, providing a more sinusoidal waveform to the motor that ultimately reduces heat, providing for a more quiet motor operation due to the elimination of some of the harmonic currents, and reducing short circuit values. However, these improvements may not offer enough of a solution to eliminate resonance.

Dv/dt filters take reactor technology one step farther by adding resistors to the reactors, thus creating a tuned filter. A dv/dt filter changes, or "tunes" the resonant frequency of a circuit. The goal is to change it to something so high that the probability of this kind of problem is very low. Going back to the clothesline analogy, its like tying a fishing weight onto the clothesline somewhere along its length and trying to repeat the experiment, where the weight dampens your ability to shake the line. A much higher frequency and intensity is needed to obtain the standing waves. In the power distribution world, this resistance changes the parameters to the point where resonance is a near impossibility for most power systems.

As for the ground fault problems, it is due most likely to capacitive coupling of the wires to ground. The good news here is that a tuned filter will surely reduce the third harmonic, which is probably the one that is causing the ground fault trip. If that doesn't help, a more sophisticated ground fault detection sensor that calculates the 60 Hz component of current may be necessary.

Conclusion

Most installations never become afflicted with the resonance phenomenon. This is the first time I ever saw it since VFD technology became popular about 25 years ago.

The best way to avoid problems with VFD technology is develop and maintain a set of guidelines for use when working with VFDs, and abide by these rules. I attribute my lack of familiarity with this phenomenon to the following rules I have always adhered to:

1. Always keep the VFD as close to the motor as practical, although in some cases this obviously cannot be observed.

2. Install "inverter-rated" motors. This means that the motor must meet the requirements of NEMA MG-1 Part 31.40.4.2. Prior to this standard, we used to make sure that the motor had Class F insulation with a service factor of 1.15. Under no circumstances did we specify the more common Class B motors. The NEMA spec takes the Class F requirement one step further by requiring the motor to pass certain voltage spike tests.

3. Conductors between VFD and motor, if installed underground, should have better quality insulation than conventional THHN building wire. Better dielectric qualities will reduce moisture penetration and maybe some capacitive coupling, thus reducing some of the ground current. Complete capacitive coupling however, can only be reduced significantly by using shielded cabling, which means cable that is probably

rated for at least 1,000 volts.

4. Slower motor speeds reduces the speed of the internal fan in the motor. Add to that a dirty voltage sine wave, and this is a perfect recipe for overheating the motor. Indoor motors should have oversize fans if possible. Outdoor motors are usually totally enclosed non-ventilated types, but they should be installed to avoid direct sunlight.

It is virtually impossible for the engineer to determine if a particular application of a VFD would cause resonance. VFD manufacturers do not offer enough data to make these determinations, and motor impedance characteristics are not known

As with every technology, the cutting edge becomes the bleeding edge for those who are paid to have the expertise that is needed for customers. Problems with new technology in the power distribution industry usually take about a year or two to surface. My first goal is to understand the technology as best as possible, and then to recognize the pitfalls and avoid them.

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