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Variable-frequency drives are beneficial, but you must avoid voltage spikes that can cause winding failure.

When you want to control motor speed, you usually choose a clutch or a variable-frequency drive (VFD)—also called an inverter. In most cases, the advantages of VFDs make them the better choice, so much so that industry installs 10,000 to 15,000 VFDs each week. But VFDs have their limitations; for example, they cannot multiply torque. Misapplication can be expensive and frustrating. But correctly applied, VFDs can reduce costs while increasing success with production goals.

How VFDs work

The primary purpose of a VFD is to enable constant-speed ac induction motors to run at variable speeds. Two factors determine the speed of an ac induction motor: the frequency of the supplied power and the number of magnetic poles per phase. For example, at 60 Hz the synchronous speed of a four-pole motor is 1800 rpm (120 x 60 cycles/sec divided by 4 poles = 1800 rpm). Unless one of these factors changes, the speed remains constant. But a VFD can change the utility’s sinusoidal ac power to variable-frequency dc current, making it possible to adjust (reduce) the speed of ac induction motors almost infinitely.

The most common method VFDs use to accomplish this is pulse width modulation. By sending the motor pulses of dc voltage in varied widths, an inverter mimics the increasing and decreasing amplitude of an ac sine wave. The pulse at the center of each wave is the widest (longest duration), while those on either side of it are progressively narrower (shorter duration). When VFDs modulate the width of pulses in this way, they are referred to as pulse-width modulation inverters (PWMs).

The amplitude or peak voltage of each pulse is, in theory, about the same as the maximum amplitude of the sinusoidal voltage supplied by the utility. The polarity of the pulses changes from positive to negative during the second half of each cycle, replicating the polarity shift that occurs with ac power during each complete cycle.

With the VFD, you can adjust the motor speed by simply changing the frequency of the simulated sine wave. Decreasing the frequency slows the motor, while increasing it (within limits) causes the motor to speed up. Although VFD technology works well in most situations, serious problems may arise with some applications and motor-drive systems.

Switching frequency and cable length problems
Because a VFD sends out several thousand pulses each second, the switching frequency can become a problem. This is true especially if the cable between the drive and motor is more than 50 ft long. In such cases, a reflected and an incident pulse can meet at the motor terminals, effectively doubling the voltage that surges into the motor winding.

Similar to a wave striking a beach, a pulse’s amplitude can increase as it reflects back and crosses other incoming waves. Extensive testing by motor manufacturers and others shows that cables longer than 50 ft contribute to the higher voltage spikes that cause motor winding failures.

Extensive testing shows you can expect voltage spikes of 1500-2000 V or more at the terminals of a motor rated for 460 V operation. Unfortunately, standard insulation systems will not handle this kind of overvoltage. IEEE Standard 43 specifies proof-testing the insulation system integrity of new 460 V windings only once at 2000 V. The standard does not account for the voltage stress a VFD may impose several times each second throughout the life of a motor.

Some motor manufacturers have developed VFD-duty motors by upgrading winding voltage-withstand capability and reducing the core and winding losses. Likewise, several drive manufacturers have improved the quality of output power from the drive. Faster rise times may be desirable from a control perspective, but a slower rise time is gentler to the motor. The relationships between cable length, motor insulation, and VFD rise time are complex. Each variable plays a part in determining the corona inception voltage, which is the threshold at which high voltages partially discharge, ionizing trapped air and deteriorating insulation. If a particular combination (motor, VFD, and cable length/type) works well, changing any one variable can change everything.

Some end users employ line filters to protect their motors. Such filters dissipate the energy increase caused by long cables. Filters are not particularly expensive (about 10 to 20 percent of the cost of the drive), but they do add more components to the system. When possible, it is preferable to avoid cable runs longer than 50 ft.

Increased heating
Even where cable length is not a problem, motors can run 10-20 C hotter on a simulated 60 Hz PWM waveform than on real sinusoidal power. Excess heat is a major cause of insulation deterioration and failure. Insulation life drops by half with each 10 C increase in temperature.

That means the insulation system of a motor that runs 20 C hotter than its rated temperature would last only one-fourth of its normal life.

Adding to the problem, VFD-driven motors generally operate at lower speeds. The fan therefore will dissipate less heat, leading to an even hotter motor and more heat in the windings.

Fortunately, most VFD applications today involve motors driving fans or pumps. These are centrifugal loads, so the power required to drive them increases as the cube of the speed increase. Conversely, driving the pump impeller at a lower speed reduces power requirements significantly. That means less current, so heating due to the current density of the winding also decreases. These factors do not necessarily offset each other, however, so predicting the winding temperature is difficult.

Final tips

VFDs offer many benefits, not the least of which is the ability to directly drive variable-speed loads using ac induction motors. If you elect to install one, try to avoid long cable runs. You also should consider using a line filter or reactor to reduce or eliminate harmful voltage spikes.

Another option might be to buy an inverter duty replacement motor. If the motor is large and expensive, a cost-effective alternative may be to have a local service center rewind it using inverter-duty wire and special insulation. You also should specify additional varnish treatments to fill spaces between wires, increasing the corona inception voltage (the threshold at which the corona effect occurs). The additional varnish also improves heat conduction from the wire to the laminations, helping to cool the motor. These steps should prolong the life of the motor when operating with a VFD. **MT**

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