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Motor Insulation Stress

Modern, pulse-width modulated (PWM) AC drives put stresses on motor insulation that are greater than those experienced when the motor is run across the line on pure sinusoidal power. These additional stresses will cause the normal aging process that affects all motors to occur more rapidly. Sometimes this will result in unsatisfactory motor life. This issue of *Applied Technology* attempts to explain the causes of these stresses in a non-technical manner and suggests solutions to the universal problem.

There are two major characteristics of a PWM drive that create the stress on the motor and a number of other factors that contribute to the magnitude of the stresses.

The output of a PWM drive consists of many pulses, whose widths are varied to control the voltage. Although the width of each pulse can vary, the voltage of every pulse is equal to the DC bus voltage. DC bus voltage is about 650 volts in a 460 volt system, 300 volts in a 208 volt system, and 825 volts in a 575 volt system. The rate of these pulses is called the carrier frequency. Typically this ranges from about 2,000 to 20,000 pulses per second.

Viewed on a oscilloscope at the output of the inverter section of a drive running into an open circuit, the voltage of these pulses will appear as perfect rectangles. The inverter transistors are switches and are either full on or full off. However, the pulses received at the motor will be far different. The difference is caused by the impedance and capacitance of the leads and the motor. The "turn-on" and "turn-off" will no longer be instantaneous, and the voltage will initially overshoot the DC bus value.

The turn-on time is called the rise time. The maximum voltage value of the overshoot is called the peak voltage.

In measuring rise time, a standard has been developed for consistency. The standard concentrates on the most important segment of the turn-on where the voltage is increasing most rapidly. The rise time is defined as the amount of time required for the voltage of the pulse to go from 10% to 90% of the DC bus voltage. Rise is measured in microseconds.

Peak voltage is simply the maximum voltage of the pulse. Peak voltage of two times the bus voltage is not unusual.

To control motor insulation stress, it is important to have both a low peak voltage and long (slow) rise time.

Motor Considerations

Motor manufacturers are aware of these stresses, and have established guidelines through NEMA for peak voltage and rise time.

NEMA standard MG 1-1993 Part 30 applies to "General Purpose Motors Used with Variable Frequency Controls". It states that when a motor built to these standards should be able to withstand the following peak voltage and rise time:

Peak voltage $\leq$ 1000 volts
Rise time $\geq$ 2 microseconds

NEMA standard MG 1-1993 Part 31 applies to "Definite Purpose Inverter-Fed Motors". A motor built to these standards should be able to withstand the following peak voltage and rise time:

Peak voltage $\leq$ 1600 volts
Rise time $\geq$ 0.1 microsecond

In most applications, using any PWM drive will exceed one or both limits of the General Purpose standard. In most applications, VLTs will meet both of the limits of the Definite Purpose standard.

Recommendation

Use a new motor that meets Part 31 of this standard. Most “inverter duty” motors do, but there is no standard for an “inverter duty” motor. All Lincoln VTAC motors sold by Graham exceed this standard. We are so confident in the combination of Lincoln VTAC motors and VLT drives that we will warranty Graham sold VTAC motors against motor insulation breakdown for the same time period as the VLT drives. This warranty applies regardless of the number of motors connected, lead length, carrier frequency or line voltage.

Be especially careful when retrofitting drives to motors of 10 HP or below or using new general purpose or high efficiency motors of 10 HP or below. These motors are often constructed differently than larger motors. Often they do not share the same phase insulation paper, magnet wire, and winding techniques used on larger motors.

Drive Considerations

There are a number of different drive and application considerations.

Carrier Frequency

Changing the carrier frequency does not change either peak voltage or rise time. It simply is the number of pulses that the motor will be subjected to each second. The more pulses, the more stress over time. In installations were motor noise is not a concern, it is desirable to set as low a carrier frequency as motor sound level will allow. This will reduce the stress and lengthen the life of any motor. However, if the levels of MG 1-1993, Part 30 or Part 31 are exceeded for a corresponding motor, life will probably be unacceptable even at the lowest carrier frequency.

Recommendation

Set carrier frequency as low as possible.

Lead Length

The amount of voltage overshoot changes with the length of the leads. If there was no wire of any kind after the output transistors, there would be no overshoot. The longer the motor leads, the greater the inductance and capacitance, and, in general, the greater the overshoot. Unfortunately it is not practical to specify a maximum lead length. That is because a lead length of only 20 feet can cause an overshoot of 50%, and a resulting peak voltage of over 1000 volts on a 460 volt system. Even this short lead length requires a motor built to MG 1-1993 Part 31 standards. Longer leads create greater overshoot, but there is no simple relationship between lead length and peak voltage.

Long lead length lengthens rise time. Long rise time is desirable, but not at the expense of higher peak voltage. Long rise time will not compensate for high peak voltage, or vice versa.

Recommendation

Keep motor lead length as short as possible.

Line Voltage

Most discussions of motor insulation failure assume a nominal voltage of 460 V AC. Different guidelines are appropriate at other voltages. Most motors are constructed of the same materials whether applied at 208, 460 or 575 V.

In general, motors applied at 208 volts will not have phase insulation breakdown problems. This is because the peak voltage will never exceed 1000 volts.

Applying motors at 575 volts increases the peak voltage by 25% above the 460 volt levels, bringing peak voltage near or above the MG 1-1993 part 31 value of 1600 volts.

Recommendation

208/230 volts - Most general purpose motors should be acceptable.

575 volts - Motors meeting MG 1-1993 Part 31 must be used, and other precautions can be considered for 575 volt applications.

Choice of voltage - If it is possible, use 208 or 230 volts for low horsepower applications of about 10 horsepower and below. It is often the lower horsepower motors that are most apt to fail.

Multiple Motors

Field experience shows that multiple motor installations are at special risk. The reason for this is not always clear. Contributing factors are that multiple motor installations are typically long lead installations.

In addition, multiple motor installations tend to have smaller motors, which may be built to standards less demanding than MG 1-1993 Part 30 or Part 31.

Recommendation

In addition to using motors built to MG 1-1993 Part 31, it may be desirable to equip the drive with one of the output devices listed below.

Other Possible Precautions

Although the best precautions are described above, there are additional possible solutions. These are useful when the above precautions cannot be taken, or if the problem occurs in spite of the precautions.

Output Load Reactor

Output load reactors, already supplied as standard equipment on the VLT®3500, can be added to drives that do not have them. A three-phase output load reactor increases the impedance of the output. The reactor resists the rate of rise of current, and therefore increases the rise time.

Recommendation

This device can be added to drives that do not already have them built-in. Use if insulation stress is caused by too rapid a rise time. Output load reactors are most effective on applications with short motor leads and motors of 10 HP or less.

Output Clamp Module

This full-wave, three-phase diode bridge rectifier with dissipating resistors is designed to be used in conjunction with the VLT®3500's standard output load reactor. It clamps the peak voltage level to about 750 volts on a 460 volt system.

Recommendation

This device can be used on the VLT®3500. Use if insulation stress is caused by too high a peak voltage. An output clamp module is most effective on applications with long motor leads.

Output LC Filter Module

This three-phase inductor and capacitor module will both lower the peak voltage and increase the rise time that the motor sees. It also will reduce motor noise.

Recommendation

This is probably the best solution if it cannot be determined what causes the motor insulation stress, although it is also the most expensive solution.

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