Air Handler and Large Rooftop Unit Shaft Grounding Ring Usage

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INTRODUCTION

Variable frequency drives (VFD) have become very popular for their ability to control a motor's frequency and therefore the rpm of a driven fan in HVAC equipment. In controlling a motor's frequency, a VFD's installation can create effects that may damage the motor if not properly mitigated. A popular form of mitigation is the usage of shaft grounding rings (SGR). However, shaft grounding rings are often used when not necessarily required.

This paper discusses when a shaft grounding ring is needed, how the installation of a VFD and associated field wiring can cause damage to a motor and how a shaft grounding ring can mitigate this damage.

IS SHAFT GROUNDING REQUIRED?

A shaft grounding ring is not always needed to protect the motor from voltage sent from the VFD. The damaging effect of the peak voltage sent to the motor from the VFD is dependent upon the length of the cable that connects the VFD to the motor. Most VFD manufacturers have identified a critical length of cable; any cable length below this value should not see voltage spikes high enough to cause motor damage. This can be seen in the equation below. Here, S_{pulse} is the speed at which voltage travels down the cable from the drive to the motor, and is often estimated at 500 feet per microsecond, and t_r is the rise time.

$$L_{critical} = \frac{S_{pulse(feet/\mu s)} \times t_{r(\mu s)}}{2}$$

When the length of the cable is kept less than a certain length, defined as the critical length or $L_{critical}$, the time required for the voltage pulse to travel from the VFD to the motor is less than half the rise time of the DC voltage pulse. When these conditions exist, the reflected voltage pulse seen at the motor is less than the damaging value. Thus, when the length of the cable running from the VFD to the motor is less than the critical length, the voltage pulses created by the VFD should not cause damage to the motor.

For a VFD with a rise time of 0.1 microseconds this critical cable length is 25 feet. Thus, as long as the length of the cable connecting the VFD to the motor is less than 25 feet, the voltage spikes caused by the VFD should have no damaging effects on the motor, and therefore no motor protection, or shaft grounding ring, is required.

VFD OPERATION

A VFD indirectly controls the speed of the fan by manipulating the speed of the fan motor. In doing so, the VFD changes both the frequency and voltage of the motor. Most VFDs today are pulse width modulation (PWM) drives. A PWM drive takes incoming AC line power, converts it to a fixed DC voltage, filters the voltage, and then creates a representative AC output power with adjustable voltage and frequency using DC pulses. The representative AC output voltage of the VFD is not a smooth sinusoidal wave form, rather a very rough representation, as it is created based on the time averaging of the DC pulses. The creation of DC pulses to mimic an AC waveform is shown in Fig. 1.

Creating a representative AC voltage output from DC voltage pulses can cause voltage spikes, which have the potential to damage a motor. In creating DC pulses, there is often a voltage overshoot resulting in a higher than desired peak voltage. This peak voltage, if too high, can damage the motor. Figure 2 shows this overshoot, and also highlights the rise time, or t_r, of the voltage phase.

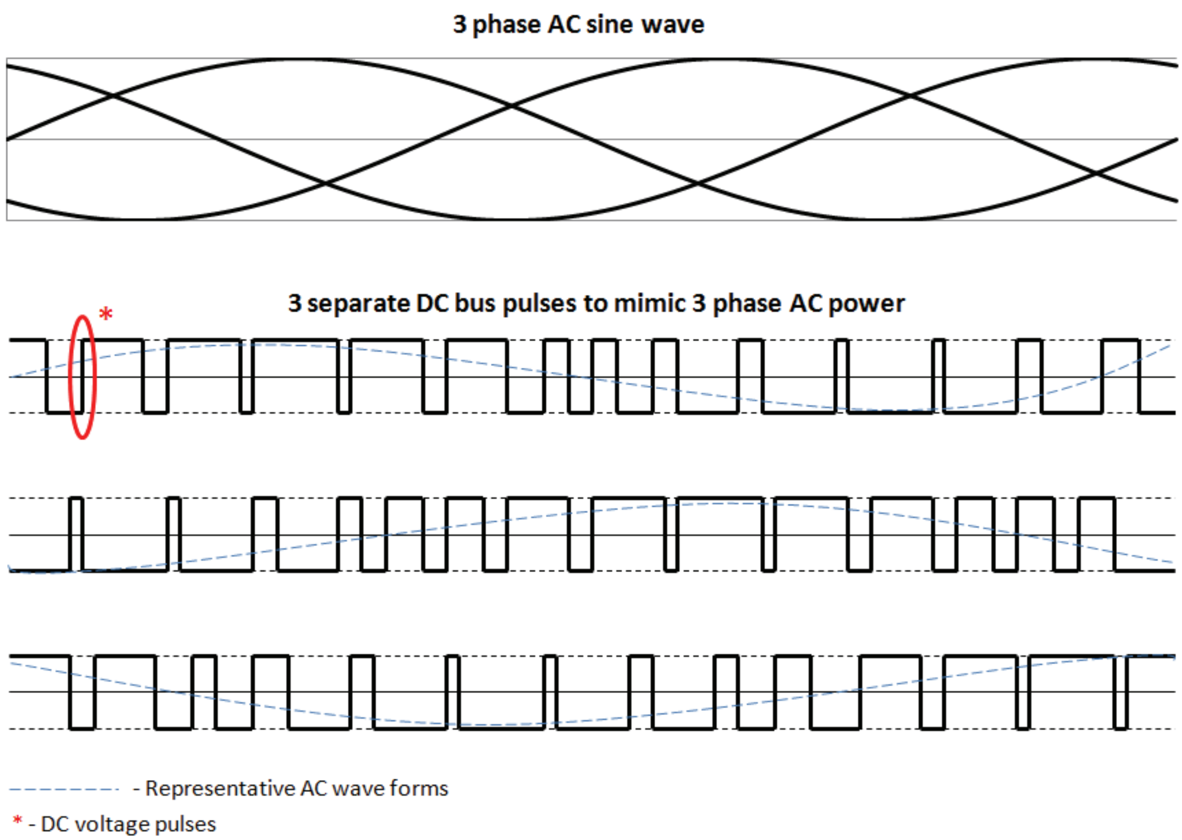

Figure 1 – Representation of DC Power Pulses Created by VFD

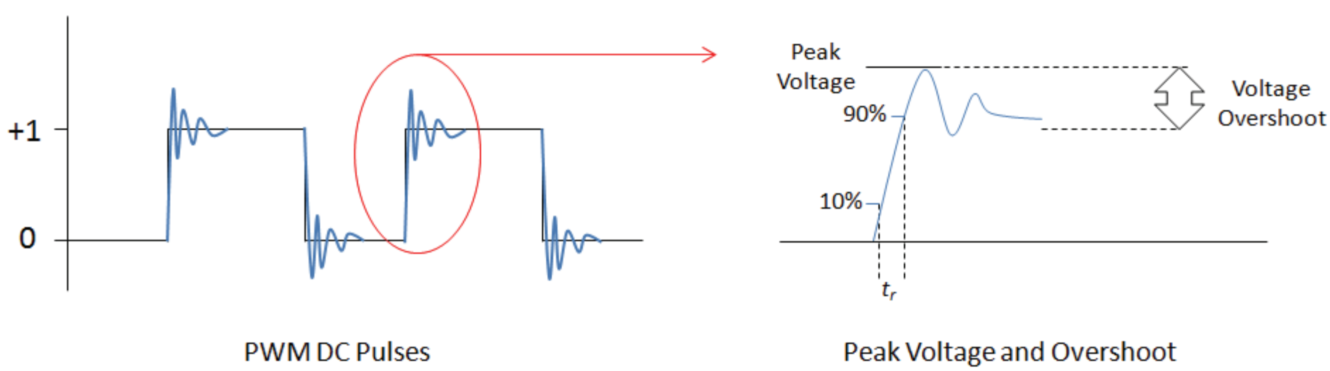

Figure 2 – Peak Voltage and Voltage Overshoot

The rise time represents the amount of time it takes for the voltage to increase from 10% to 90% of its peak value. In most current VFDs, this rise time is very short, typically around 0.1 microseconds. The importance of this rise time plays into the motor cable length described earlier in this white paper.

The peak voltage can damage the motor based on the magnitude of reflected voltage pulses. Similar to how a wave ripple in a pool of water will reflect off of a barrier and combine with the incoming ripples, a voltage wave traveling down a wire will experience a similar phenomenon. In an air handler (AHU) or large rooftop unit where the fan motor is controlled by a VFD, the "wave" is the voltage spike created by the VFD and the "barrier" is the actual motor. As the voltage waves reflect off the motor and combine with the incoming waves, the voltage spikes can become very large.

As the size of these spikes increase, the potential for motor damage and even failure increases. These voltage spikes can build up on the shaft of the motor until they find a discharge path to ground. The path of least resistance to ground for the voltage in most cases is through the motor bearings. As the voltage spikes increase and overcome the resistance of the oil film layer in the bearings, the shaft current will discharge causing pits and fusion craters or fluting in the race wall and ball bearings. These pits and craters will continue to develop until ultimately causing the motor to fail, usually preceded by an audible warning as the bearing rolls over the pitted or fluted surface (See Fig. 3.)

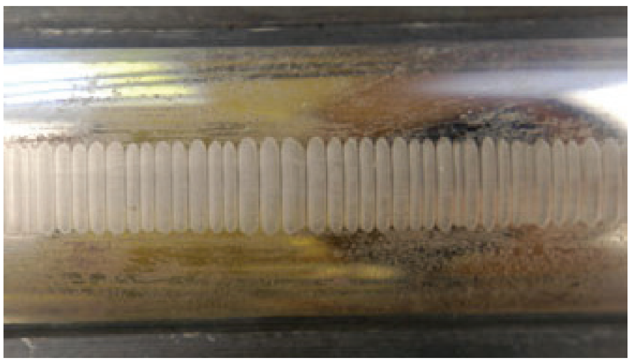

Figure 3 – Bearing Fluting
Photo courtesy of Electro Static Technology Inc.

MOTOR PROTECTION METHODS

Several different measures can be taken to protect the motor and its bearings. Insulation can be used to isolate the bearings, forcing the shaft current to find an alternate path to ground. However, insulating bearings can be expensive, and some high frequency VFD induced currents can pass through the insulation and damage the bearings. Additionally, if the insulation forces the shaft current to find an alternate path to ground, the damage that the motor would have seen may just simply be passed to another connected piece of machinery. Ceramic bearings could also be used as a means of bearing protection, but with similar drawbacks as seen with other insulating methods described above.

The best option to protect the motor and its bearings from this damage is through the use of a shaft grounding ring, for example, the AEGIS® shaft grounding ring manufactured by Electro Static Technology Inc. A shaft grounding ring mounts on the motor shaft, and utilizes specially engineered conductive micro-fibers to re-direct the shaft current away from the motor bearings to ground. Simply put, a shaft grounding ring provides the path of least resistance to ground. Thus, not only are the motor bearings protected, but the rest of the motor and any connected equipment are as well.

SUMMARY

Shaft grounding rings provide a great measure of protection for a VFD controlled motor but are only needed when the length of the cable connecting the VFD to the motor is longer than the critical length. Carrier models that have a cable length from the VFD (ABB ACH550-UH model) to the motor less than the VFDs critical length of 25 feet include:

1) All factory-installed VFDs on 39M Series air handlers
2) All factory installed VFDs on 48/50A, 48/50P, and 48/50N Series large rooftop units.

In general, it is recommended that the VFD and motor be supplied as a factory engineered and mounted system. This system is designed with a cable length from the VFD to the motor short enough so that a shaft grounding ring is not required.

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