PROPER APPLICATION OF VFD CONTROL TO EVAPORATOR FANS

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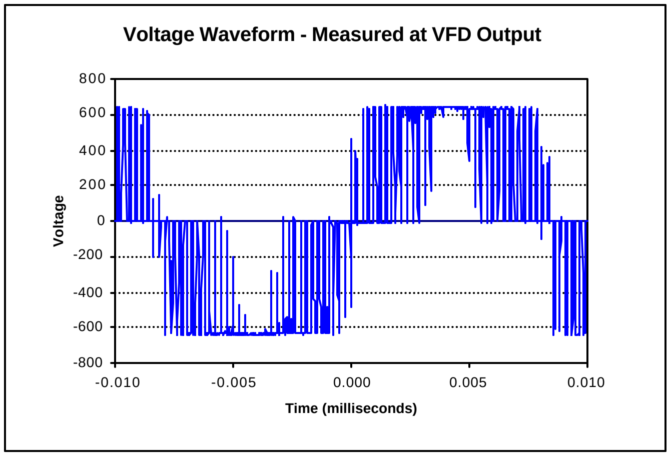
Introduction

This brief guide is targeted to vendors, contractors and end-users of variable frequency drive (VFD) technology. This specific document addresses evaporator fans, common in refrigerated warehouses and controlled atmosphere storages.

Background

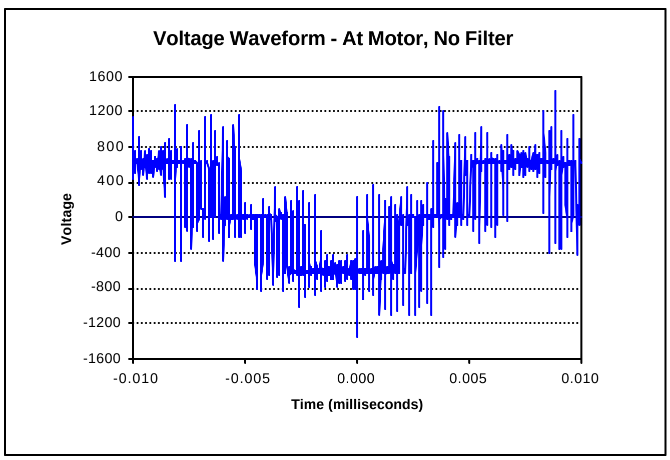
Simply stated, a VFD converts the utility voltage sine-wave into DC voltage. The VFD then sends DC voltage pulses (≈ 650 Volts) of varying width and polarity to the driven motor. The waveform at the VFD output could resemble that shown to the right. This VFD technology is called "pulse width modulated, or PWM".



In general, the motor draws a nearly sinusoidal current waveform when "served" with this PWM waveform. Unfortunately, this waveform can also cause motor failures.

Reflected Waves, Corona Inception & Motor Failures

The wire leads between the VFD output and motors have capacitance. This circuit causes a "reflected wave" phenomena, with waveform voltage overshoot that can be 1400 Volts or higher.



The energy contained in the reflected wave is absorbed in the first windings of the motor, and causes the inception of corona. The corona, where electrons are stripped from the air molecules and bombard the wire insulation, can eventually wear through the wire insulation. At this point, the motor will fail. The fans stop turning, and the VFD will usually trip out on a ground fault or over-current condition. Depending on the many factors exacerbating the problem, motors can fail in a matter of hours, or after several years. Some facilities have experiences total motor failure resulting from a lack of proper VFD design and application.

General Solutions

There are four ways to inhibit or eliminate the problem of motor failure resulting from reflected waves:

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1. Keep Lead Lengths Short: Although there is no hard rule of thumb, it appears that keeping lead lengths in the range of 10, 20 or 30' may be acceptable. However, even at these distances, the right combination of wiring, motors, and other system characteristics can stress the motor insulation system to the point of failure.

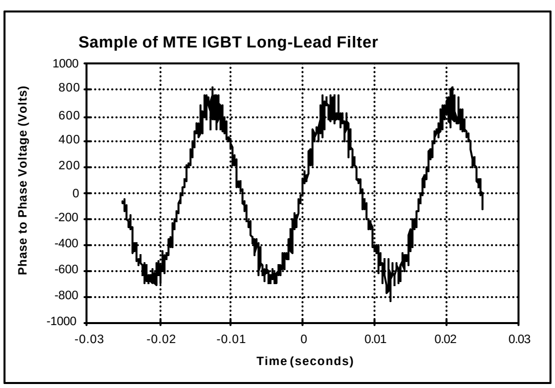
2. Install Inverter-Rated Motors: In response to the reflected wave problem, NEMA generated a standard for inverter-grade motors. This standard, frequently referred to as the NEMA MG1 Part 31 specification, is a lengthy description all motor characteristics required for the wide range of inverter applications. However, to avoid the pitfalls of the reflected wave phenomena, Section 31.40.4.2 indicates that the motor must be designed to handle 1600 volts at a 0.1 micro-second rise time. Many motor manufacturers have upgraded or created new lines of motors to meet this standard. These include the following:

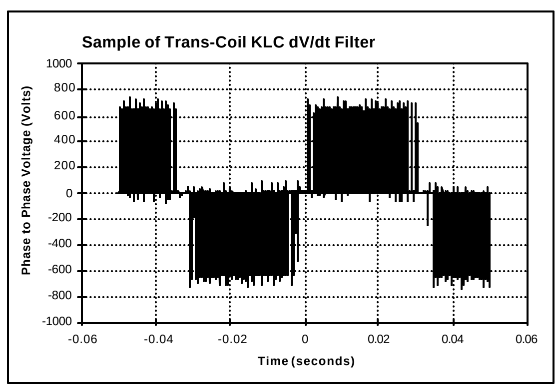
Motors Meeting NEMA MG-1 Part 31.40.4.2	
Manufacturer	**Motor Line**
General Electric	A$D & X$D
Lincoln	VTAC & CTAC
MagneTek	"Speed Engineered"
Marathon	Blue & Black Max
Reliance	E-Master, XE, XEX
Siemens	RGZESDI
US Motors	Varidyne
Toshiba	EQP III Series

These manufacturers have prominently published product literature and specifications documenting compliance with MG1 Part 31.40.4.2. Other major motor manufacturers have made some lesser improvements to motor insulation, unfortunately falling short of MG1 Part 31.40.4.2. The final category of motor manufacturers has made no improvements to motor insulation addressing these issues.

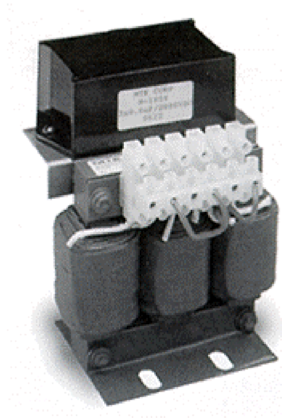
Note that this list may change as motor manufacturers respond to the growing market for VFDs. The motor manufacturer should provide factory-generated literature documenting compliance with MG1 Part 31.40.4.2. In addition, an updated version of the NEMA specifications may be complete by the time of this writing.

3. Install Output dV/dt Filters: A filter can be installed at the drive output to minimize or eliminate the reflected wave. Some VFD manufacturers build their own filter (e.g., Cutler-Hammer's $Moto_{RX}$ filter), while most rely on two after-market products; Trans-Coil's KLC filter and MTE's IGBT Long Lead Filter. A sample of the resultant waveform from each filter is shown below:





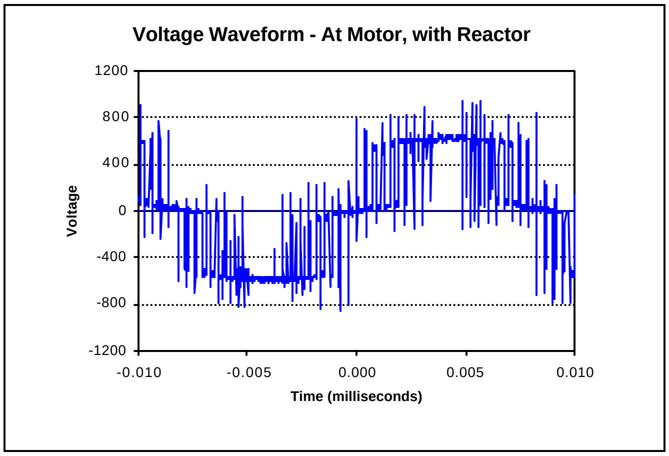
MTE's approach is to filter the output of the VFD to provide a nearly sinusoidal voltage waveform at the motor leads. Trans-Coil's approach is to eliminate the problematic reflected wave. Each design has advantages relative to the other, although a comparison will not be provided here. Again, these filters are installed at the output of the VFD, either in their own NEMA enclosure, or within the larger VFD NEMA cabinet itself. The MTE filter is shown for reference.



Some VFD manufacturers (e.g., Allen-Bradley and Cutler-Hammer) build a reflected wave "trap". This device is installed at the motor-end of the leads. The resultant waveform is quite similar to that provided by the Trans-Coil KLC filter, virtually eliminating the waveform overshoot.

For evaporator coil applications, the reflected wave trap is typically not the best solution. Multiple motors, cold or freezing space temperatures, and difficult-to-reach locations make an output dV/dt filter more attractive.

In some cases, a simple reactor can be installed. Although this solution is "helpful", the waveform can still contain significant spiking. An example is shown to the right. Unless the application is well researched and the capabilities of the motor insulation system are well documented, installing a simple reactor should be avoided.



4. Operate at 230 Volts: Nearly all evaporator fan motors can be wired for 230 or 460 Volt operation. If 230 Volt operation is chosen, the issue of motor damage from reflected waves is all but eliminated. Voltage spikes shouldn't exceed 700 or 800 Volts, which is well within the typical 1000 or 1200 Volt capability of standard motors.

Some existing facilities operate at 230 Volt, although they are often small and old. If the facility is 460 Volt, two options are available to operate at 230 Volt:

- Install a master 460-to-230 Volt step-down transformer to serve all evaporator coils. Wire the motors using the 230 Volt setup.
- Install individual step-down transformers for each VFD. This is obviously more expensive than a master transformer.

General Rules for Successful Installation

New Construction Installations

Clearly, on a new construction project, the best approach is to start with motors that fully comply with NEMA MG1 Part 31.40.4.2. Again, compliance with this standard should include factory-published literature. Verbal, custom or on-the-spot guarantees by motor manufacturers and vendors are not sufficient.

When choosing the motor, bear in mind that there are substantial differences between motors that comply with MG1 Part 31.40.4.2. At this time, only the Lincoln VTAC and CTAC line is guaranteed for 5 years, with no need for filtering at any lead length or VFD carrier frequency. Issues of efficiency, warranty, a single motor/VFD manufacturer, ect. can all play a substantial role in choosing the best motor.

With robust motors installed, filters shouldn't be required. However, always consult with the motor manufacturer and obtain their recommendations. It may be that for some particularly tough applications, a reactor or dV/dt filter may still be required.

If the fans can be easily served with 230 Volt power, this is a very attractive option. In facilities such as Controlled Atmosphere (CA), where a number of similar rooms are all fed from a common mezzanine area, a single step-down transformer could easily be installed. In this situation, the choice of motor is not nearly as critical.

Retrofit Installations

Retrofit projects should be approached with caution and care. There are really only three options that offer "peace of mind" for those parties involved:

1. Install true dV/dt filters (not simply reactors) on the VFD output.
2. Retrofit the motors with NEMA MG1 Part 31.40.4.2-compliant motors. In general, this solution is costly and may price the project out of consideration by the customer.
3. Convert the application to 230 Volt.

Remember that CA facilities are very sensitive to motor failures. Once the CA room is loaded with fruit and sealed, it is nearly impossible to replace a failed motor without significant inconvenience to all parties. If each fan motor has individual wiring that extends to the VFD, the failed motor can be isolated. However, if the motors on an evaporator coil all convene at a single junction box on the coil, the problem motor can't be isolated without entering the CA room, somehow getting up to the coil, and manually disconnecting the problematic motor.

56-Frame Motors - Caution!

Many evaporator coil manufacturers utilize small 56-frame motors in the 1/3 to 1½ hp range. These motors are custom OEM versions supplied primarily by Franklin Electric, Baldor, and others. The motors utilize a belly-band mounting scheme, where the fan shroud wraps around and clamps down on the body of the motor. These motors are more problematic for two reasons; 1.) the small frame size and low cost of the motors make them extremely frail for VFD applications, and 2.) the motors are custom, and usually can't be replaced with off-the-shelf motors.

Franklin Electric can "beef-up" motor insulation with better wire, phase insulation, fiberglass tubing on end-turns, and additional care during production. This has worked successfully on several retrofit projects. One evaporator coil manufacturer, Krack Corporation, is considering a sweeping change to all motor designs to include inverter-grade insulation systems. These better motors should be supplied on new construction projects. They can also be installed for retrofit projects, although the cost of replacing motors will likely hamper the economics of the project.

For additional insurance, a reactor or dV/dt filter may still be recommended by the motor manufacturer. Carefully approach these retrofits with sufficient design consideration prior to installation.

<u>Disclaimer</u>

This paper was prepared by Cascade Energy Engineering for the express purpose of raising awareness and general education of the reader. Under no circumstances should these recommendations be blindly followed without appropriate consultation with motor, VFD, and filter vendors. Cascade Energy Engineering considers a review by an electrical engineer or other qualified personnel as mandatory for a successful project. If you have general questions concerning this paper or a VFD application, contact Marcus Wilcox of Cascade Energy Engineering at 509-529-8040, or mwilcox@bmi.net