



ENGINEERING BULLETIN No. 43

Product: Variable Frequency Drive Application **Date:** July 2008

Purpose:

Variable frequency drives (VFDs) are an essential component in today's modern applications of industrial refrigeration and commercial comfort cooling for evaporative condensers, evaporators, cooling towers, closed circuit coolers and other equipment. Proper operation of all the components of these systems is required to maintain the efficiency and reliability that's expected of them and the VFD is no exception. This bulletin will explain the basic functions of the VFD, along with identifying potential issues related to its operation. In the following pages, recommendations for good VFD application practices will be presented along with accessory items that are designed to prevent motor failure and other operating issues.

Introduction:

Variable Frequency Drives (VFDs) are electronic devices used for the purpose of controlling the speed of AC motors. The benefits of a VFD's application on industrial refrigeration system components and other equipment outweigh its tradeoffs, providing they are properly applied.

The primary benefit of using VFDs compared to using standard starters is the ability to adjust the speed of the motor to fit the constantly changing variables in the applications. For evaporators, condensers and cooling towers, VFDs allow the unit to be more efficient by matching the thermal capacity to the system load, thereby conserving energy.

Since their inception in the 1980's, VFDs have become progressively more efficient and are now used in many industrial applications because of their energy saving capabilities, versatility, lower cost, and reliability with respect to older methods of controlling motors.

- **Performance:** VFDs can quickly respond to a load change or speed requirements without the need for a system operator to constantly monitor these factors. Communication interfaces; such as, Modbus and DeviceNet allow users to set up automated programs with specific commands for a VFD, based on the conditions of virtually any application.
- **Versatility:** Since VFDs feature optional self analysis, built in communications abilities, diagnostics and allow the system to be controlled automatically, the VFD

is a useful tool in a variety of cases. As mentioned the element of control allows for easy adjustment to different conditions and conserves energy by improving efficiency.

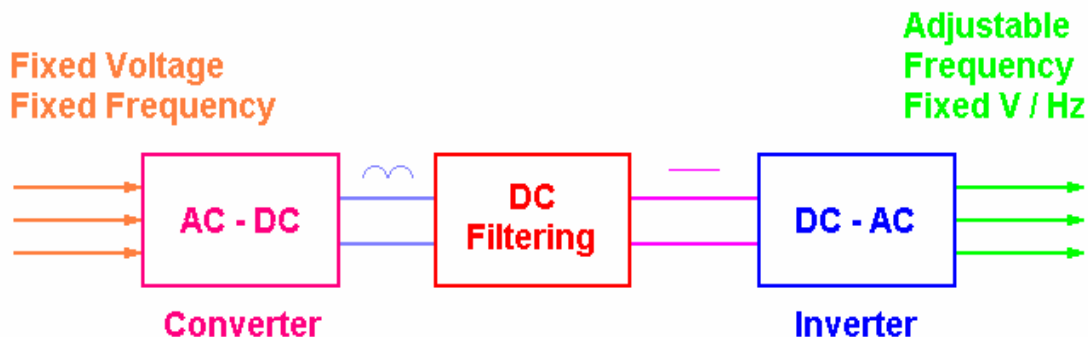
- **Cost:** VFDs have no moving parts to maintain, no need for external controls and due to their increasing popularity they have become relatively inexpensive.
- **Reliability:** Between the lack of moving parts, built in protective circuits, 2-3 year warranties and easy to use diagnostics, VFDs are very reliable if installed and set up correctly for their application.
- **Size:** VFDs have become lighter and more compact than the early units making them easier to install closer to motors. This is an important application feature that will be discussed in more detail.

VFD/Motor application:

Motor Design and Selection: Advances in electronics and motor manufacture have made AC induction motors more reliable than ever, but even the highest quality motor can be irreparably damaged if the VFD is not compatible with the motor. Numerous parameters must be considered in order to properly couple a VFD with a motor: torque requirements, system voltage, cable lead length, switching frequency, etc. It is important to consult both the VFD and motor manufacturer’s recommendations to ensure proper inverter/motor setup and prolong system service life.

NOTE: NEMA does not govern the use of the terms “inverter duty”, “inverter capable”, “inverter ready”, etc. It is important to understand the NEMA MG-1 part 30 and 31 specifications. These two NEMA sections detail the requirements for the motor in order to be suitable for use with an inverter.

| How Does the VFD Control the Motor Speed?



Pictured above is the basic process by which a VFD alters typical AC power so that it can adjust the frequency of the power going to the motor terminals. The VFD driven motor is slightly less efficient than a motor with a standard starter, since it is only

simulating the sinusoidal waveform. However, the energy savings are obtained through the VFD's ability to vary the speed of the motor.

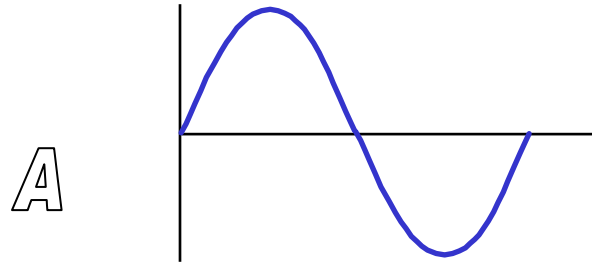
- (Variable torque load) + (Variable speed) = Energy savings
- The following are equations referred to as the **affinity laws**:
 - $Q2 / Q1 = N2 / N1$,
 - $P2 / P1 = (N2 / N1)^2$, and
 - $H2 / H1 = (N2 / N1)^3$,

Where N = fan speed, rpm; Q = flow, cfm; P = pressure, static in. H₂O; and H = horsepower.

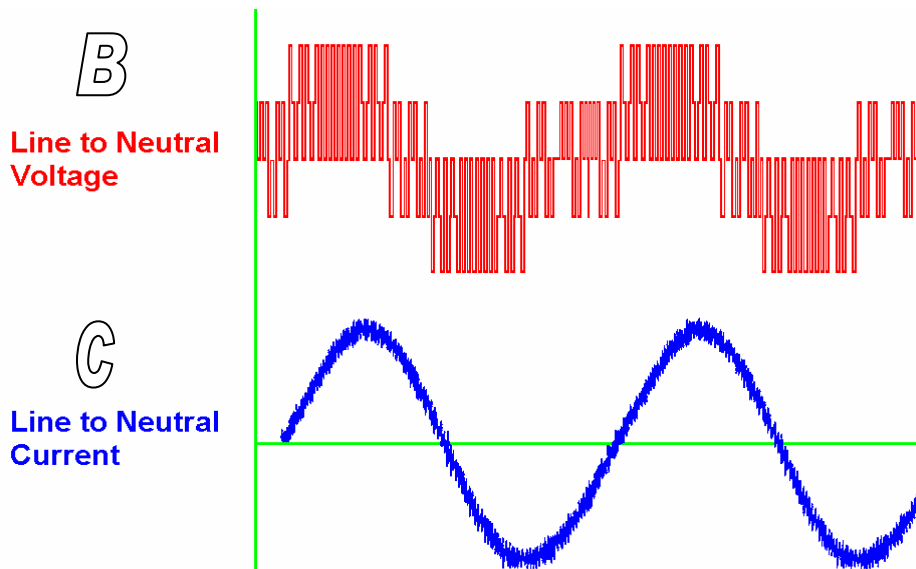
- Using the equations listed above, it has been determined that energy consumption for VFD controlled equipment motors can be reduced by as much as 2/3 compared to motors without a VFD.

The following is a visual representation of the basic current and voltage associated with a VFD. Graph A shows the curve that is typically referred to as a sinusoidal waveform, because in its simplest form, the graph can be represented by the function $f(x) = \sin(x)$. Besides being the fairly consistent waveform of power provided by power plants, it is the ideal shape for efficient AC motor operation. Graph B shows how the VFD's voltage waveform simulates the sinusoidal waveform, by pulsing at extremely short, variable intervals (frequency). The VFD's frequency adjusts the height (voltage) of each pulse to match that of the current and control the motor speed. Graph C shows the resultant current to the motor.

The power company typically supplies a reasonably Smooth sinusoidal waveform:



The VFD output waveforms in voltage and current:



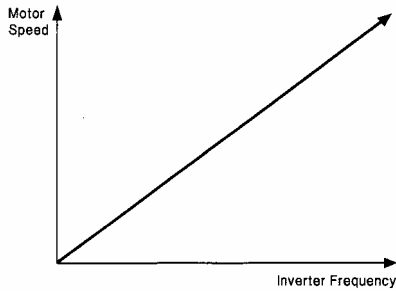
Curve A = The relatively smooth curve of AC power provided by most power companies.

Curve B = The VFD's simulated sinusoidal output voltage waveform.

Curve C = The VFD's output current waveform has the carrier frequency pulses riding on it.

Below is a basic graphical and numerical representation of how the VFD alters the frequency of its simulated sinusoidal wave to modulate the motor speed. Higher frequency equates to a higher motor speed.

Affect of Frequency on Motor Speed:

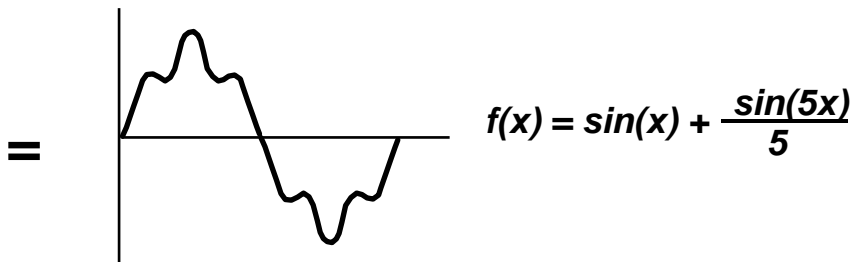


$$S = 120 \times \frac{f}{P}$$

Where: S = The motor synchronous speed
f = The applied frequency
P = The number of motor poles

AC LINE DISTORTION AND HARMONICS

Laboratory testing and field experience have shown that the operation of a VFD or other elements causing the current to deviate from the sinusoidal form may cause power problems in facilities. This potentially detrimental effect is caused by a phenomenon called **harmonics**. Any function may be made from the sum of its harmonics (see graph below), so any distortion of the desired waveform may be represented in this fashion.



A nonlinear device, such as a VFD, will draw distorted waveforms, which are comprised of harmonics of the source. Harmonics cause disruption in electronic equipment within the facility and cause motor heating. VFD's should be specified with 3% Line reactors to reduce the harmful effects of harmonics on the motor. Quality VFD's typically have built-in line reactors up to certain a horsepower. If the VFD does not have built-in line reactors, it is recommended to add them to limit the interference to the electrical components caused by harmonics.

Application Issues: Preventing Motor Failure

Primary Issues: What can go wrong?

- **Noise vs. Heat:** Pulse width modulation or (PWM) is a method of reducing noise in electric motors via the VFD. This is accomplished by reducing the interval of each pulse. However, PWM can raise the potential for degrading or burning the windings and causing transient voltage spikes along the shaft of the motor.
- **Bearing/Shaft Currents:** Degradation and pitting of the motor's bearings can be caused by transient voltage spikes. This can occur when a VFD frequency is set higher than recommended and/or the reflected wave voltage occurs.
- **Reflected wave voltage:** Reflected wave voltage can cause voltage spikes double that of the source. There is a direct correlation between the cable length between a VFD and its motor, and the potential for harmful voltage spikes caused by reflected waves.

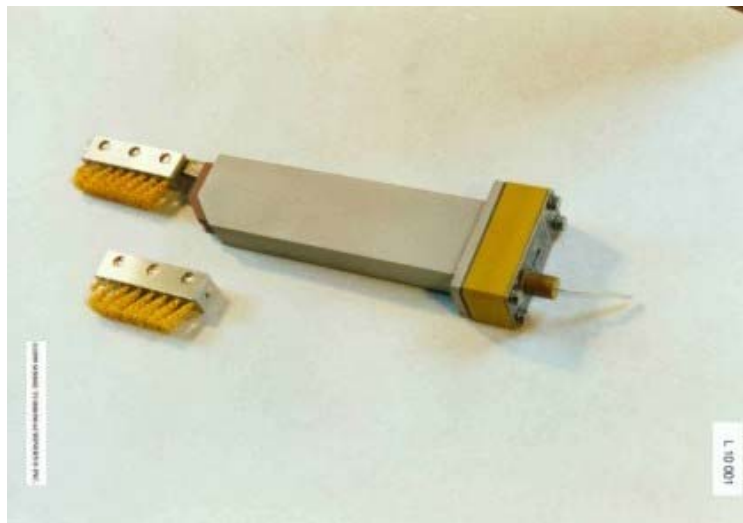
VFD Good Application Practices:

Select a high quality VFD that is compatible with Evapco fan motors. Many variables in the VFD configuration and installation can affect motor and VFD performance. Two particularly important parameters to consider when choosing and installing a VFD are switching frequency and the distance between the motor and VFD often referred to as lead length. Consult the VFD manufacturer's recommendations for proper installation and configuration.

- **Drive Switching Frequency Setting Under 5 kHz:** The switching frequency of the VFD determines the cleanliness of the output voltage to the motor. Higher switching frequencies typically tend to reduce auditory noise at an increased risk of detrimental transient voltage spikes and shaft/bearing currents. Reducing the frequency of the pulse width modulation (PWM) of the VFD will reduce the negative impact of transient voltage spikes and shaft/bearing currents. **A general rule of thumb for adjusting the PWM is to adjust the VFD switching frequency to 5 kHz or less.**
- **Lead Length Between VFD and Electric Motor:** The probability of high voltage spikes greatly increases the longer the cable length is between the VFD and the motor terminals. Due to the differing impedances between the motor and the cables, the electrical waves may be reflected. If full wave reflection occurs, a voltage spike of double could travel through the motor terminals, potentially damaging the windings and causing shaft/bearing currents. These currents can also degrade the motor bearing grease and cause the motor windings to fail. A relatively straightforward method of minimizing this risk is to mount the VFD as close as possible to the motor. The maximum recommended lead length without power

conditioning is dependent on the selected motor, the selected VFD, voltage, switching frequency and wire specification. Refer to the motor and VFD manufacturer's documentation for recommendations. When maximum recommended lead lengths are exceeded, power conditioning options are available.

- **Shaft Grounding Brushes:** Shaft grounding brushes are gaining popularity as one of the best ways to protect AC motors from the detrimental effects of bearing currents. This device allows currents traveling along the shaft to be safely shunted away from the bearings by grounding the shaft. There are also **shaft grounding rings** which are similar in their function to grounding brush kits. It is recommended that a brush kit or grounding ring be installed on most motors that are located more than 100 ft. from the VFD.



Shaft grounding Brush

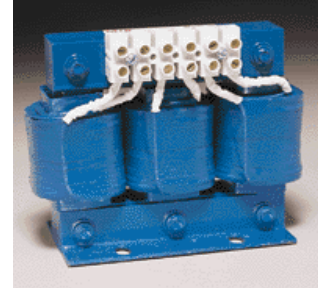
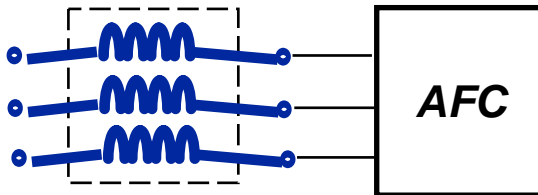


Shaft Grounding Ring

- **AC Load Reactor:** An **AC load reactor** is the simplest, lowest cost solution to limit motor damaging transients. Load reactors use impedance to effectively “smooth” voltage transients. AC Load Reactors are an option if the VFD is

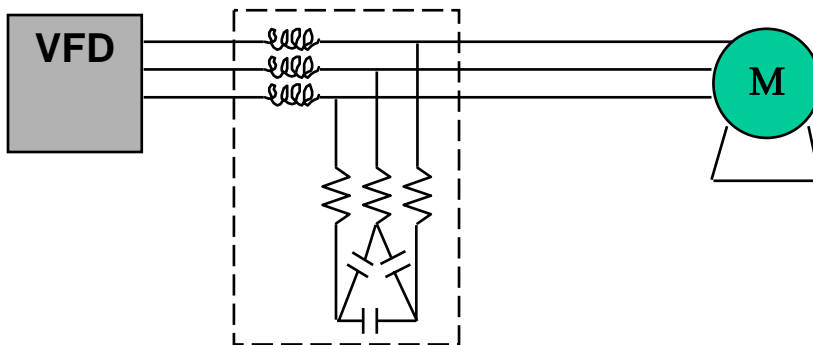
mounted between 100ft and 300ft away from a VFD rated motor. Standard motors require load reactors regardless of the distance between the VFD and the motor. Note: A single load reactor can be mounted at the VFD to protect multiple motors.

Load Reactor

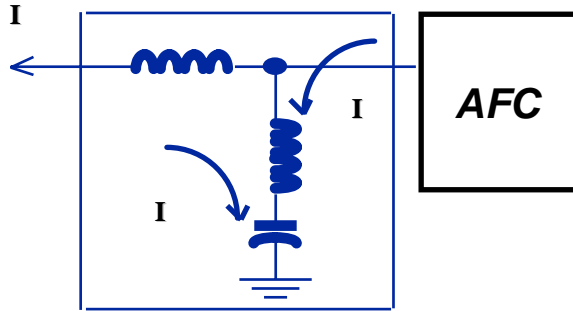


Load Reactor

- **“LC” Low Pass Filters:** “LC” Low Pass Filter Systems combine capacitance, reactance and resistance to form a low pass filter. It is a large, somewhat expensive device, but it is very effective for reducing harmonics by converting PWM voltage into a sine wave. This is an option if a VFD is mounted 300ft-1000ft from equipment motors.



- **Tuned Trap Filters:** Tuned trap filters are designed to shunt unwanted harmonic currents to the ground. Due to its 300 Hz signal frequency it is possible to import a relatively small harmonic current into the line. The systems reduce overall harmonic distortion, but they are tuned to shunt only one specific harmonic frequency to the ground, so they can be expensive and require system analysis to recognize the different harmonic current(s) in the AC line. More than one tuned trap filter may be required if there are multiple harmonic currents. This is an option if a VFD is mounted over 1000ft away from the motor. Note: Tuned trap filters are very difficult to install and tune. Qualified technicians are required to install these devices. Typically, installing a VFD more than 1000 ft. from the motor it’s controlling proves to be too costly and complex of a task to justify.



**Single stage tuned trap filter
with series reactor**



**Single Stage Tuned Trap
Filter**

Summary:

Many end-users have benefited from the energy savings offered by properly applied variable frequency drives (VFDs) in industrial refrigeration and commercial comfort cooling applications. Greater system control yields numerous benefits, but only if the proper attention is given to selecting the correct VFD, equipment motors and protective accessory items for each application. This bulletin is intended to forge a basic understanding of the functions of the VFD, and identify the potential issues related to its operation. Within this document are recommendations for safe and reliable VFD application practices. In addition, a basic explanation of various accessory items designed to prevent motor failure and other system operating issues is provided.