VFDs

Are they Electrical Parasites?

Since Nikola Tesla applied for patents in 1888, the induction electric motor has seen a number of changes. In the past 100 years the electric motor has been scrutinized and reconfigured many times to create an extremely efficient workhorse that transfers electrical energy into mechanical energy.

Let's look at a typical example of a 100 hp motor running in an area that has an average cost of $.10 per kilowatt hour. In this example our 100 hp motor is 95 percent efficient but runs straight across the line 24 hours a day, 365 days a year. Just to keep this motor fed with electricity, the annual cost will be about $46,000 per year.

The Variable Frequency Drive (VFD) has an important beneficial role as it has the ability to modulate the speed of the motor and the amount of power the electric motor uses. Thus the motor only consumes the amount of power needed to keep the application running. Unfortunately, there are also some detrimental problems with the technology that may cost the facility unless the technology is understood and deployed correctly.

By Ned (Scott) Frank

WHAT IS A VFD?

VFDs are electronic speed controllers used mainly to modulate and reduce the overall speed and power consumption of an electrical motor. They can be used as soft starters for equipment that has a large rotational mass, thus reducing belt ware and large electrical peaks when starting large pieces of equipment. VFDs have other options that are useful like capturing a reverse spinning loads prior to start up, and they can also be used to over speed a motor for specific applications such as fan walls.

Pulse Width Modulation (PWM) VFDs have three basic components (Figure 1). First there is a “Rectifier” section, then a “DC Filter” section, along with an “Inverter” section.

The rectifier is a set of diodes that changes the incoming AC into DC. The DC voltage is then filtered in the DC Filter section to remove the ripple from the rectifier. The DC voltage is then used to power a set of switching transistors called the Inverter.

The inverter is a group of Insulated Gate Bipolar Transistors (IGBT) that have high switching speeds. They are transistors that turn on and off for varying durations of time, sending an output to the motor at a different voltage and frequency than the incoming signal.

An important concept is that motors have to maintain a fixed voltage to frequency ratio in order for it to work properly. For example, if a motor was running at 120 volts 60 Hz 1,750 RPM, and our application needed to be run at half speed of 875 RPM, we would not only need to reduce the voltage by half to 60 volts, but we would also have to reduce the frequency to 30 Hz to maintain the voltage to frequency ratio.

HARMONIC DISTORTIONS

The Rectifier portion of the drive creates some unwanted anomalies known as harmonic distortions. Harmonic distortions are basically unwanted electrical feedback into the buildings power system or incoming electrical utility. Harmonic distortions can lead to mysterious equipment failures, voltage sags, or spikes within the building, which can affect adjacent applications. They can also be responsible for equipment having intermittent problems.

Rectifiers use a number of diodes that, when forward biased, pass current in only one direction, allowing the circuit to seemingly to flip the negative cycle of the incoming sine wave and make it positive.

Looking at the diagram of a simplified bridge rectifier (Figure 2), we can see that as the positive half cycle of the sine wave (in green) forward bias the green diodes, turning them on and allowing electrons to flow through the resistive load. The red diodes are turned off for the positive half cycle impeding electron flow to the resistive load.

On the negative half cycle (Figure 3), the red diodes are now forward biased and the green diodes are turned off, allowing electrons to flow the same direction through the resistive load. The result is a full wave rectified signal applied to the output of the circuit.

We found that if a capacitor was added to the output of the rectifier (Figure 4), the DC ripple could be greatly reduced. The

Figure 1.

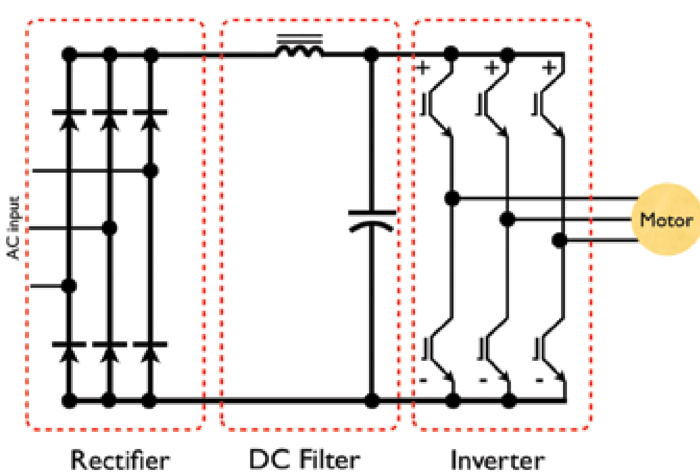


Figure 2.

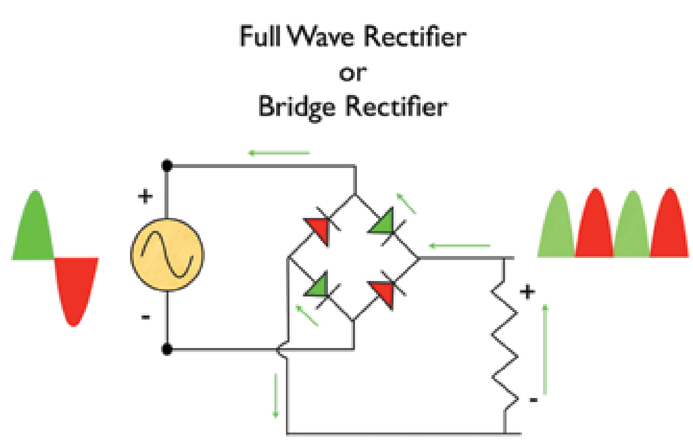


Figure 3.

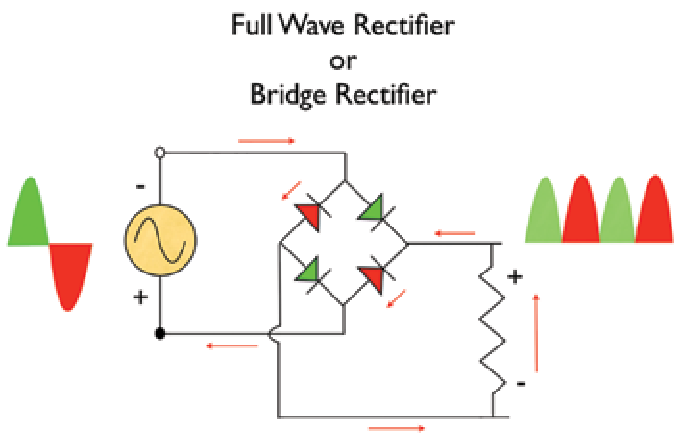
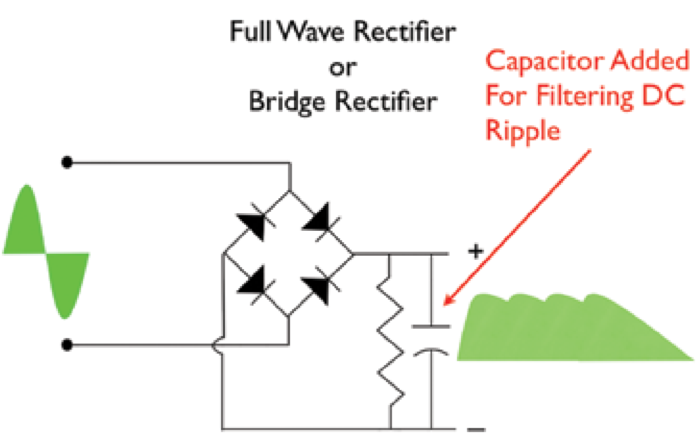


Figure 4.



capacitor of the right size would initially charge but not have the ability to discharge due to the increase of the Resistive Capacitive Time Constant, thus smoothing out the output wave form.

The electrical switching back and forth in the rectifier circuit is what causes anomalies back feeding into the incoming power. It is much like water hammer when you immediately shut off the flow of a running faucet. The backlash of the shock wave is pushed back up stream and felt as water hammer in the piping; a similar thing happens to the electrons as they switch from positive to negative cycles through the rectifier circuitry.

One solution is to apply line reactors (basically a coil of wire), on the input side of the variable frequency drive. These can be used to trap the shock waves from the rectifiers circuitry before they could be back fed into the building's electrical system.

LOOP GROUNDS

Loop grounds are simply two or more different points of grounding in the building's electrical system, akin to having the VFD electrically grounded to the building electrical system, and the motor grounded to building steel or the plumbing system.

Loop grounds can cause electrical noise in the building and other problems with the VFD's microprocessor. This electrical noise can also cause problems with computers such as the BAS system and other sensitive equipment associated with research. Loop grounds can also be attributed to bearing failures in the motor, as they can set up circulating currents in the motor causing electrical erosion or fluting of the bearing.

LENGTH OF CONDUCTORS FROM THE DRIVE TO THE MOTOR

Each conductor is basically a series of resistive capacitive and inductive circuits that create impedance to the speed of the pulses that are being fed to the motor.

Figure 5 shows the output of a single phase of the drives inverter circuit, one can see that the drive is trying to simulate a sine wave by creating short pulses that are varying in amplitude and time duration. The switching speed of the drive is more commonly known as the carrier frequency.

The carrier frequency can wreak havoc in leads that are too long as the signal can react with the impedance of the cables, producing resonant frequencies. This is like snapping a bullwhip that is tied to a fence post—the outgoing pulse either hits the motor and damages the stator windings, or it is reflected back to the drive causing damage to the IGBTs.

MOTOR STATOR PROBLEMS

As an incoming sine wave excites the motor's stator, a magnetic field is produced at each of the motor's poles that expands and contracts "smoothly" at the same rate of the incoming amplitude and frequency of the incoming signal.

However, when the motor receives an input signal that is not sinusoidal, the effects can be detrimental for a number of the motor's components. PWM technology produces an output waveform that is a pseudo sine wave. It is creating an output waveform that is a series of pulses varying in amplitude and duration (Figure 5), that when reconstructed, is trying to emulate a sine wave at the drives output.

The output signal is chopped up much like a tree branch that went through a wood chipper. The motor then has to somehow reconstruct all the pieces and use them to excite the magnetic

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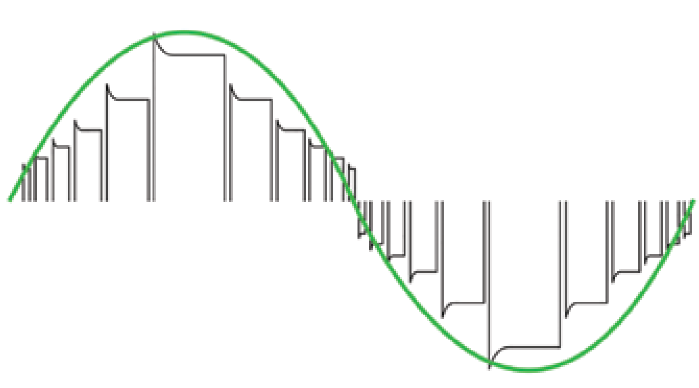
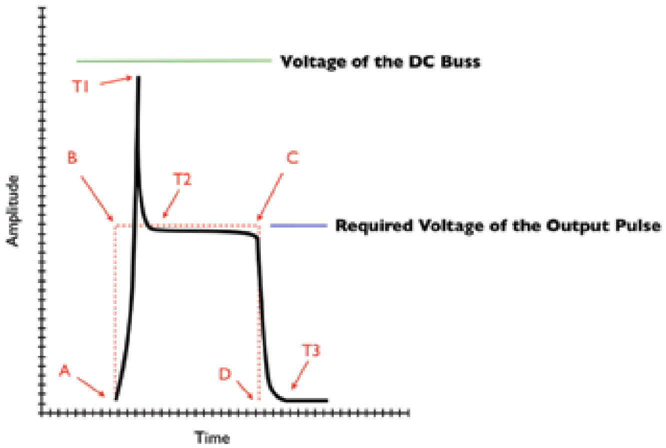


Figure 6.



field of the the stator. The result is a number of problems, one being the motors flux fields do not expand and contract smoothly, causing the stator windings in the motor to vibrate. The vibration over time will eventually cause the windings to fail.

MOTOR BEARING PROBLEMS

The red dotted line (Figure 6) A,B,C,D is the outline of the square wave output the IGBT is trying to make. But electrically it is impossible for the IGBT to react fast enough to produce a signal that comprises right angles.

As the IGBT turns on at point A, it immediately opens the gate to the DC buss allowing high voltage to flow to the output. The IGBT then tries to limit the voltage at point B. Because the rise time from point A to point B is so fast (typically in micro seconds), the IGBT allows a short spike of high voltage from the DC buss to pass to the output (identified here from point A to T2) essentially overshooting the desired voltage of the required pulse. The IGBT then tries to shut off at point C, but because of the lag time, it actually over shoots the actual desired shut off point of the gate. The switching actions required of the IGBT happen incredibly fast, unfortunately not fast enough, as the motor sees all the information in the output wave form (Figure 5).

The motor has no idea what to do with the high voltage spikes shown in Figure 6. As the pulses cut the windings of the motor they produce flux field anomalies that cause eddy currents build up on the rotor and a slight voltage is produced. This may be as low as a half volt or as high as five volts. The currents want to flow to ground, and the easiest path is often through the bearing.

As the voltage builds up on the rotor it eventually overcomes the insulating properties of the thin film of lubrication between the ball and the bearing races. Small electrical arcs are produced creating a microscopic weld in the substrate of the bearing (Figure 7).

A closer look at the edge of the electrically eroded area with a scanning electron microscope (Figure 8) shows that the damage to the bearing substrate is severe.

An even closer look (Figure 9) is the same sample magnified 10,000 times. One can clearly see that the arc not only produced a significant pit in the substrate, but the metal was hot enough that it left small puddles of material on the surface of the bearing substrate. This could have been lifted from the substrate of the race, or it could have been material from the ball bearing as it passed the point where the micro weld was created.

WHAT DOES THIS MEAN?

In a typical ball bearing application there is a small almost microscopic pressure wave that precedes the actual ball as it rolls forward in the race capturing the load of the rotating application. (Figure 10) is exaggerated so that the reader can see the pressure wave. The pressure wave is created by the force applied either due to the weight of the application on the bearing, or the lateral force applied by tensioning the belts.

The metal substrate of the bearing is extremely hard but also elastic. If the substrate of the bearing is damaged, small cracks or chips form in the surface and essentially spall causing a catastrophic failure of the bearing.

Figure 7.

Figure 8.

Figure 9.

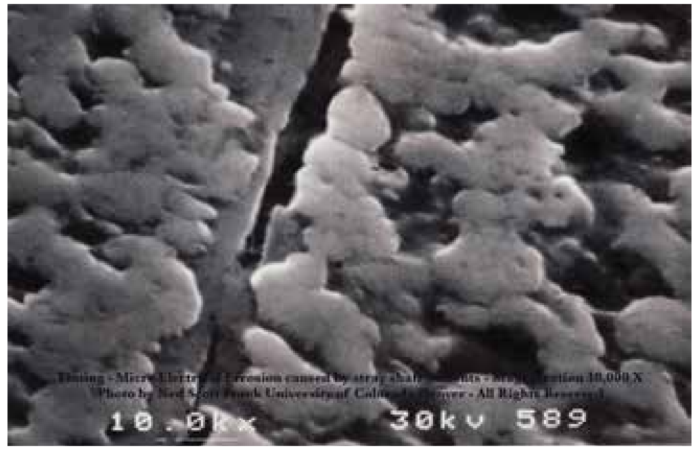
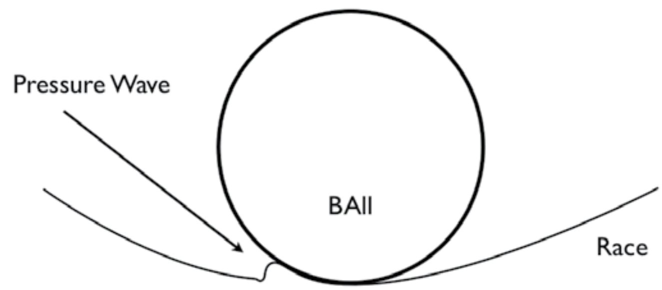


Figure 10.



SHAFT GROUNDING

There is really no "fix" for circulating eddy currents, as this is a phenomenon inherent in the PWM technology. The preferred method of mitigation is to install a shaft grounding kit on the end bells of the motor to create a parallel path for the damaging currents away from the bearings.

Motors can also be ordered with insulated bearings; this can be done a number of ways. The end bells of the motor can be machined and phenolic cups installed in the bearing cups, or ceramic-coated bearings can be installed.

There are problems with insulating the motor bearings in that the charge on the rotor can now be transferred to the belts, much like a Vander Graph generator. The electrons from the rotor create a static charge on the belt as it travels up to the fan bearings, and now instead of the electrical arcs damaging the bearings of the motor, the problem is transferred to the driven apparatus.

VFD OPERATING PARAMETERS

VFDs have certain operating characteristics that should be observed as they are applied to any given application. First the minimum speed at which the motor is driven should be no less that 30 percent of full speed. Moving the motor at speeds slower than 30 percent of nameplate not only reduces the cooling of the stator, but also puts heavy electrical stresses on the motor windings, as the pulses from the VFD are more defined, this can amplify the strength of eddy currents and accelerate bearing damage.

VFDs also have a window of efficiencies as they are applied to HVAC applications. The bulk of the savings a VFD produces is defined in a window from about 45 percent to about 90 percent of full speed. If the application runs at a constant speed below 60 percent of the motor nameplate speed, than that could mean that the equipment for the application is oversized. Consequently, if the application is consistently running over 85 percent of the nameplate speed of the motor, than it could mean that the equipment is undersized for the application.

SUMMARY

There is no doubt that Pulse Width Modulation Variable Frequency Drive technology is here to stay. The industry has now come to the table and working diligently to find solutions for many of these problems. Because the technology is advanced, even the experts disagree about the causes and effects of some of these phenomena.

The problems described here are only a few of the common issues a facility will encounter with this technology. Take the time to educate yourself and your staff, and the time to evaluate motor failures, cutting a bearings open to find the cause of the failure. Ask why a motor failed multiple times in a specific application.

As with any technology there are tradeoffs, and VFDs are no exception. The key here is to look at each application from its inception, through design, installation, and start up. Develop a checklist to make sure that all the elements of the application are being looked at and that best practices are being followed.

Follow advice from not only the manufacturer of the drive, but others as well, and select an equally efficient inverter duty motor. Install good shaft grounding technology prior to start up. Also make sure that the drive is installed for the right reasons and that it has the capabilities needed to run the applications in the most efficient parameters.

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