GENERAL CABLE VFD CABLES

An Overview of Variable Frequency Drive Cables

By General Cable, November 2013

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OVERVIEW OF VARIABLE FREQUENCY DRIVE CABLES

INTRODUCTION

Variable Frequency Drive (VFD) cables emerged in the 1990s to help minimize operational issues with VFD systems. With the incorporation of Insulated Gate Bipolar Transistors (IGBTs) into inverters, switching speeds have increased by nearly two orders of magnitude from what they were in earlier Silicon Controlled Rectifier (SCR) and Gate Turn-off Thyristor (GTO) technology drives. This has caused a significant increase in the high frequency information output from the drive inverters. In some installations, traditional power cables had issues handling these high frequency signals leading to system problems.

A portion of these issues can be solved by simply selecting the proper VFD cabling. However, it can be difficult determining exactly which installations require VFD cables in order to minimize problems in the system, and which will perform adequately with traditional power cable installed.

It all comes down to justifying the premium for a cable solution that may or may not be needed, depending on the specifics of the installation. Let's look at a few things we know.

We know that in some installations, VFD cables solve system problems — from motor issues to premature cable failure to control problems; in other installations, using standard power cable works just fine. Why the difference? These systems are extremely complex with many variables to consider such as drive types and specifications, filter or reactor installation, cable lengths, and proximity to other electronics. Additional variables include the type of cable glands, terminations, high frequency bonding straps, and ultimately, overall installation practices.

The challenge of variable frequency drive installations is that they involve many components, along with environmental and installation variations. This makes the workings of these systems seem less like well-defined science and more like black magic.

While a lot of progress has been made in understanding IGBTs since they were first incorporated into drives, there are still a number of areas that require more research. This paper serves as an overview of what we know about VFD cables and how they can help minimize issues in VFD systems.

ISSUES RELATED TO OTHER ELECTRONIC SYSTEMS

Noise radiated from VFD systems can negatively affect instrumentation, radios, alarms and other equipment. The severity of the problem is a function of the proximity of this equipment to the drive system as well as the switching speed of the drive, cable layout, cable length, cable terminations and the nature of the equipment itself. There is a need to have a working understanding of what is going on here because of the multitude of variables in this equation.

All too often, installation practices require an inverter to motor power cables to be situated in close proximity to data, communication or control cables. With the significant number of control and automation systems installed in facilities today, these system cables can find themselves in close proximity to the inverter-motor cable at multiple points along the cable's path. Prior to IGBT technology, we could often run power cables next to these other cables, controls and automation equipment without incident. In fact, often the installation of early technology (slower switching) VFD systems could use standard power cables installed side-by-side with these other cables and things worked just fine.

This fact makes upgrading an older VFD installation to a new VFD system a lot more complicated. Let's imagine a situation: you have an old VFD system with its inverter-motor cable installed in a tray right alongside other cables. Even though that tray runs in close proximity to other control and automation systems in your plant, everything is working as expected. You're in charge of upgrading your VFD drive system. If the old VFD is replaced and the existing cable system is used, will there be any issues? It's definitely something that will need to be evaluated as there are many more variables in play with today's IGBT technology drives.

Older VFDs using SCR or GTO technology have rise times that measure in microseconds. Newer VFDs using IGBT technology have rise times that can be in the tens of nanoseconds. Faster switching speeds have reduced power losses in the drive, but they also produce stronger electro-magnetic (EM) fields around the cable. These stronger fields are the cause of induced voltages/currents in nearby cables and other electrical systems. In cables, this can cause dangerous currents and voltages, and could wreak havoc with the communication of data and control signals. In electrical systems, issues can range from intermittent operational issues to component failure and damage. Be aware that these "other systems" could include a nearby inverter in another VFD.

To better control the Electromagnetic Interference (EMI) from the cable, shielding is required. VFD cables are designed with a continuous overall shield providing low transfer impedance at high frequency. Correctly designed and installed terminations should also provide a low resistance to ground, low impedance at high frequency, and a 360˚ electrical connection to the cable's overall shield.

SYSTEM ISSUES RELATED TO CABLES

A VFD system can put more stress on a cable's insulation, and the motor, than has been seen in traditional 60 Hz systems.

This can lead to premature cable failure if not accounted for. Let's compare some voltages.

A traditional 60 Hz sine wave has a peak voltage (V_P) of:

$$V_P = \sqrt{2}V_{RMS}$$

Where V_{RMS} is the RMS voltage of the system.

In a traditional 480-Volt 60 Hz system, the peak voltage sent to the motor is:

$\sqrt{2}\,480$ or 679 volts.

In contrast, VFD inverters do not produce sinusoidal output voltage but instead generate a series of pulses that approximate a sine wave. The peak voltage of these pulses at the VFD inverter is equal to the VFD's DC bus voltage. This DC voltage (V_{dc}) is produced by a three-phase rectifier and can be expressed as follows:

$$V_{dc} = \frac{3\sqrt{2}}{\pi} V_{rms}$$

Where V_{rms} is the RMS voltage of the supply to the VFD.

This means that in a 480-Volt drive system, the peak voltage output from the drive is the same as the DC voltage, which is:

$\frac{3\sqrt{2}}{\pi} 480$ or 648 volts.

But that is 31 volts less than the 60 Hz system. How can a lower voltage cause more stress?

The lower voltage is not causing more stress. The higher frequency signals are the cause of the increased stress because they can cause reflected waves in the cable. Reflected waves occur because of a mismatch in the high surge impedance of the motor and the low surge impedance of the cable. The greater the mismatch, the closer the wave reflection is in amplitude to the original source waveform. The cable sees the sum of these two waveforms, which can approach twice the amplitude of the source wave. This is close to what we experience in cables connecting today's inverters and motors.

Let's go back to our 480-Volt system and assume a worst-case scenario — that our reflected wave is equal to our source wave. With no reflected waves, the cable will see 648 volts peak. Allow a reflected wave to develop and now that same cable is seeing a 1296 peak voltage. This voltage is much higher than the 679 peak voltage seen in traditional 480-Volt 60 Hz power cable systems. If the installed cable is rated for 600 V (850 V peak with a 60 Hz waveform), the peak voltage of the reflected wave is 448 volts over the peak voltage that the cable was designed to handle. This higher voltage, along with the fast rise times of the pulses, adds significant stress on the cable, decreasing cable life.

Fortunately, there is a solution to the reflected wave phenomenon. By using shorter cable runs, reflected waves can be prevented from ever occurring. To estimate the maximum cable length in feet, multiply the VFD pulse rise time (in milliseconds) by 246. Not all installations can be designed with cable lengths short enough to eliminate the chance of reflected waves. If you cannot eliminate these waves, you may want to consider using a VFD cable designed to handle the additional voltage stress.

SYSTEM ISSUES RELATED TO MOTORS

Motors have been known to experience issues in modern VFD systems. Premature motor failure due to bearing fluting is a common problem.

One contributing factor to bearing fluting is high motor frame voltage with respect to the inverter frame. If the inductance between motor and the VFD is large enough, the reactance at high frequencies can support voltage drops of over 100V between the motor and inverter frames. This voltage will cause a current to flow. If the motor shaft is connected via a metallic coupling to the gearbox or other machinery that is solidly grounded and near the same ground potential as the inverter frame, it is likely that shaft currents will flow due to the shaft's "better" path to ground. Sometimes called the "shaft grounding current,'' it may flow through the bearings of the motor, the machine bearings, or both.

If that shaft grounding current flows through bearings, then bearing fluting can occur causing premature motor failure.

But why would there be high voltage on the motor frame?

Again, it is due to the high frequency components generated by the drive. In a nice slow analog 60 Hz system, the net current flow of the three conductors at any point in time is zero. This is not the case in a VFD system because the waveform of each phase is the approximation of a sine wave (made up of those pulses we talked about earlier) there is a net current flow (common mode current). This current originates at the inverter and must return to the inverter. We must minimize this current to keep the voltage between the motor and inverter frames as low as possible. Two ways of doing this include the use of a shielded cable that has a low transfer impedance at high frequency (reducing the impedance between the inverter frame and the motor frame); or through the use of a symmetrically designed cable with three grounds in the interstices of the power conductors (reducing the total induced current/voltage in cable grounds). The best VFD cables have both of these components in their construction to provide the best assistance in combating current flowing through bearings.

SUMMARY

There are three recommendations for cabling that may be used in VFD applications: shielded cables (addressing issues in other electronic systems and reducing bearing currents); cables with an adequate insulation thickness (addressing standing waves); and cables with a symmetrical design (addressing induced currents related to bearing failure); all of which may help reduce or eliminate several performance issues in a VFD drive system. These three cable attributes are found in the VFD cables offered by most major manufacturers including General Cable.

While it's not easy to determine which installations require VFD cables, specifying cables that have been designed to mitigate the issues as discussed in this article will help to ensure that your system will operate as expected when you expect it to.

General Cable has a strong tradition of dedicated leadership in the integration of research, design, engineering and manufacturing of generation after generation of industrial cables. With the ability to process an extensive variety of material into thousands of cable constructions for sustained and continuous operations in challenging environments, General Cable has the people, equipment and experience to help define the right cable for your application.