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MEDIUM VOLTAGE DRIVE CABLES

There has been a lot of discussion about which cable to use between a Variable Frequency Drive (VFD) inverter and the motor. Most of that discussion has focused on low voltage drives (drives rated under 2000 volts). What about medium voltage drives? After all, medium voltage drives need cable too! Why has all the focus been on low voltage drives? Let's remedy that situation.

Likely, there are several reasons medium voltage drives don't get the same level of cable attention as low voltage drives: 1) low voltage drives have been around much longer; 2) many more low voltage drives are sold than medium voltage drives; and 3) until recently, medium voltage drives used a different technology than low voltage drives.

But, over the last decade, that last fact has been changing. Today, most medium voltage drives use the same basic technology that low voltage drives have used for decades, the Insulated Gate Bi-Polar Transistor (IGBT), a voltage sourced device. Most if not all of today's low voltage drives rely on IGBT technology and there are good reasons for this. An IGBT is a very fast device with rise times in the tens or hundreds of nanoseconds. The IGBTs are located in the drives inverter section and allow the drives to create an output of Pulse Width Modulated (PWM) waveforms. These waveforms look like a series of square waves of different wavelengths, and they trick the motor in to thinking it is seeing a waveform of a different fundamental frequency than the 60 Hz traditionally used. IGBT-based drives offer many benefits like increased efficiency, better control, lower cost, and reduced drive size.

But remember, the motor is no longer seeing a sine wave. It is now seeing a PWM waveform, which, along with advantages, has drawbacks, the main one being lots of high frequency components. IEEE papers tell us that, when you add up all the frequencies involved with the drive and their harmonics, these waveforms have frequency components up to and over 30MHz. It's because of these high frequencies in the voltage's output that VFD Cables were created, and why their use can mitigate a variety of drive system issues.

In the past, VFD cables were not required in medium voltage drive systems because these drives used a completely different technology, a current-sourced topology using something like a Silicon Controlled Rectifier (SCR), Symmetric Gate Commutated Thyristor (SGCT), or other device in the thyristor family.

Each drive topology (current-sourced or voltage-sourced) has its own strengths and weaknesses. Current-sourced medium voltage drives, which were once standard, do not create the high frequency pulse width modulated (PWM) waveforms that low voltage IGBT drives do.

Those high frequencies are the source of many of the headaches you can experience in low voltage drive systems. As medium voltage drives systems did not generate those high frequency components, medium voltage drives could operate without those headaches. (Don't worry! The drive manufacturers put other headaches into medium voltage drive systems to keep it interesting for you.)

But things change. Today many medium voltage drives use the same IGBT technology found in low voltage drives. That means that those drives experience similar system challenges as low voltage drives. Most drive manufacturers have focused development on these newer technology IGBT medium voltage drives and many have discontinued their current-sourced medium voltage drives.

Rockwell Automation, however, gives users the choice of the medium voltage drive topology they want to use. They offer both types of medium voltage drives. Current-sourced medium voltage drives, like the PowerFlex® 7000, and voltage-sourced (IGBT) medium voltage drives, like the PowerFlex® 6000. Both drives have advantages and disadvantages, but those are beyond the scope of this article. Talk to your Rockwell Automation representative to find out which drive is best for your application.

From a cable perspective these drives are quite different. In low voltage systems, the only reason to run a VFD cable between the inverter and the motor is to handle the high frequency voltages and currents that those drives generate. As a current-sourced medium voltage drive output does not contain high frequency signals so there is no need to install a VFD cable. You still need to meet the minimum requirements of the code for a medium voltage system, which means, here in United States, you must use a cable with a metallic shield over each insulated conductor. Beyond code requirements, follow the recommendation of your drive manufacturer. Medium voltage current-sourced drives operate very similarly to standard 60Hz power, which means you can pretty much use standard medium voltage cable and installation practices.

It gets a little more interesting with medium voltage drives using the voltage-sourced IGBT. These drives do create high frequency currents and voltages just like low voltage drives. So, what do you need to do? You need to install a cable between your drives inverter and motor that has some of the same features as low voltage VFD cable. But things are a little different between a low voltage and a medium voltage drive and its inverter to motor cable. Let's compare and contrast a medium voltage drive system with a low voltage drive system to learn more about this.

In a low voltage drive system, ideally, you want your inverter to motor cable to have the following characteristics:

1) Three copper phase conductors
2) A thermoset insulation like ethylene propylene rubber (EPR) or cross-linked polyethylene (XLPE). Not polyvinyl chloride (PVC) insulation which Type THHN cables have.
3) An overall metallic shield
4) Three ground wires in the interstices of the three-phase conductors

Let's examine each item in detail:

1) Three Copper Phase Conductors

Many low voltage drives use terminals that are designed to be used with copper wire. If you use aluminum wire, the connections can loosen and cause premature equipment failure. Therefore, most low voltage VFD drive cables have copper conductors.

In medium voltage drive systems, there are no terminals in which to plug the cable. Medium voltage cables must be terminated with medium voltage termination kits. During this process a lug will be installed on each phase conductor. This allows for the use of either copper or aluminum conductors and the cable stranding can be either compact, compressed, or concentric. Medium voltage drives give you much more flexibility when it comes to choosing the cable's conductor. While you have wide latitude in using copper or aluminum and various types of stranding, one area you will want to pay a little more attention to is the number of conductors. Medium voltage cables are manufactured with either a single conductor or with three conductors.

A cable with three conductors is preferred electrically because the cables are arranged in a triangle under the jacket and are in very close proximity to each other. This close arrangement lowers the cables reactance and reduces cable losses. If single conductor cable is used, and if those conductors are laid parallel to each other, higher losses exist and the current carrying capacity of the cable is reduced. If you plan on using single conductor cables, keep the length less than 300 feet. If you decide to lay the single conductor cables parallel in a tray, transpose the phases every one-third of the length of the run.

For example, if the drive output phases are U, V, and W, lay the cables in the order:

Phase U - Phase V - Phase W for the first third of the run,
Phase V - Phase W - Phase U for the second third of the run, and
Phase W - Phase U - Phase V for the final third of the run,

For cable lengths greater than 300 feet, use three conductor cable.

2) Thermoset Insulation

Low voltage drives can create reflected or standing waves due to the fast rise times of the square waves they produce. Rise times can be faster than 100 ns. These reflected waves are caused by the impedance mismatch between the surge impedance of the motor (which is high) and the surge impedance of the cable (which is low). That mismatch acts like a wall, bouncing the voltage waveform in the cable back toward the drive. As a result, the cable can experience voltage peaks of as high as 2.4 times the DC link voltage of the drive. That's over 1,550 volts peak in a 480-volt drive system. Thermoset insulations are better at handling higher voltages than thermoplastic insulations like the PVC found in Type THHN. In smaller sizes, the thin PVC insulation in THHN has been known to fail.

In medium voltage cables, PVC is not allowed to be used as an insulation compound, only thermoset insulations are allowed. This is ideal for variable frequency drive applications. The most common medium voltage cable insulations are either crosslinked polyethylene (XLP or XLPE) or ethylene propylene rubber (EPR). Both insulations are perfectly fine to use in drive applications. Medium voltage cables are available in 100%, 133% and 173% insulation levels. As you can experience reflected waves in medium voltage drives utilizing IGBTs, don't use an insulation level of 100%, use the 133% level to get a more protection from these peak voltages.

3) An Overall Metallic Shield

In almost all low voltage power applications unshielded cable is used. Because the low voltage drives generate high frequency PWM waveforms, electromagnetic interference (EMI) is generated and can cause interference in the operation of plant control and communication systems. The best way to mitigate this EMI is to use a shielded cable. In low voltage applications the most practical means of accomplishing this is to use a copper tape or braid over the cabled core and under the cable jacket.

MV cables are not constructed with an overall shield, but they are required to have a shield over each insulated conductor. EMI emitted from that conductor is controlled when that shield is grounded, which is required by code. Because these individual conductor shields mitigate the majority of EMI generated, no overall shield is required. Will a high-performance overall shield further reduce EMI? Probably, but we are getting to the point of diminishing returns. Most drive manufacturers do not see a need for an overall shield on medium voltage drive cable. Shielded conductors are just fine, but make sure those shields are in the form of a copper tape or copper braid and not in the form of concentric wires (also known as concentric neutral). You will get better EMI mitigation with a copper tape shield. Try to get a tape overlap of at least 25% because, for best cable performance, you don't want the tape to gap when the cable is installed around a bend.

4) Three Symmetric Ground Wires

In low voltage cables, each phase current induces a voltage in the ground wire(s). If the ground wire is part of a circuit (which it is), it will have a current flowing in it. By having a cable with three grounds placed symmetrically in the interstices of the phase conductors, some very nice cancellation effects occur which minimize that ground current.

MV cables typically do not have three grounds, but they have something that low voltage cables do not have and that is their individually shielded conductors. These shields create their own symmetry and the same cancellation effects happen within these shields as happens in the three grounds in a VFD cable. These shields also act as ground wires but, instead of being place in the interstices of the phase conductors, they are rotated 60° and place concentrically over each phase conductor. This gives you essentially the same cancellation effects as in the symmetrically designed low voltage VFD cable without the need for three ground wires.

What about Grounding?

It is recommended that you ground the cable shield at both ends. Doing so provides a low impedance, controlled path for the common mode current that drives create. Having this path available reduces the amount of uncontrolled high frequency currents flowing in the ground system and building steel, which can create issues for other equipment near that current. Grounding both ends of the cable should be done unless you have an application involving fundamental frequencies above 100 Hz. If that is the case, contact your drive manufacturer for best practice. They may recommend you only ground one end of the cable.

Grounding both cable ends has the upside of providing a controlled path for common mode current to return to its source (the drive's inverter). but it also has the downside of creating a current flow in the ground. This is called a ground loop. Some engineers will tell you that you don't want a ground loop. In this case, I disagree. With drive systems, the current loop is always going to exist. You want that current to return to its source through the controlled path of the cable shield and grounds instead of having it return through an unknown path via building steel. This return current only becomes a problem if the cable shield does not have enough copper to handle that current flow. Check the cross-sectional area of your shields and ground wires. If their cross-sectional area is less than half the area of a phase conductor, run a separate ground wire from the drive to the motor. The total cross-section of the shield and this bonding conductor should be >50% of the phase conductor.

Hopefully, you have found this information helpful in your understanding of motor cable needs in medium voltage drive systems. By following the recommendations above and your manufacturer's guidelines, you can expect to have a much more trouble-free experience with your medium voltage drive system.