Application Note

Begin with the End in Mind – Proper VFD Cable Termination

Beginning with the end in mind is not only one of the 7 habits of highly effective people, it's also a great philosophy to have when working with variable frequency drive (VFD) cable!

If you have variable frequency drives at your facility you probably have heard of variable frequency drive cable. VFD cable has been shown to improve system performance by reducing electromagnetic interference (EMI), minimizing ground currents, controlling common mode current (which if left uncontrolled can damage motor bearings) and more. You may know a lot or a little about this specially designed cable that runs from your drive's inverter to the motor. A lot of companies make VFD cable and a lot of salespeople from these companies will tell you that you should be running this cable. They may be right, but that is only half the story. The other half of the story is if you don't properly terminate this cable, you lose most of the benefits it can provide.

While many cable manufacturers will tell you that you need to be running VFD cable, very few of those companies will talk to you about how to terminate this cable. It's understandable. Most of these companies' experience is in cable, very few have any expertise in drives. But, the fact remains that this specially designed cable requires special terminations that most electricians are not familiar with. Proper termination of this cable is very important. I am not talking about just being NEC compliant, I am talking about terminating the cable, to maximize the benefits of the VFD cable's construction. If you don't terminate this cable properly, you lose many of the benefits the cable can offer you. Let's look at four rules you can apply to help you get a VFD termination that will allow your VFD cable to perform to its potential!

Rule #1: Terminate the Cable Shield at Both Ends

Most electricians have never dealt with a shielded power cable. The only shielded cables they have worked with are shielded control cables. While these cables are similar in that both have a shield, the purpose of the shield is quite different, and therefore requires a different termination. Our experience in working with electricians across the country is that termination methods of VFD cable vary greatly. Some electrical houses believe both ends of the shield need to be terminated, others insist that only one end of the shield be terminated. We have even seen some that simply cut the shield off at both ends and let it float! What's the right way?

Rockwell, in their **Wiring and Grounding for Pulse Width Modulated (PWM) AC**

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Drives[1] document states, "Shields of motor and input cables must be bonded at both ends to provide a continuous path for common mode noise current." This is one way in which VFD cable differs from communication cable. While terminating one end of a communication cable allows the shield to reduce EMI emissions from control signals, that's not what you want to do with a VFD cable. The VFD's PWM waveform contains many high-frequency components, which requires the cable shield to be terminated at both ends to minimize EMI. Also terminating VFD cable at both ends allows common mode current to return to the drive through the cable shield.

But wait, you say! If we terminate the shield at both ends, that's going to create a ground loop! Actually, that is not true. The ground loop already exists. Drives create common mode current. That current gets pushed to the motor from the drive through the cable's phase conductors. It has to return to the drive. We want that current to return through a path we control. That path is the cable shield. If the current does not return through the cable shield, it will return through a different path. One possible path is for the current to return through the motor frame – motor bearings – motor shaft – connected factory equipment – building steel, and, finally, back to the inverter. If this path is taken, the current will flow in packets when it discharges across the bearings, causing bearing fluting, (repetitive ridges in the bearing race) which damages motors.

The best return path we have is through the cable shield. So terminate it at both ends!

Rule #2: Use Large Surface Area, 360° Shield Terminations

Rockwell's document mentioned above also tells us, "The cable connector must provide 360° contact and low transfer impedance from the shield or armor of the cable to the conduit entry plate at both the motor and the drive (or drive cabinet) for electrical bonding.

Not only do you want to bond both ends of the cable shield, you want to bond them to a specific place and make sure that bond has a low transfer impedance. We are most interested in the transfer impedance at high-frequency because when you combine the drive's base operating frequency, the PWM carrier frequency, and the effective frequency derived from the switching time of the PWM voltage pulses as well as all harmonics, the total frequency spectrum of the currents ranges from near DC to over 30 MHz."[2]

At these frequencies, skin effect plays a primary role in impedance. Skin effect is the effect where high-frequency currents flow mostly near the outer surface of a conductor and not through its entire cross-sectional area. This is why large surface areas, like building steel, are of a lower impedance path than traditional paths, like ground wires. Ground wires do not have a large surface area and, in a VFD system, they are seen as a high impedance path for the common mode current.

The cable shield, on the other hand, is a large surface area path. We want to make this the primary path for the common mode current and we can do this by using large surface area connections

1 Rockwell DRIVES-IN001Q-EN-P - June 2019

2 Evaluation of Motor Power Cables for PWM AC Drives -Bentley and Link, IEEE Transactions on Industry Applications Vol. 33 No.2

between that shield and the motor entry plate and the drive entry plate or cabinet. Why not the grounding terminal? Again, because of high-frequency. Entry plates and cabinets have much more surface area than the grounding terminal.

A 360° termination of the shield is a method of ensuring a large surface area connection between the cable shield and the termination device. This device can be in the form of an EMC cable gland, which, while very common in Europe, are available in North America. Another method of termination is to wrap a tinned copper braid bonding strap around the shield, secure it with a constant force spring, and bond the end of the strap to the motor or drive. Either of these terminations, which wrap 360° around the cable shield, will create a large surface area bond with low impedance at high-frequency.

Rule #3: How to Handle Drain Wires

One common VFD cable construction is a cable with:

- Three phase conductors
- One insulated full-sized ground
- A full-sized bare drain wire
- An overall copper braid shield covered with a jacket.

Drain wires are most commonly used in foil shielded communication cables to provide an easy and reliable method to bond the shield. As it is difficult to reliably bond a thin length of aluminum foil, the drain wire, which is in contact with the foil, can be easily grounded.

The problem with drain wires in VFD cables is many electricians think they know exactly what to do with them: cut them off at one end and use the drain to terminate the other end. This is exactly what we do not want to happen. We want the cable to be terminated at both ends with low impedance, 360°, large surface area terminations. Drain wires do not accomplish this. It is not necessary to connect the drain wire to ground if you terminate the shield with a proper termination kit or EMC cable gland. If this is done, you can simply cut the drain wire off.

Rule #4: How to Handle Three Ground Wires

Another common VFD cable construction is a cable with three phase conductors, three ground wires symmetrically placed in the interstices of the phase conductors, an overall copper shield, and a jacket. This construction is technically superior to the construction described in Rule #3 as it reduces induced ground currents, but the construction creates another issue. Typically, motor termination housings do not accommodate landing three ground wires. This situation can be resolved by splicing a pigtail connection to the three ground wires and terminating that pigtial in the motor housing.

Ground sizes vary in these symmetrical designs. The pigtail need not have a cross-sectional area equal to the sum of the three cable grounds, it only needs to be sized to meet equipment grounding requirements per the NEC. Remember, the cable ground wires are simply there to meet code and provide a path for fault current. They do little to provide a lower impedance path for the high-frequency common mode currents. Those currents travel primarily on the shield.

Southwire offers accessories to assit you in properly terminating your VFD cables. Datasheets for our glands and termination kits can be found here.

By following the four rules above, you can maximize the performance of your VFD cable system, reducing EMI, creating a controlled path for common mode current, and helping improve efficiencies in your operations.

Steve Wetzel is a Principal Engineer for Southwire Company. He has worked with drives and their cables for over 20 years and regularly speaks at industy events on the topic.   Steve holds a Bachlors of Science degree in Electrical Engineering from the University of Wisconsin in Madison. He also serves on various industry standards committees.