

Application Note

AN004

Enhance System Performance and Safety with Parallel VFD Cables

VFD cabling allows for easier installation, while offering significant cost savings

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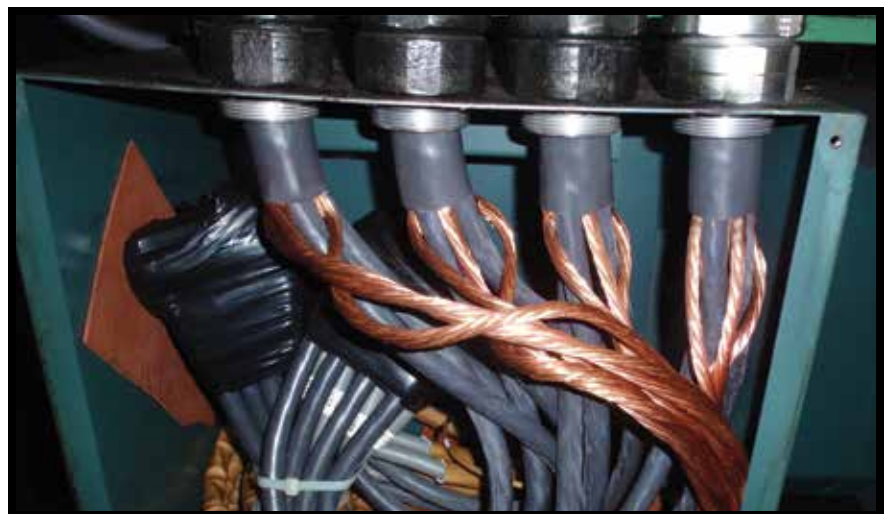
The construction and proper termination of variable frequency drive (VFD) cables can make a significant difference on how effectively a system can mitigate issues associated with VFD generated noise. The difference between various types of cables – for example, construction-grade VFD cables with rigid stranding and ground conductors meeting the minimum code requirements, or flexible VFD cables with as much as 300 percent of circuit conductor size in ground potential copper – can be extremely significant in determining the performance of a system.

That said, many users of larger systems often times must compromise their system's performance when installing systems requiring cable ampacity above 260 amps. Ampacity is the maximum amount of electrical current a device can carry before overheating, or as limited by statutory requirements. Virtually all available VFD cables offered in 250 MCM (thousand circular mils) and larger would fall into the construction-grade category. To compound the issue, as cables grow larger, the specific ampacity, or amps per circular mil, goes down significantly.

To illustrate this, let's take a look at the [National Fire Protection Association's \(NFPA 70®\) National Electrical Code \(NEC®\)](#), specifically Table 310.15(B)(16), which is defined as Allowable Ampacities of not more than three insulated conductors in a raceway, cable or buried underground. At 90°C, 500 MCM is rated at 430 amps, and the specific ampacity is 0.86 amps/MCM. Under the same conditions, a 1/0 American wire gauge (AWG) conductor is rated for 170 amps, with a circular mil area of 105.6 MCM. Therefore, the resulting ampacity of a 1/0 conductor is 1.61 amps/MCM. Compared to 500 MCM, 1/0 AWG provides 94 percent more current for a given amount of copper. Given the cost of copper, the potential cost benefit is significant.

Beyond the cost benefit of reduced copper in the conductors, the utilization of conductors 4/0 and smaller gives the user access to high performance VFD cables and their associated performance benefits. These benefits include larger grounds, better shielding, flexible tinned stranding, easier installation and termination tighter bending radius.

Construction-grade VFD cables are typically built to meet the [UL 1277 \(Tray Cable\) standard](#). This standard dictates that a 500 MCM cable must carry a minimum of 2 AWG ground. While this may be code compliant, it is less than optimal in protecting the system from the effects of current noise and other drawbacks common in high-power drive systems. In fact, virtually all commercially available VFD cables at more than 250 MCM offer smaller grounds than those found in a high-performance 4/0 AWG VFD cable with 100 percent ground. Since the largest



single factor in VFD cable performance is the effective impedance of the ground system (at the frequencies of the generated current noise), selection of cables that optimize the total ground potential copper and conductor surface area (for high-frequency performance) can result in a significant reduction in common mode current and its harmful effects.

In addition, anyone who has ever terminated a 500 MCM VFD cable knows how difficult the job can be. While code permits the shielded VFD cables to be bent to a radius of 12x the diameter (per NFPA 70 Article 300.24), or approximately 30 inches – the force required to bend a cable to such a radius often exceeds that available on the

job site. Added to that, the large bend radius ensures that it is likely impractical to enter the motor junction box from any place other than the top, where any penetrations increase the likelihood of water or oil ingress. And once inside the junction box, the large conductors will be difficult to bend and manipulate into effective terminations. The use of parallel constructions can significantly ease the cable handling difficulties, and reduce the overall cable weight installed in cable trays.



Figure 1. Termination for parallel ground connections on drive.



Let's take a look at the NEC® code provisions and how they apply:

Parallel installations are permitted under 300.3(B)(1) (Conductors)(Paralleled Installations) provided they are in accordance with 310.10(H) and that grounds are in compliance with 250.122. In addition, parallel runs in cable trays must comply with the provisions of 392.20(C). In each case, the user should be careful to consult the local authority who has jurisdiction.

Article 310.10(H) – Conductors for General Wiring, Installation, Conductors in Parallel

Allows conductors 1/0 and larger to be installed in parallel, as long as they comply with the following provisions: 1) same length, 2) same conductor material, 3) same conductor size, 4) same insulation type, and 5) terminated in the same manner. Ampacity of cables shall be in accordance with 310.15. Article 310.10(H)(5) dictates that sectioned equipment grounding conductors can be used, and their combined circular mil area (CMA) can be considered for compliance with Table 250.122. This dictates that the ground in each parallel multi-conductor cable must be sized to carry the full fault current.

Article 392.20(C) – Cable Tray, Cable and Conductor Installation

Cable ampacities must comply with 392.80(A)(1)(c). This provision designates that cable ampacities shall be in accordance with 310.15(B)(16) and that adjustment factors are limited by the number of current carrying conductors in a cable (always three for VFD), but not by the number of conductors in the cable tray. 310.15(B)(16) applies as long as the cable fill is in conformance with section 392.22. If one cable diameter spacing is used between multi-conductor cables per 392.80(A)(1)(c), then ampacities may be determined based on Informative Annex B, Table 310.15(B)(2)(3).

Article 250.122 – Size of Equipment Grounding Conductors

Ground conductors shall be in compliance with Table 250.122. Motor circuits must be sized in accordance with 250.122(D)(1) or 250.122(D)(2). The latter dictates that short-circuit sizing for motor circuits is determined based on the short-circuit protection rating, or in the special case of an instantaneous trip breaker, the maximum permissible dual-element time-delay fuse selected for branch circuit protection under 430.52(C)(1) Exception No. 1. In most cases, the resulting dual-element time-delay fuse size is 175 percent of the full load current (FLC), rounded up to the next standard fuse size. Regardless of whether a drive or motor starter is used, the rules of 430.6 and associated tables must be used to determine FLC – not to be confused with motor full load amps (FLA) – and such currents must be used in determining the value of short-circuit current referenced in ground selection for 250.122.



Let's work through an example that features:

- 500 horsepower (HP)
- National Electrical Manufacturers Association (NEMA) class B
- Cables installed in a cable tray

Motor Nameplate Data:

HP 500 Voltage 460 RPM 1750 FLA 607
Design NEMA B

- Determine required cable ampacity
 - The motor conductor size must be determined by 430.6, which will in this case reference table 430.250, providing an FLC of 590 amps for 500 at 460V.
- Determine Overcurrent Rating - in this case we are using an instantaneous trip breaker
 - Maximum motor overcurrent protection will be the next standard dual-element time-delay fuse size above 175 percent of FLC, or 1.75×590 amps (1032 amps). The next standard fuse size would be 1,200 amps.
- Determine Ground conductors requirements
 - Based on the 1,200 amps of short circuit current, per Table 250.122, the minimum size of the individual ground conductors – based on the code requirement that each ground conductor must be capable of handling – all the ground fault current would be 3/0 AWG. This means that each cable applied in parallel must contain a 3/0 ground.
- Determine the conductor ampacity required
 - Based on Motor FLC, conductor ampacity is typically 1.25 percent of motor FLC per 430.6.
 - Conductor ampacity = $590 \times 1.25 = 738$ amps.

HP	FLC per Table 430.250	Conductor Ampacity required@480V 75C	Max Over Current Protection@ 175% +Size	30C Ambient 75C Max Conductor using 310.15(b)3	Ground Size per Table 250.122 AWG
100	124	155	225	1 x 2/0	4
125	156	195	300	1 x 3/0	4
150	180	225	350	1 x 4/0	3
200	240	300	450	2 x 1/0	2
250	302	378	600	2 x 3/0	1
300	361	452	700	2 x 4/0	1/0
400	477	596	900	3 x 3/0	2/0
500	590	738	1200	4 x 3/0	3/0

Table 1. Sample buildup of conductor ampacity, over-current protection with dual-element time-delay fuses and ground size

Note 1. Note that each cable must have sufficient grounds to comply with NEC requirements, and grounds in separate multi conductor cables cannot be combined to determine conformance with Table 250.122 requirements

Now we need to figure out the actual conductor rating, and any applicable derate factors that may apply.

The following assumptions will be made regarding the installation:

The cables will be installed in a ventilated (Ladder-type) cable tray, and the tray will be uncovered. Allow at least one cable diameter of spacing between each cable. This special case allows us to reference the ampacity tables of Annex B Table B.310.15(B)(2)(3) In the case where the tray fill limits of section 392 are used, we would defer to Table 310.15(b)(16) and apply any applicable derate factors. Since we know in this case that each cable must have at least a 3/0 AWG ground, we will look at the number of 4/0 conductors that will be required. Per the table at 40°C ambient, 90°C conductor temperature, each conductor has ampacity of 287 amps. Three conductors would have a combined ampacity of 861 amps. Since this exceeds the required 738 amps, this combination of conductors may work.

First, we must verify the termination temperature of the drive. If the drive termination temperature is less than 90°C, this temperature must be used for conductor

selection. As is typically the case, the drive manufacturer has in fact listed the equipment terminals at 75°C. This means we must look to the 75°C column to determine conductor rating. Based on that, 4/0 is rated at 245 amps. The net 40°C ampacity of 3 x 4/0 AWG is only 735 amps, but a temperature correction factor of 1.13 can be applied for

30°C ambient temperature. The net amps are now 830. As this meets the current and short-circuit requirements, 3 x 4/0 AWG cables would be required for this 500 HP drive system. Had we not been able to use the special provisions of Annex B, then the solutions of 4x3/0 as shown table 1 on the previous page may apply.

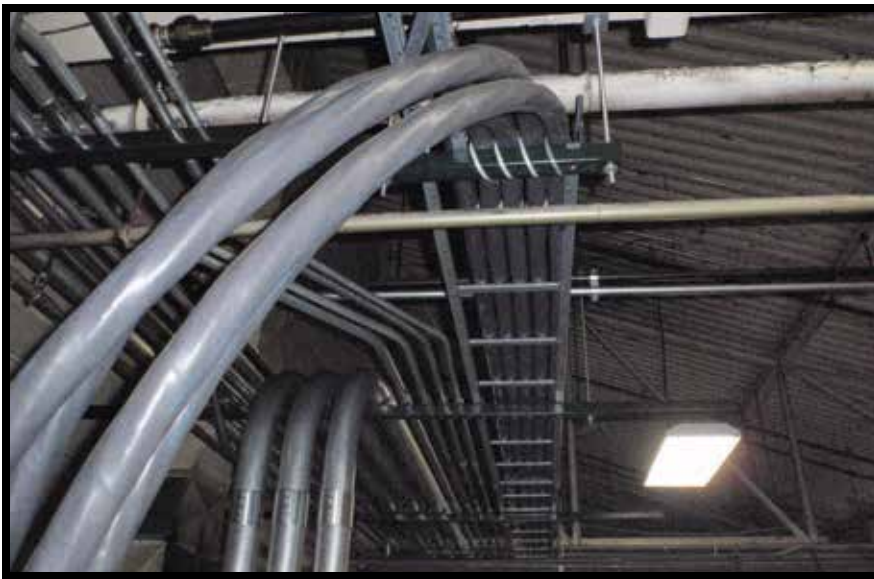


Figure 2. Quadruple 4/0 AWG Belden 100% ground VFD servicing a 600HP motor via cable tray.

When comparing the parallel solution to a single-conductor solution, consider these elements:

- Copper use is reduced
- Cables are more flexible and easier to terminate
- Lower pulling force is required
- Much more ground copper is installed leading to reduced noise emissions

The basic rules for parallel conductor applications.

1. The conductors must be equal in length, and the same construction
2. Conductors must be 1/0 AWG or larger
3. Grounds in each cable must comply with NFPA 70 (NEC) 250.122
4. Cables must be joined at both ends
5. Each cable must contain one of each phase of the load

NOTE:

The example shown is for a specific application under a specific set of conditions, and may not be applicable to any given situation. Always consult your Local Authority having Jurisdiction for local and regional code compliance and interpretation questions

References

1. National Fire Protection Association Website: National Electrical Code (NFPA 70) - 2014 Edition www.nfpa.org/70
2. UL Website: Electrical Power and Control Tray Cables with Optional Optical-Fiber Members (UL 1277) - 2013 <http://ulstandardsinfontet.ul.com/scopes/scopes.asp?fn=1277.html>