EDITION 20
VOLUME 2

EVALUATING VFD SYSTEM PERFORMANCE
WHY CABLE SELECTION AND TERMINATION MATTER

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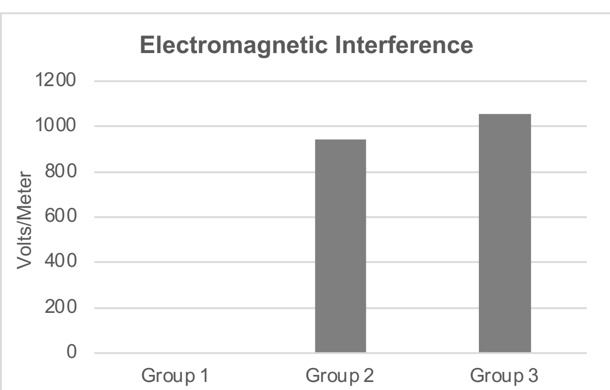
Variable Frequency Drive (VFD) cable entered the market in the 1990s, but since then the industry has seen virtually no development of standards, universally accepted constructions, or consistent installation practices. This lack of progress has hindered drive system performance and created widespread confusion. In the absence of standards, manufacturers were free to create "innovative" cable designs that may or may not have improved performance. As a result, marketing often became the deciding factor in a product's success rather than technical merit. Misunderstandings and inaccurate information about the purpose of VFD cable and proper installation practices became commonplace, and reliable data was difficult to find.

A certified drive start-up specialist told Southwire that without solid data, most engineers are hesitant to recommend VFD cable. His feedback prompted Southwire to conduct comprehensive testing to compare system performance. Eight cable constructions and termination methods (all widely used in the field) were evaluated.

The results, published in an IEEE PCIC paper, now give engineers the hard data needed to understand how cable design and installation choices affect system performance. The objective of this evaluation was to establish a clear performance baseline for VFD systems by examining key system attributes. The attributes evaluated include radiated electromagnetic interference (EMI), reflected waves, ground current, ground voltage, shield current, common mode current, and motor shaft current. The study assessed how different cable constructions perform under these conditions and compared how various cable types and termination combinations influence these system parameters. Our testing and evaluation also considered several installation and system level factors, such as short versus long cable runs (30ft vs. 300ft), different fundamental operating frequencies, and the effect of applied torque or load. While cable length and construction showed measurable impact, changes in fundamental frequency and applied load did not produce meaningful differences in system performance.

TEST & MEASUREMENT EQUIPMENT

- VFD 1 | 5 Hp Drive, Model: ACS580
- VFD 2 | 5 Hp Regen Drive, Model: ACS880
- Motors | 5 Hp Motor, Model: IDVSM3665T
- Oscilloscope | Tektronix 2 GHz Oscilloscope, Model: MSO58B
- Voltage Probe | Tektronix 100 MHz Differential Voltage Probe, Model: THDP0100
- Current Probe | Tektronix 30 MHz Rogowski Coil Current Probe, Model: TRCP0600
- Current Probe | Tektronix 100 MHz AC/DC Current Probe, Model: TCPA300
- EMI Meter | Vlifree EMF Detector 5 Hz - 3.5 GHz, Model: EMF01



Radiated EMI

LOWER IS BETTER

RADIATED EMI

Our testing found that radiated EMI was significant on both unshielded cables and shielded cables that were installed with the shield not grounded. Radiated EMI was reduced to zero when either one or both ends of the cable shield were bonded to ground. This can be further illustrated by the results of our testing in the graph.

Group 1 - Terminated shielded VFD cables
Group 2 - Non-terminated VFD cables
Group 3 - Unshielded non-VFD cables

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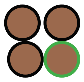
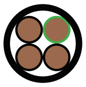
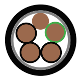


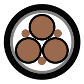
CABLE 1: Four insulated single conductors without a shield or overall jacket rated type THHN/THWN.



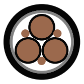
CABLE 2 & 3: Four insulated conductors under one jacket, without a shield.



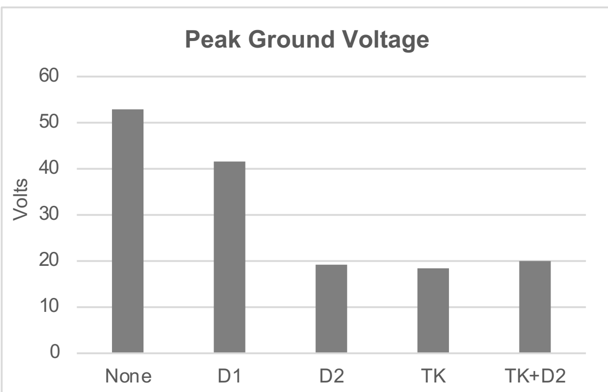
CABLE 4 & 5: Four insulated conductors and one drain wire with an overall shield and jacket.



CABLE 6 & 7: Three insulated conductors and three bare grounds symmetrically laid in the interstices covered with an overall shield and jacket.

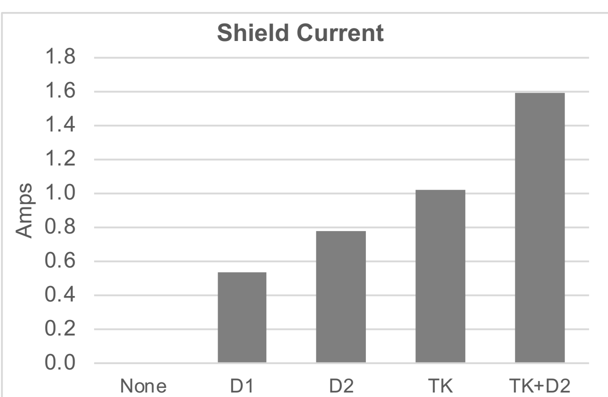


CABLE 8: Three insulated conductors and three bare grounds symmetrically laid in the interstices and covered with an overall continuously corrugated welded aluminum armor, acting as the cable shield. The armor is covered with an outer jacket.



Peak Ground Voltage based on termination method

LOWER IS BETTER



Shield current

HIGHER IS BETTER

REFLECTED WAVES

Our testing found that cable length was the primary factor in reflected wave magnitude. Cable construction was not a factor in determining the peak voltages measured during these phenomena. 300ft cable lengths resulted in a 38% increase in peak voltage over 30ft lengths. In order to reduce reflected waves, additional devices, like load reactors, sine wave filters, and dV/dt filters must be used as a complementary device with the VFD cable.

GROUND CURRENT AND VOLTAGE

Testing showed that current spikes are about 10x higher on standard cable than on terminated VFD cable constructions. It was also observed that the cable ground wire voltage peaks are about 3x higher on the standard cable than on terminated VFD cable constructions.

Our performance evaluation showed that grounding the shield helped reduce voltage peak magnitude on the ground conductor. Grounding the shield at both ends reduced voltage spikes significantly more than the common practice of only terminating a single end of the cable at the source.

SHIELD CURRENT

While RMS shield current varied greatly with cable termination method, peak shield current was influenced less. This demonstrates the need for proper cable shield termination at both the drive and the motor. Low impedance at high-frequency shield terminations allows more of the CMC (Common Mode Curent) created by the drive to return to the source via a controlled path.

None - No shield or float shield
D1 - Drain wire attached to only the VFD end
D2 - Drain wire attached to both the VFD and motor ends
TK - Termination kit attached on both the VFD and motor ends
TK+D2 - Termination kit and drain wire attached on both the VFD and motor ends

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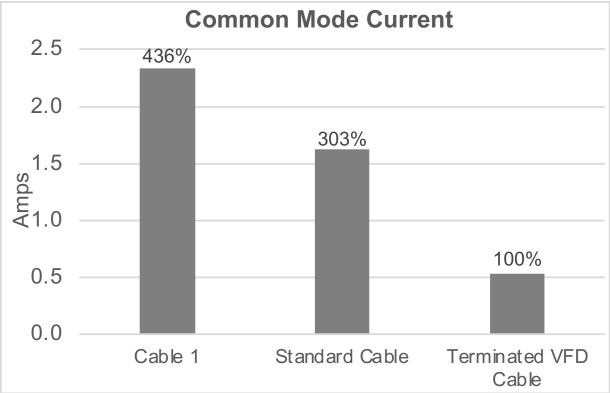
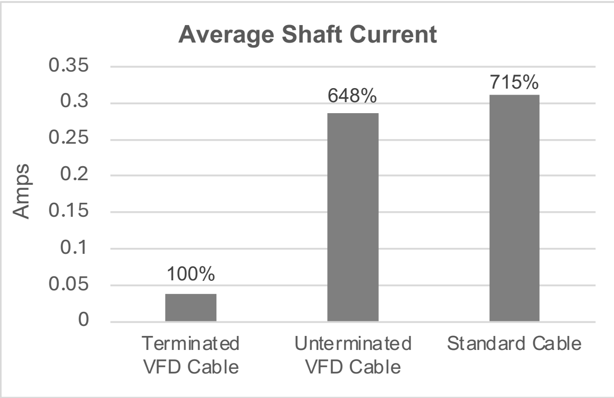


Common mode current

LOWER IS BETTER

COMMON MODE CURRENT

The unbalanced instantaneous power output from the VFD creates additional currents. When the combined currents from the phases, grounds, and shield are added together, the resulting value is the Common Mode Current (CMC). This current, if not properly managed and controlled, many issues like motor failure, nuisance drive trips, and even drive failure can occur. As shown by the graph, properly terminated VFD cable significantly reduces CMC.

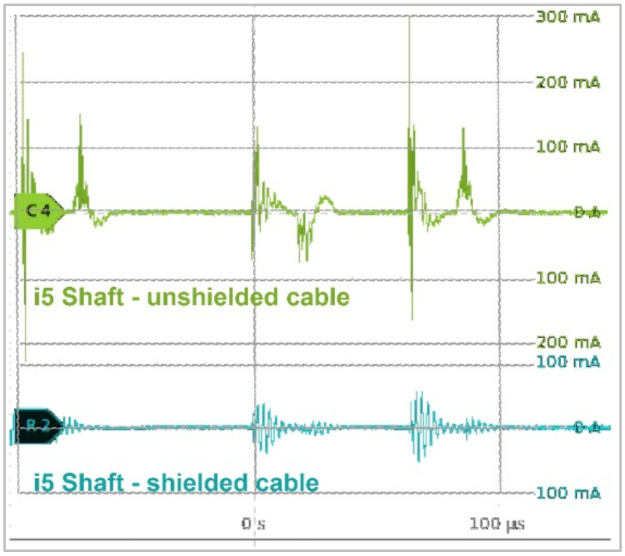


Motor shaft current

LOWER IS BETTER

MOTOR SHAFT CURRENT

VFD cable significantly reduces motor shaft current when installed properly. This protects the motor bearings and can help to reduce motor failure.



Shaft current comparison

LOWER IS BETTER

SUMMARY AND CONCLUSION

Cable construction and termination methods played major roles in improving system performance. Shielded cables always significantly outperformed unshielded cables in terms of overall system performance when the shield was bonded at both the drive and motor. Outside of cable construction, system performance varied greatly depending on shield termination method. Connecting the shield by utilizing a low-impedance bonding to system protective earth (PE) helps to reduce the magnitude of the voltage and current spikes seen on the factory ground and motor shaft.

Cable construction with symmetrical bare grounds in contact with the shield allows the shield to be somewhat effective, even when proper termination methods are not used. This should be considered as not all installers use best practice when installing cables between drives and motors. For more information, download a copy of our IEEE paper: **Evaluation of How Inverter to Motor Power Cable Types and Termination Methods affect System Performance** at: https://ieeexplore.ieee.org/document/11289103

ABOUT THE AUTHORS

STEVE WETZEL

Steve Wetzel has an electrical engineering degree from the University of Wisconsin – Madison and is a Technical Sales Director for Southwire Company. He is a member of the Insulated Cable Engineers Association (ICEA) and is chair of ICEA S-138-738 Power Cables Rated 2000 Volts or Less for use Between Variable Frequency Drives and Motors. Steve started learning about VFD systems and cables when he worked for Siemens, who created the first VFD cable construction in the 1990s. Steve presents at customer and distributor training sessions and industry events each year on the role of cable in drive systems. He has authored numerous application notes on various aspects of the inverter to motor cables.

KEVIN WAHL

Kevin Wahl is a Chief Applications Engineer as part of Southwire's CableTechSupport™ Services team. He received his bachelor's degree in mechanical and electrical engineering from Fairleigh Dickinson University in 2018. Prior to joining Southwire in 2022, he was a product development engineer for a German-based cable manufacturer with production facilities worldwide. This career path has equipped him with deep insights into global industry trends, international codes and standards, environmental stewardship, and safety regulations outside of North America. He is a subject matter expert in a diverse range of industrial applications but has been working with VFD cables since the start of his career in 2014. Kevin serves on many technical committees, including ones hosted by the National Electrical Manufacturers Association (NEMA). This paper, co-authored along with Steve Wetzel, Tahar Irid, Rick Hoadley, and Rick Akey, is his first submitted to IEEE PCIC.

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