ROBUST VFD SOLUTIONS TO MEET INDUSTRY STANDARDS

By **John Gavilanes,** Director of Engineering

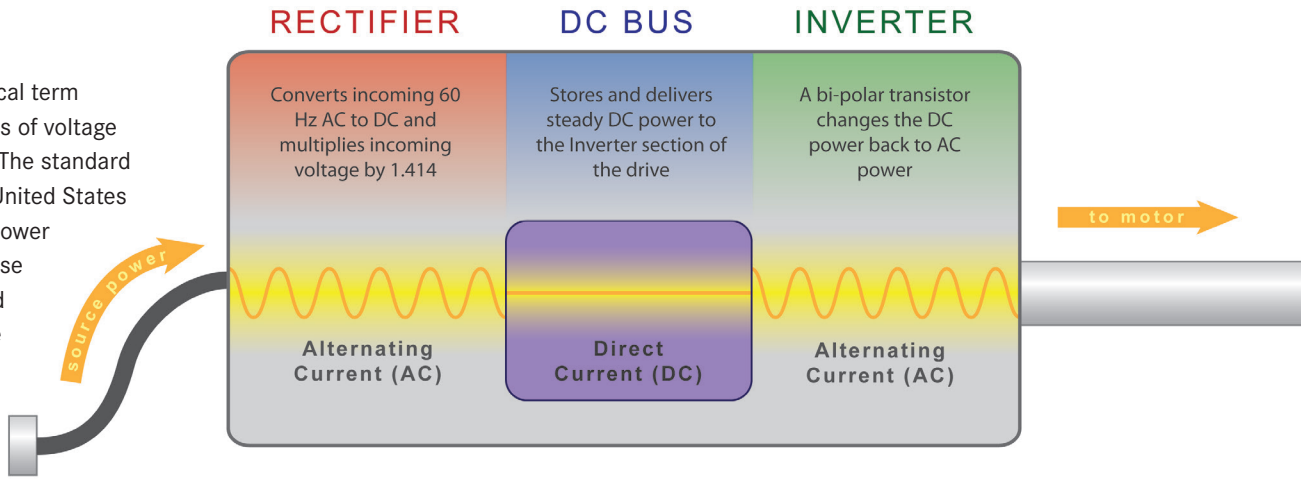
VFDs – also commonly referred to as Adjustable or Variable Speed Drives – improve the efficiency of motor-driven equipment and allow for accurate continuous control over a wide range of operating speeds. The VFD market is continually expanding on an ever increasing scale to help support the highly intelligent and sophisticated machines designed by engineers. As is such to help insure uninterrupted operations, cable performance has never been more in the spotlight. Machinery utilizing high performance VFD motors are being shipped with cables from overseas manufacturers to help complement the "complete package". It is critical to insure that these cables also conform with NFPA codes and regulations so there are no compliance issues during the installation process. To help combat these types of issues the 2018 edition of NFPA 79 in chapter 4 section 4.4.2.8 addresses specifics concerning cable type requirements for adjustable speed drive systems. In addition the 2017 National Electrical Code requires that only cables with the appropriate types of approvals are suitable to extend beyond the confines of the Industrial platform into cable trays, and throughout the building infrastructure to the accommodating control panels.

VFD THEORY

Frequency is an electrical term describing power pulses of voltage and current over time. The standard frequency level in the United States is 60 hertz (Hz) or 60 power pulses per second. These power pulses are called frequency cycles; there is one positive and one negative pulse of voltage in a single frequency cycle. Regional power companies provide the source power for all electrical operating equipment. The source power may go through a factory's transformer to either step up (increase) or step down (decrease) the voltage, but the frequency will remain constant at 60 hertz.

There are four main components of a drive system: source power, a VFD, the cable, and the motor. Ancillary components – resolver/encoder feedback devices, tachometers, sensors, and relays – may also be incorporated for increased performance.

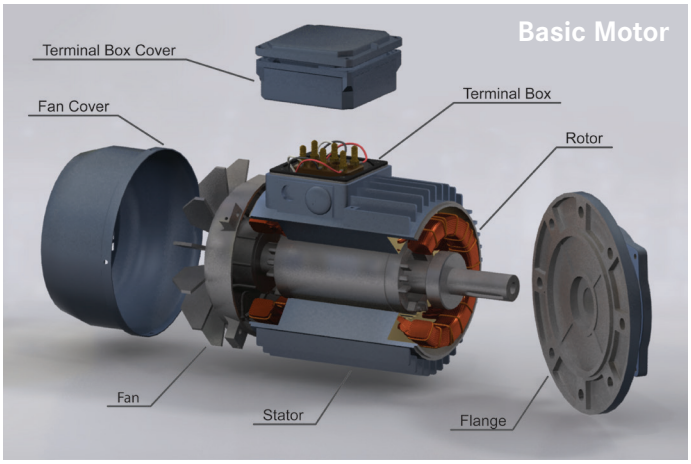
Variable frequency drives have become increasingly prevalent in industrial applications where frequency is used to adjust the speed of the motor. The primary role of the drive is to send the power pulses that control the motor's start-up, operating speed, and stopping functions. Increasing the frequency of the drive will increase the motor's speed; conversely, decreasing the frequency will cause the motor to slow down. The VFD performs three steps in order to adjust the speed of the motor (see illustration below):



Alternating current is the primary source of electrical power in the USA. The VFD's first job is to convert the source power from alternating current (AC) to direct current (DC). During conversion, the voltage of the source power is multiplied by a factor of 1.414, though the frequency remains at 60 hertz. For example, an incoming source power of 460 volts AC will be converted to 650 volts DC. This process is necessary before the power can be later changed back to AC so that the variable frequency can be used for VFD applications.

The second part of the drive is the DC bus, an electronic component that stores energy. The DC bus acts as a large storage battery which supplies DC power to the third part of the drive, the inverter. The inverter converts DC back to AC, allowing for the inverter to control the frequency of the current sent to the motor, which then affects its operating speed. This is the advantage of using a variable frequency drive. Pulse width modulation (PWM) frequency is approximately 20,000 hertz and offers finer control by only varying a few cycles of current at a time. However, the power source frequency is 60 hertz; at that frequency, affecting a few cycles only offers a limited degree of change and does not allow for control as precise as with PWM.

The VFD outputs a flow of AC power pulses at a certain frequency which provides or maintains the desired speed of a running motor via power supply cables. It is extremely important to select the appropriate cable for the application to avoid any disruption in power pulses, which would result in a drop in precision control of the motor and potential downtime.



A basic motor consists of a rotor, which physically rotates, and the stator, which remains stationary. When power is applied to the stator, a rotating electromagnetic field is created, which causes the rotor to turn. The stator is constructed by winding insulated wire a specific number of times in a defined configuration. This area is the defenseless part of the motor; the wire insulation is extremely thin and can get nicked during the winding process. These nicks in the wire become bare spots of exposed conductor from which high-voltage spikes may arc to the unit's housing, leading to motor failure.

WHAT HAPPENS

The conversion of power from AC to DC and then back to AC is not a clean transition. Unfortunately, power distortions created during conversion are sent back through the source power system, resulting in unwanted additional voltage and current. This higher flow of power causes the motor to run faster, causing overheating and high-voltage stress. In applications using sensitive clock or timing functions, critical electronic equipment can become confused. The motor and power supply cables that carry these electrical distortions are not immune to damage.

Non-linear power is defined as a change in voltage without the same change in current. Under ideal conditions, the motor anticipates a power pulse and regulates the correct amount of current provided so the increase in speed can be sustained. However, with non-linear power the current does not properly support the motor's requirements, and the distorted current can create high-voltage stress and cause excessive heat.

A spike is an exceptionally quick increase in voltage that occurs for a very short period of time. During inversion, the voltage must rise from zero to 650 volts, then back to zero approximately 20,000 times per second. During this process, the nominal voltage can overshoot from 650 volts to 2,000 volts or more. A longer length of power supply cable will experience greater and more intense voltage spikes than a shorter cable length. Even though voltage spikes last for only millionths of a second, permanent damage may result with improperly-designed cables.

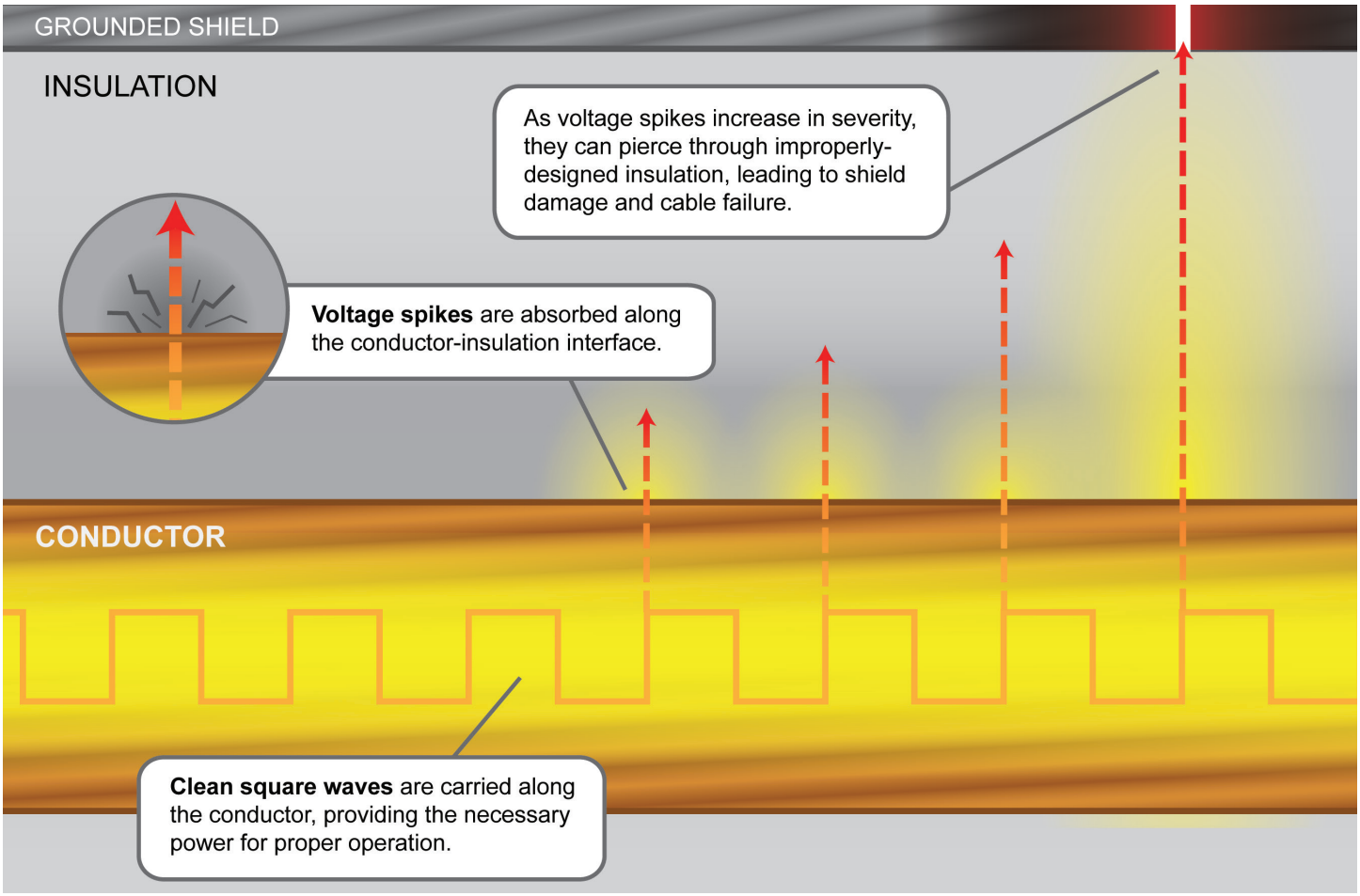
During initial motor start-up an inrush of current occurs, causing the motor and power supply cable to act as a large capacitor which must be charged up to its normal operating level. When the motor is first energized there can be a draw of up to six times its full load power requirements. It is critical that the installed cable is of adequate AWG size to avoid any significant voltage drop.

THE PROBLEM WITH CABLE

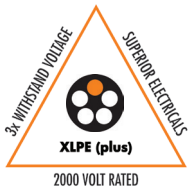
The cable itself can be the most critical component to the VFD system. The drive has a self-diagnosis program and a shorted motor can be easily detected. A voltage spike lasts only a few millionths of a second and the equipment will just drop off line. When a cable's insulation is punctured from a voltage spike, the current travels into the braid shield. This creates an extreme amount of heat and causes the braid to burn until a large enough hole has been created, at which point the cable insulation heals itself. This process will repeat at different locations along the cable length until total failure has occurred.

There are many methods of diminishing unwanted electrical conditions in the components of a VFD system. In order to protect cables from power distortions during the process of rectification, the 2018 National Electrical Code requires that the size of source power conductors is 125% of the full load current of the drive. Changing the pulse rate or switching the inverter to a slower frequency can eliminate some harmonics.

Filters, reactors, and isolation transformers can be added to the drive to clean off harmonics but can cause additional voltage drops from the power supply. Since VFD motors are double- insulated, any nicks in the insulation windings can be avoided. After utilizing all of these methods, the cable is often the most vulnerable component remaining in the VFD system. If the power supply cable is manufactured to prevent failure due to power distortions, then the system as a whole is equipped to handle the type of power that a VFD generates.

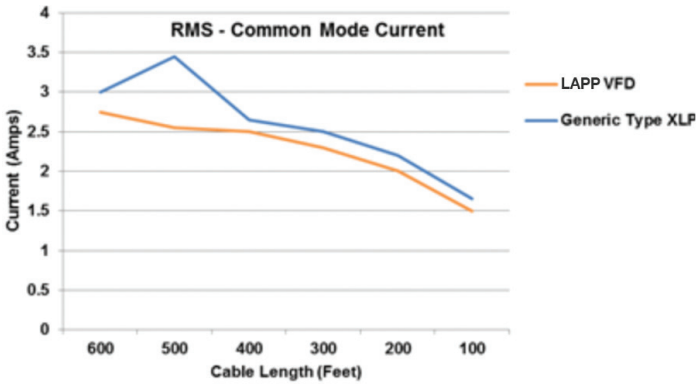


LAPP'S INSULATION MATERIAL: XLPE (PLUS)



For applications requiring precision control, such as those involving servo motors, LAPP ÖLFLEX® VFD cable with XLPE (plus) insulation ensures problem-free performance and offers a 2000 volt rating at the same insulation thickness as that of 600 volt cables. This exceptional feature creates cables that are lighter in weight, easier to handle, and save space in tray installations while meeting the demanding voltage and power requirements for 2000 volt VFD/servo systems ÖLFLEX® VFD 2XL products provide cable solutions exclusive to LAPP that are not available from any other worldwide cable manufacturer! VFD cables with XLPE (plus) are recommended when electrical performance parameters are critical to ensure the functioning of all electronic equipment. When compared to standard Generic Type XLPE, cables with XLPE (plus) clearly stand out in many ways. The cable charging current is minimized and results in superior performance when compared to that of the Generic Type XLPE cables. They can also tolerate three times the dielectric withstand voltage of the Generic 600 volt cables as per UL 1277 (6000 volts), and can maintain continuous operation up to a maximum of 2000 volts (AC) per UL.

For VFD cables, the insulation materials used are very critical. Use of the XLPE (plus) insulation ensures minimal Common Mode Current along the various cable lengths. With VFDs, certain cable constructions can cause excessive charging currents and can interfere with proper application performance, resulting in unnecessary drive tripping and/or system damage. When compared to the standard Generic Type XLPE cables, the XLPE (plus) insulation provides superior results as depicted in the graph below:



Note: The term "RMS" refers to Root Mean Square values. This graph is based on the actual performance tested independently by one of the leaders in variable frequency drives and standards used in industrial automation equipment.

This issue is generally associated with VFDs which are 480V AC or greater and 5 HP or smaller. When the IGBT (Insulated Gate Bipolar Transistor) of the VFD switches over to DC Bus voltage, a "surge" charging current is sent down the cable. The cable charging current path can be from phase to phase conductor, or from phase to ground conductor or cable shield. The cable charging current that returns on the ground conductor or cable shield is often referred to as the Common Mode Current.

LAPP'S INSULATION MATERIALS: LAPP SURGE GUARD

ÖLFLEX® VFD cable with Surge Guard insulation is unique among motor power-supply cables. Compared to larger-diameter VFD cables such as standard Generic Type B or THHN conductors used in conduit, LAPP VFD cables with Surge Guard offers the perfect solution. These cables are smaller in diameter and very flexible, which makes them ideal for use in areas where the allowable space is either too tight or restricted.

LAPP Surge Guard has a thermoplastic semi-conducting layer extruded over the conductor, followed by PVC insulation and a nylon covering. Surge Guard insulation enables the cable to withstand the electrical phenomena that occur in VFDs under typical conditions of use: reflections, standing waves, and voltage spikes. The key component of the LAPP Surge Guard is a semi conductive compound applied over the copper conductors. During periods of high voltage spikes, this semi-conductive coating disperses the electrical stress experienced by the conductor and prevents damage to the insulation. This coating results in improved cable reliability, increased dielectric strength properties, and extended service life. In addition, tests performed under the ICEA T-24-380 standard show that corona inception and extinction levels improved significantly when semi-conductive compounds were used as part of the insulation system. These compounds assure that LAPP Surge Guard insulation reliably helps maintain functional cable integrity under extreme operating conditions.

LAPP Surge Guard insulation is completed with an extruded second layer of PVC/nylon. This tandem component allows operation under high temperatures and provides superior mechanical strength. In addition, the cable will maintain its superior crush and impact resistance to help support the UL TC-ER listing.

LAPP GLOBAL STRANDING

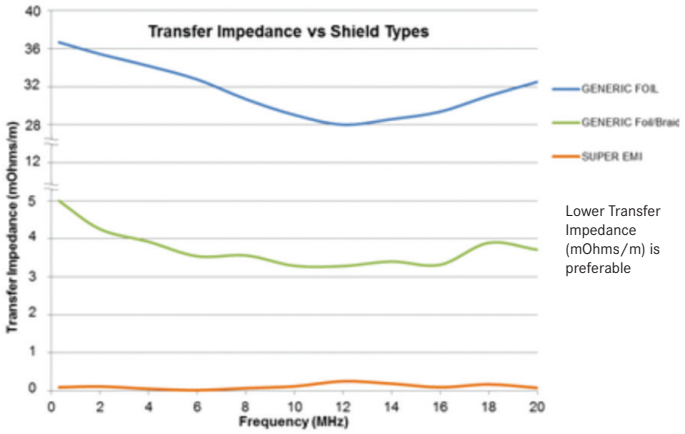
The stranding configurations of ÖLFLEX® VFD cables offer several advantages. ÖLFLEX® VFD cables automatically comply with both North American (UL, CSA) and Class 5 European (VDE) conductor stranding standards. The unique stranding provides a "one size fits all" global termination solution. In addition, the resulting Circular Mil Area (CMA) is greater when compared to North American Wire Gauge (AWG) sizes. Larger CMA means lower DC resistance, resulting in significantly lower voltage drop across identical cable lengths when compared to cables provided with the same AWG sizes. The table below indicates the severity of voltage drop in a competitor's sample compared to a sample of ÖLFLEX® VFD 2XL:

Cable Sample	ÖLFLEX® VFD 2XL	Generic VFD Type B
AWG Stranding	12 AWG; Class 5	12 AWG; 65/30
Circular Mil Area	7665	6500
DCR (Ω/1000 ft.)	1.36	1.73
Current	5	5
Calculation: DCR x Current	1.36 x 5 =	1.73 x 5 =
Voltage Drop (volts)	6.8	8.7

ÖLFLEX® VFD 2XL exhibits approximately 25% less DC resistance than the VFD Generic Type B product. This substantial difference precipitates a significant decrease in voltage drop, a higher current carrying capability, and the option of accommodating applications that require longer cable lengths. More copper means less resistance which results in less heat generated.

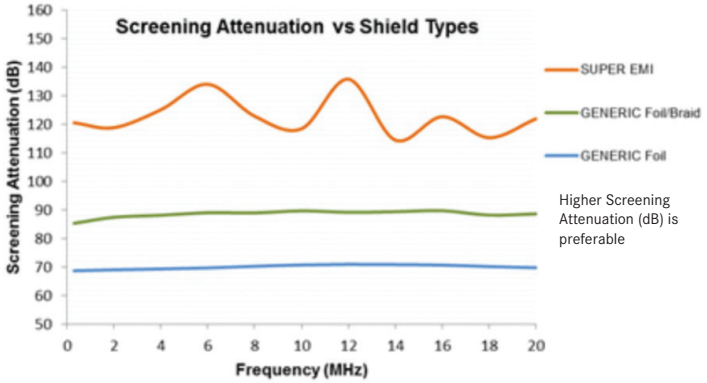
SUPERIOR LAPP SUPER EMI SHIELD

All LAPP VFD cables are constructed with superior Super EMI shielding consisting of a tri-laminate foil tape in combination with a high-coverage tinned copper braid. Cables with the Super EMI shield offer excellent transfer impedance characteristics:



Note: Transfer Impedance relates to a current on one surface of a shield to the voltage drop generated by this current on the opposite surface of the shield. Transfer impedance is used to determine shield effectiveness against both internal and external interference signals. Higher transfer impedance values are indicators of poor overall shield effectiveness performance.

The shielding provides immunization against noise interference in two ways. Externally generated noise cannot enter from outside the cable, causing internal signal disruptions. Any noise generated from within the cable itself is prevented from exiting, which would cause unintended disruption to nearby sensitive electronic equipment. Shield effectiveness testing verifies the outstanding performance characteristics of LAPP Super EMI shield in comparison to other cable shield types:



Note: Screening attenuation is the measurement of decibel ratio between the internal and external signals of a device. In short, it is a ratio of electric or magnetic field strength before and after placement of a shield. For Screening Attenuation readings of lower dBs are indicators of poorer overall shield effectiveness performance.

A QUICK AND INNOVATIVE TERMINATION SOLUTION

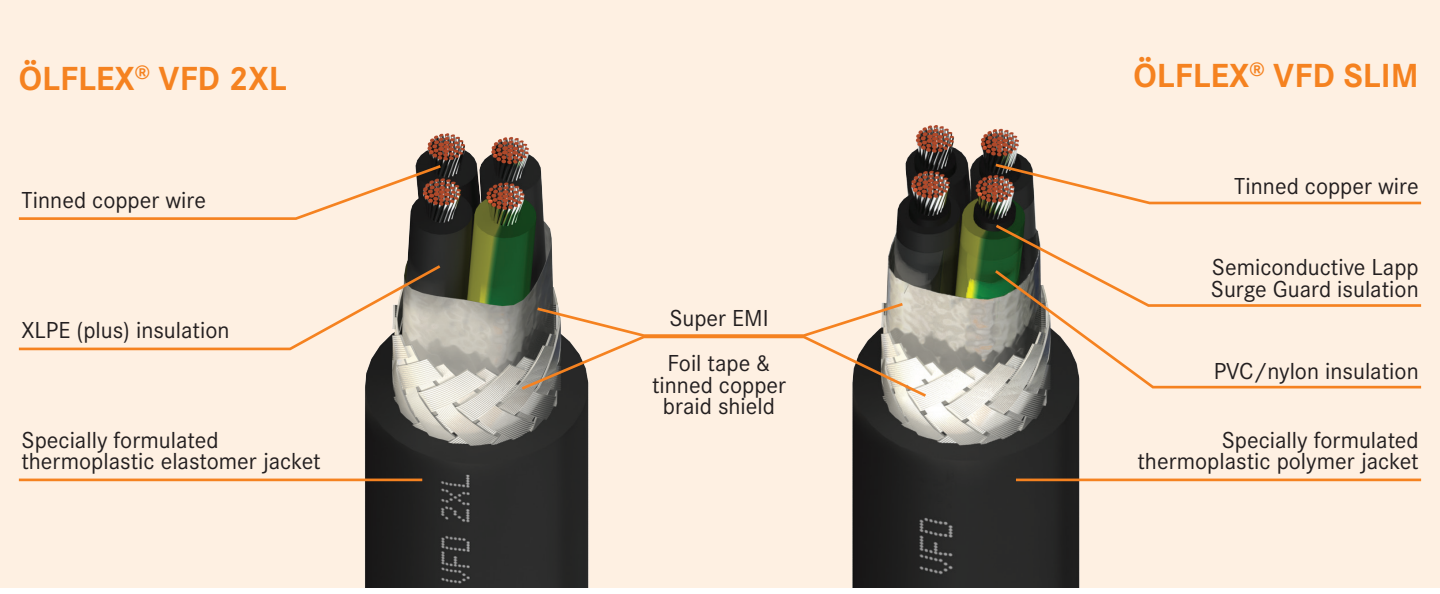
LAPP offers a wide variety of cable glands, which fully complement the Super EMI shield system by quickly and easily providing a full 360° circumferential cable shield termination solution. The full 360° is considered the most effective termination method for cable shield grounding. The SKINTOP® MS-SC is ideal for use with smaller-gauge cables as they generally exhibit consistent concentricity and minimal eccentricity characteristics. Larger-gauge cables can be more challenging as they are inherently characterized by increased dimensions and corresponding fluctuations in core concentricity. In these instances, ensuring a full 360° shield termination can be a tedious and daunting task. SKINTOP® MS BRUSH provides the ideal solution as this cable gland can conform to these cable irregularities and effortlessly ensure full termination. SKINTOP® INOX SC and SKINTOP® HYGENIC SC are manufactured of robust stainless steel, which features a very smooth surface finish with no sharp protrusions, corners, or edges. The smooth finish prevents the growth of bacteria and other micro-organisms from adhering to the surface making these glands the ultimate choice for the food and beverage industry. Stainless steel durability also offers high corrosive application suitability and superior resistance to wash down. SKINTOP® products are also referenced in Rockwell Automation's Wiring and Grounding Guidelines for Pulse Width Modulated (PWM) AC Drives, further establishing creditably as the industry's leading cable shield termination solution.

ÖLFLEX® VFD JACKETS

The jackets used for ÖLFLEX® VFD cables consist of either innovative specially formulated thermoplastic polymer or elastomer compounds that are environmentally friendly. These jacket compounds allow LAPP VFD cables to be used in applications for which a solution did not previously exist.

Superior flexibility ensures easier handling and routing during installation, especially when dimensional limitations require that a tight bend is needed. This one feature alone helps to speed up the installation process which in turn saves time and money. ÖLFLEX® VFD cables provide exceptional flame resistance as they all comply with the UL Vertical Tray and CSA FT4/IEEE 1202 flame tests. Compliance with these flame tests allows for installation within the industrial infrastructure. Exposure to harsh coolant types of environments will not present any issues either as ÖLFLEX® VFD cables comply with UL Oil Res I and II stringent test requirements.

ÖLFLEX® VFD jackets have exceptional resistance to crush and impact forces as these cables all maintain the UL TC-ER listing. Cables which are TC-ER listed have gone through the same mechanical crushing tests as required under UL 1569 (Metal Clad Cables). LAPP cables exceed the crushing requirements specified under UL 1569 by at least 50%. The TC-ER listing guarantees that cable is suitable for tray installation in the industrial infrastructure.



Exploded view of ÖLFLEX® VFD 2XL and ÖLFLEX® VFD SLIM cables. ÖLFLEX® VFD 2XL is a reduced-diameter cable, which provides three different voltage ratings (600, 1000 and 2000V).

As the use of armoring is not required, this results in huge cost savings from both the product cost and associated installation. No armor means a much lower priced cable that is smaller in overall diameter, weighs much less, and installs more quickly and easily than the armored cable counterparts.

Where a wide range of outdoor environmental conditions exists, ÖLFLEX® VFD cables can cover both the low and high temperature range. The sunlight resistance attribute verifies that the cable is suitable for all weathering conditions presented by outdoor installations. For applications which require a wide operating temperature range, all ÖLFLEX® VFD cables pass the severe low temperature extremes of -40°C (cold bend) and -25°C (cold impact) testing and can be used up to a maximum continuous operating temperatures of 105°C.

THE ÖLFLEX® VFD ADVANTAGE

LAPP products are tested in accordance with applicable agency standards in our state-of-the-art UL Client Test Data Program (CTDP) approved laboratory. LAPP employs the same methods, procedures, and types of equipment used by UL when testing our products. We also have an internal 5V (validation) process which continuously confirms product integrity to uphold our timeless industry leading reputation for quality. Cables are tested daily to verify that performance requirements are maintained and that overall product quality is being held to the higher LAPP standard.

LAPP VFD cables are comparable to the recommended cable designs specified for Allen-Bradley (Rockwell Automation) drives used in Type 1, 2, 3, 4, and 5 installations. The following table provides a general evaluation of the improved features of LAPP VFD cables in comparison to the commonly known VFD Generic Type B product. It can easily be seen that LAPP VFD cables provide superior performance when compared to similar product types offered (see LAPP VFD Advantages table).

REGULATORY COMPLIANCE OR CONSEQUENCE

Any cable installation in an industrial plant, commercial building or residential structure may be subject to inspection by the local Authority Having Jurisdiction (AHJ). It is important to remember that interpretation of NEC code requirements and subsequent adoption of any new regulations can differ by state, city, or county. No one wants to be held liable concerning insurance claims, lawsuits, installation violations, and the associated hefty fines. A printed legend on the cable jacket is the only verifiable method that an inspector has to validate a cable's listings, ratings, and further determine application suitability.

Everyone involved – including the electrical contractor and inspector – wants to avoid any mistakes and potential problems during or after an installation. Fifty years in the business has given LAPP an intuitive expertise in making cable selection problem-free. Our cable selection ensures that the correct approvals are provided for the described VFD application so neither the customers nor the inspectors will come across any problems. LAPP's regulatory approvals are far superior to those of the competition's VFD Generic Type B and also have the added benefit of usage in Canadian building installations. In addition, the CE Marking indicates acceptability for use in the European marketplace.

REGULATORY CODES

In an ideal application, a VFD and motor would be installed in a protected environment and as close together as possible. However, industrial environments do not allow for this ideal set-up. A cable may be exposed to uncontrolled conditions, such as hazardous atmospheres, temperature variations, chemicals or oils, and exposure to physical damage at continued intervals. Resilience to harsh surrounding environments is a primary concern; cable performance characteristics are key features during the selection process. In applications where the distance from the VFD to the motor is further, the cable may require routing through the building's infrastructure. Where cable is routed through raceway track, NEC Code (NFPA 70) mandates that tray cable (TC) be used. Since tray cable will typically be unprotected by the raceway at one or more points throughout its installation, it must also be rated for Exposed Run (TC-ER). The cable's capacity to withstand crush and impact conditions, as well as chemical, oil, and temperature exposure is the primary focus for code compliance in the industrial environment.

LAPP VFD ADVANTAGES

	Products		
	ÖLFLEX® VFD 2XL	ÖLFLEX® VFD SLIM	VFD Generic Type B
	.045 XLPE (plus)	Surge Guard	.045 XLPE
	Jackets		
	Specially formulated thermoplastic elastomer	Specially formulated thermoplastic polymer	PVC

Property	Ratings			Comments
Voltage Rating (volts)	1	2	2	#1 - 2000V rated (UL TC-ER)
	1	1	2	#1 - WTTC 1000V FT4
	1	1	2	#1 - c(UL) CIC/TC 600V
Dielectric Withstand (volts)	1	2	2	#1 - 3x voltage
DC Resistance (ohms/1000 ft.)	1	1	2	#1 - Stranding meets UL & VDE
Voltage Drop (volts)	1	1	2	#1 - Lowest voltage drop
Longer Lengths (feet)	1	1	2	#1 - Longest lengths
Ampacity (amperes)	1	1	2	#1 - Highest ampacity
Corona Testing (voltage)	2	1	2	#1 - Highest inception/extinction
Capacitance (conductor – conductor)	1	2	1	#1 - Lowest capacitance
Impedance (ohms)	1	2	1	#1 - Higher impedance
Oil (aging)	1	1	3	#1 - Meets Oil Res II
Low Temperature (degrees Celsius)	1	1	3	#1 - Meets -25°C cold impact
	1	1	2	#1 - Meets -40°C cold bend
Flexibility (durometer)	1	1	3	#1 - Highly flexible
Mechanical (pound-force)	1	1	3	#1 - Crush/impact force
Shield Effectiveness (decibels)	1	1	2	LAPP Super EMI Shield vs. AM tape
	1 = Best	2 = Average	3 = Fair	

LAPP VFD PRODUCTS

Product Name	Description	UL / CSA Approvals	UL Oil Res I	UL Oil Res II	-25°C Impact	-40°C Bend	FT4 Flame
ÖLFLEX® VFD 2XL	Flexible VFD Power Cable	600/2000V – TC WTTC 1000V & CIC/TC	X	X	X	X	X
ÖLFLEX® VFD 2XL with Signal	Flexible VFD Power Cable with Control Pair	600/2000V – TC WTTC 1000V & CIC/TC	X	X	X	X	X
ÖLFLEX® VFD SLIM	Reduced-Diameter VFD Power Cable	600V – TC WTTC 1000V & CIC/TC	X	X	X	X	X
ÖLFLEX® VFD with Signal	Flexible VFD Power Cable with Control Pair	600V – TC WTTC 1000V & CIC/TC	X	X	X	X	X
ÖLFLEX® FD VFD	Continuous Flex VFD Power Cable	600V – TC WTTC 1000V & CIC/TC	X	X	X	X	X
ÖLFLEX® SERVO 9YSLCY-JB	Flexible European VFD Power Cable	1000V – AWM IEC 600/1000V	X				
ÖLFLEX® VFD 2XL SYMMETRICAL	Stationary VFD Cable	600V – TC WTTC 1000V & CIC/TC	X	X	X	X	X
Cable Glands for VFD Cable: SKINTOP® MS-SC, SKINTOP® MS BRUSH, SKINTOP® INOX SC, SKINTOP® HYGENIC SC							

CONCLUSION

The ability to withstand the abuses of the harsh industrial world of today has become a critical factor in cable selection. The continued advancement of cable performance is due to changes in standard regulations and the increased interest in evaluation of characteristics mandated by the industrial marketplace. As the market evolves with new technology and future innovations, the demand for outstanding performance features and environmental resistance of cables will only continue to grow. LAPP has once again taken a leading role in this area and is committed to serving those industries that are directly affected by these performance requirements. Since its inception 20 years ago, the LAPP Surge Guard insulation system has become a mainstay in the industry with proven reliability. Our XLPE PLUS insulation is a first for the marketplace and takes cable innovation to the next level. ÖLFLEX® VFD 2XL products are reduced-diameter cables that provides three different voltage ratings (600V, 1000V & 2000V). Smaller diameters mean less weight and space taken up in the cable tray and reduced inventory SKUs. These unique attributes provide for easier and faster routing, quicker installation, and cost savings. Now connector inventory is also reduced as only one cable is needed for termination instead of three. All LAPP products are continually monitored and tested in our UL CTDP laboratory to maintain our high quality standards, performance characteristics, and other premium features to better satisfy the needs of the industry, both today and in the future.