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Efficiency in Automation

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Working with **VSD cables** in industrial & automation applications

Description of a VSD System

A functional VSD system consists of at least three components:

- VSD device
- VSD cable
- VSD motor

Figure 1: Overview of an entire VSD system

2.1 VSD Device

Figure 2: Block diagram of a VSD device

A typical VSD device consists of the drive controller and the operator interface. In the controller, the AC input power is first rectified into a DC intermediate power (DC bus) and stored in capacitors. An inverter circuit, which typically contains a 6-diode bridge network, subsequently transforms this DC bus power back to a "Quasi" AC signal with adjustable voltage and frequency. The DC bus voltage is calculated by AC line voltage x 1.414.

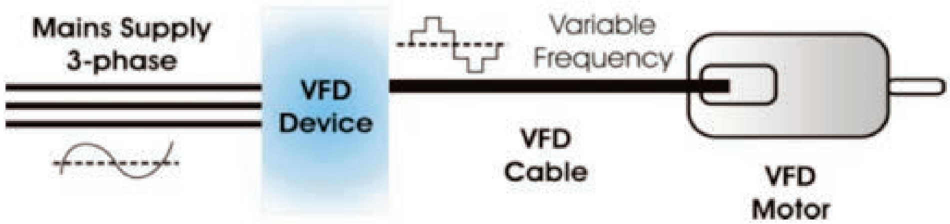

Figure 1

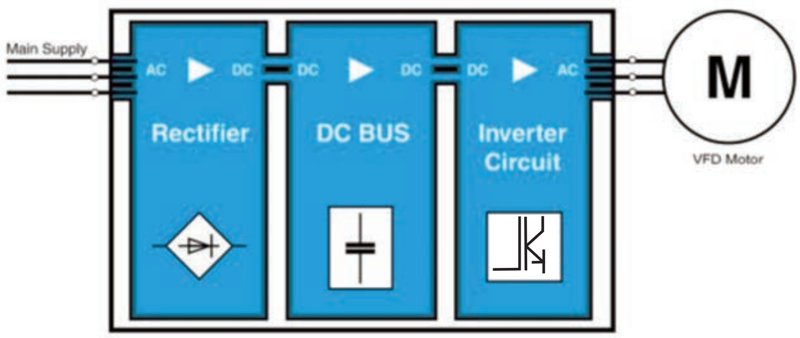

Figure 2

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VSD Cable

Figure 3: VSD cable

Variable Frequency Drive applications can cause unique electrical issues that are unlike other standard power transmission in machine applications. There are higher demands on the cable connecting the motor to the drive. Standard multi-conductor cables rated for 500V will most likely not meet the requirements of VSD applications, and can cause operating malfunctions and early failures. Cable is often an afterthought in the planning process but represents actually a very important component in the whole application.

Issues and difficulties during VSD Operation

In VSD devices, semiconductor switches are used to switch the DC bus power to the output. These switches only have two states: “on” or “off”. The PWM continually switches between these two states with a constant frequency but with variable pulse widths. The widths of the pulses determine the effective output voltage. Smaller pulse widths result in lower effective voltage and larger pulse widths result in higher effective voltage. Depending on the drive, the frequency of these pulses is between 4 and 20 kHz. Instead of steep pulses, a sinusoidal waveform of the voltage and current is desired at the motor. The pulses are smoothed by the motor’s inductance.

Few Drive manufacturers have detailed specifications for VSD cabling. The following list of common requirements can be found in most Drive manufacturer’s manuals:

- Four tinned copper conductors shielded for Drives up to 40-80 kW
- Three conductors with three symmetrical split grounds for larger Drives and Motors especially 80 kW and up.
- Low capacitance insulation
- Foil and braid shield combination (foil for high frequencies and braid for low frequencies)
- Ruggedized PVC jacket, preferably oil and sunlight resistant.

The following explain the properties of power cables for VSD applications.

Instead of just any standard power cable the use of a special VSD Power cable is required because the construction and insulation is designed to cope with the harsh demands of a VSD Application.

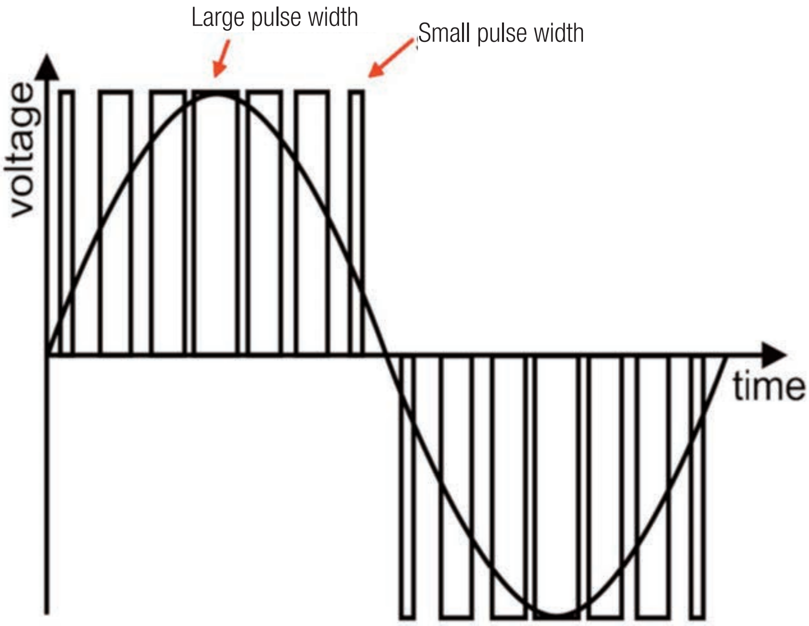


Figure 4
Pulse Width Modulation. Voltage pulses of different widths and the resulting sinusoidal waveform.

Insulation and Capacitance

Modern semiconductor switches (IGBTs) used in Drives are very sophisticated and allow for high pulse rise times of more than 3 kV/µs in VSD applications with cable lengths of several hundred feet. These constantly occurring steep voltage impulses stress the cable insulation.

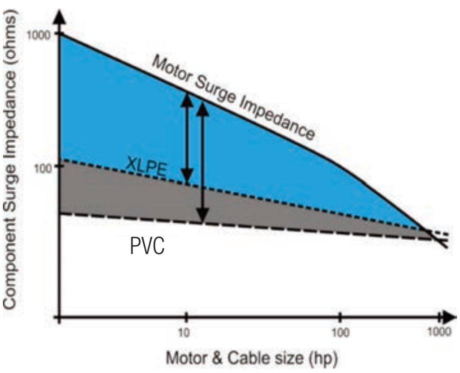
As a result of the fast binary switching, high switching frequency, and fast rise time; the length of VSD cable used in an installation becomes an important issue. An electrical characteristic called the cable capacitance indicates how much electrical charge the cable can store between its three power conductors, and between the conductors and the cable shielding.
The level of capacitance is determined by the implemented insulation material, the insulation thickness, and the shielding type. A higher cable capacitance results in higher charging currents. Therefore, low cable capacitances are desired. However, even with a low capacitance VSD cable, the capacitive cable charging current can reach 0.6 A/m. For longer cables this effect can easily cause a capacitive charging current of more than 20 A. This current stresses the cable without providing any usable power to the motor. This issue becomes especially serious for smaller drives with a power of less than 10kW, for which shielded cables are necessary. The drive voltage is also a concern. Drives that operate at 460V lead to higher charging currents than those that

operate at 230V.

During the design process of machinery with motors and VSD devices, the cable lengths must be considered. The VSD device should always be installed in close proximity to the motor.

Another issue with cables that connect VSD devices to motors is known as the reflected wave phenomenon. Both the cable and the motor have an electrical characteristic, which is called the electrical surge impedance. The electrical impedance applies to sinusoidal AC currents and is comparable to the electrical resistance in a DC circuit. When the motor impedance is larger than the conductor cable impedance, the voltage wave form will reflect at the motor terminals, creating a so called “standing wave” or also known as “reflected wave”.
The cable insulation and cable construction will have an effect on the cable impedance. It is desired to use a cable with impedance values as close as possible matched to the motor impedance. Please note that especially for smaller motors it is impossible to design a cable that matches the motor impedance, but the goal is to use a cable with the best possible match to the motor’s impedance.

The following algorithmic chart shows the large delta between motor and cable impedance but also shows that XLPE insulation offers a closer match than for example PVC. For that reason it is recommended to use XLPE in particular with



smaller motors.
Figure 5: Algorithmic chart and impedance Delta between PVC insulated cable vs. XLPE insulated cable.

This reflected wave results in a voltage pulse reflected back from the motor to the drive. Long cable lengths between the motor and drive increase the probability of the reflected wave. A reflected pulse combined with a second pulse coming from the drive may raise the voltage at the cable to up to 2-4 times, depending on pulse width, cable length and drive rectifier type of its nominal voltage (DC bus voltage), even for very short cable lengths. This over voltage increases with the cable length.
In some cases voltage spikes have been reported to peak values as high as 2150 volts in a 460 V system. High voltage spikes can lead to insulation breakdown on the motor or cable insulation, resulting in short circuits.

Figure 6

Figure 6 shows the typical output voltage of a 460V variable-frequency drive. As expected, the voltage reaches a level of approximately 650V which is the DC bus voltage. (AC line voltage x 1.414 (sqrt. of2))

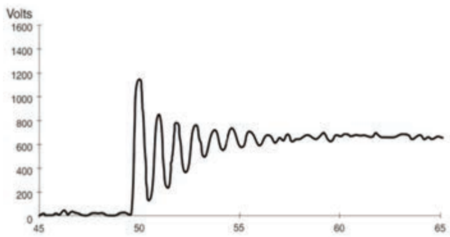


Figure 7

Figure 7: Magnification of one voltage pulse at the motor end

In Figure 7 the magnification of one voltage pulse is shown, as it appears at the motor end of the cable. It can be seen that the voltage not only reaches the 650V of the DC bus, but spikes up to almost twice that value. Thus, more than 1,200V would stress the cable.

The cable between drive and motor is a contributing factor to the strength of occurring reflected waves. The impedance of the cable can help in reducing its negative effect.

Additionally these high voltage levels can result in premature aging of the cable due to corona discharge. Mechanical stress caused by tight bends can also add stress to the insulation.

The biggest possible bending radius should be chosen, especially for bends of 90º or more.

When choosing VSD drive cables use low capacitance insulation such as cross linked polyethylene (XLPE). This reduces cable impedance.

The material of the insulation and its thickness can also affect the CIV of the cable. A thicker insulation results in a higher CIV, and thus reduces the probability of a corona discharge.

It should be noted that the corona inception voltage (CIV)declines over the lifetime of the cable due to natural aging. The presence of moisture will cause the CIV to decrease. While the presence of moisture will affect the CIV of XLPE cables by only a few percent, it can lower the CIV of a PVC cable to drop to half of its level than it would have in dry conditions.

In order to assure that a VSD cable reaches its expected life span, the insulation material and thickness are factors that have to be considered.

Furthermore, the type of insulation material that is used in a VSD cable affects the heat generation. The insulation is a so called dielectric material, a nonconductive material within the electric field of the live conductor. How much the insulation material is affected can be expressed by the dielectric constant. Since the cable acts like a capacitor, this dielectric constant is the ratio of the amount of stored electrical energy. For time-varying electrical fields which are the case in VSD applications, the dielectric constant becomes frequency dependent (generally called permittivity). The electric field polarizes the dielectric material and due to the high frequency this results in heat generation (dielectric losses within the material).

Operating temperatures

The type of insulation affects the thermal stress of the cable. The insulation material will affect how much heat the cable is able to generate at a given amperage.

Cables with higher operating temperatures permit higher current carrying capacities. This means that cable sizes can be reduced which assists in cable installation. XLPE insulated VSD cable has a conductor operating temperature of 90ºC.

Grounding System

The grounding system of a VSD cable is a vital part of its construction.

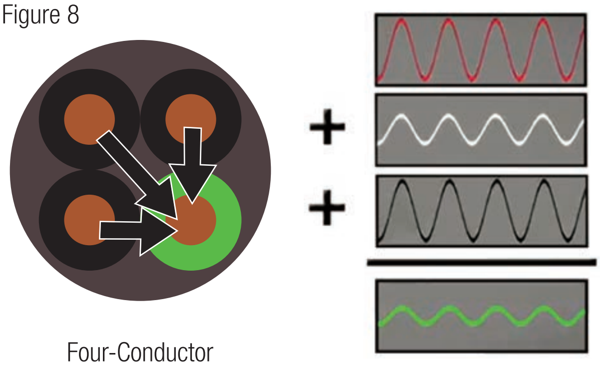
Common mode current

Is sometimes known as current noise. It is defined as any current that leaves the drive on the primary motor leads and returns through any ground path (including the cable grounds and shield).

The role of VSD cable is to provide the most attractive path for these potentially harmful currents to return to the drive with minimal disturbance to the surrounding networks and instrumentation. A cable that provides the lowest impedance ground path will be most effective in reducing common mode currents. When the VSD cable provides the lowest impedance ground path, it will mitigate common mode current flowing in to other devices/systems. Having a suitable ground system means it is possible to control where potentially harmful energy from the VSD goes.

In the simplified representation shown, the current on the ground conductor is the resultant value of the voltages on the phase conductors, allowing for the 120 degree phase shift between them. On high power applications the common mode current that flows can cause motor bearing fluting and premature motor bearing failure.

Figure 8



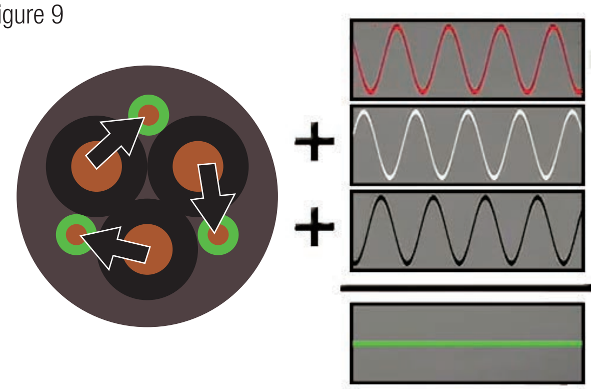
Four-Conductor
Power Cable

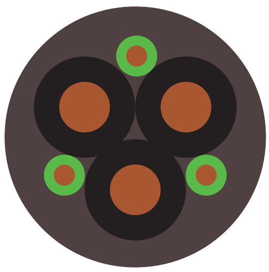
On the four-conductor cable shown above, the current flowing in the earth conductor is due to the differing voltages induced on the earth conductor, caused by the distance from each phase conductor to the earth conductor. This distance directly affects the capacitance between the different phase and earth conductors.

Symmetrical/Concentric Earth Design

In a symmetrical earth design cable the earth conductors are located in the interces between the phase conductors. This ensures the distance between the phase conductors and earth is consistant. The resultant earth currents now cancel each other out minimizing the common mode current that can flow between motor and drive.

Figure 9





VSD Cable
Three Plus Three

Minimizes:

Induced ground voltages
Induced ground currents
Motor bearing fluting
Motor bearing failure

Concentric earth designs are often recommended for applications of 30kw and above.

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Cable Comparison Chart

	SY	SWA	Lütze Drive Cable
Bend Radius	10 x O/D	8x O/D	5x O/D
Voltage	300/500V (VSDs 560V DC @ 400 VAC)	600/1000V	600/1000V
Temperature Rating	80ºC	90ºC	90ºC
Low Capacitance Insulation	No (PVC)	Yes (XLPE)	Yes (XLPE)
EMC Shielding Capability	Steel Armour (Not optimised for EMC Performance)	Steel Armour (Not optimised for EMC Performance)	Copper Braid 80% Coverage & Foil. Offers Low and High Frequency Coverage
Flame Retardancy	EN60 332	EN60 332	EN60 332
Earth System	Single Conductor Seperate Insulation 4 Core not recommended above 30kW	Single Conductor Seperate Insulation 4 Core not recommended above 30kW	Concentric Earth 3 Core System desirable for AC Drives
Meets Requirements of 17th Edition (BS 7671) for drive cable application	Only with appropriate cable marking	Yes	Yes
Direct Buriel	No	Yes	No

Advantages of Lütze Drive Cables

- Cable is 10-15% lighter than other products - this helps with cable installation.
- Smaller bend radius means the cable is easier to route and terminate.
- Low capacitance of the cable aids compliance with EN 50598 as cable losses are reduced.
- Low capcitance, concentric earth system and effective shielding allows longer cable runs in drive applications.
- Voltages withstand gives protection against transients produced by VSDs
- Low screen DC resistance affording protection agianst AC harmonics

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Shielding

In addition to an effective grounding system a good quality VSD cable has foil and copper braid shields. This combination of both shield types ensures good protection against low and high frequency interference.

The tinned copper braid must provide at least 80% braid coverage and have sufficient braid fan angle and wire gauge to ensure a low transfer resistance. The screen offers a low DC resistance affording protection from low frequency interference such as AC harmonics. If the conductivity of the shield is less than 50% of the conductivity of the phase conductor an external earth conductor is often required.

Appropriate shielding and grounding of the cable is required in order to achieve proper functionality of the VSD system.

Installation guidelines for VSD cables

- The length of the VSD cable has to be kept within the limits set by the drive manufacturer. Always avoid unnecessarily long cable runs.
- Cable shielding (foil and braided shields) must be connected at both the drive and the motor end unless the Drive manufacturer provides different guidelines.
- The shielding must be connected at a 360° contact. Connecting only the drain wire to be used for grounding and cutting off the shielding does not provide sufficient EMC noise protection.
- Where the cable has been stripped and the wires are exposed, a conductive tape should be used to improve EMC noise protection.
- The VSD cable should not be routed in the same tray/conduit as signal, networking, or communications cables. Always use separate trays or tray dividers for power and data cables.
- The cable should be stripped as little as possible. It has to be assured that the shielding is not damaged or interrupted.
- If the VSD cable has to cross signal or data cables, this has to be done at a 90° degree angle.
- The PE ground wire has to be connected at both cable ends.
- Cable bends must be reduced to a minimum. The biggest possible bending radius should be chosen, especially for bends of 90° or more.

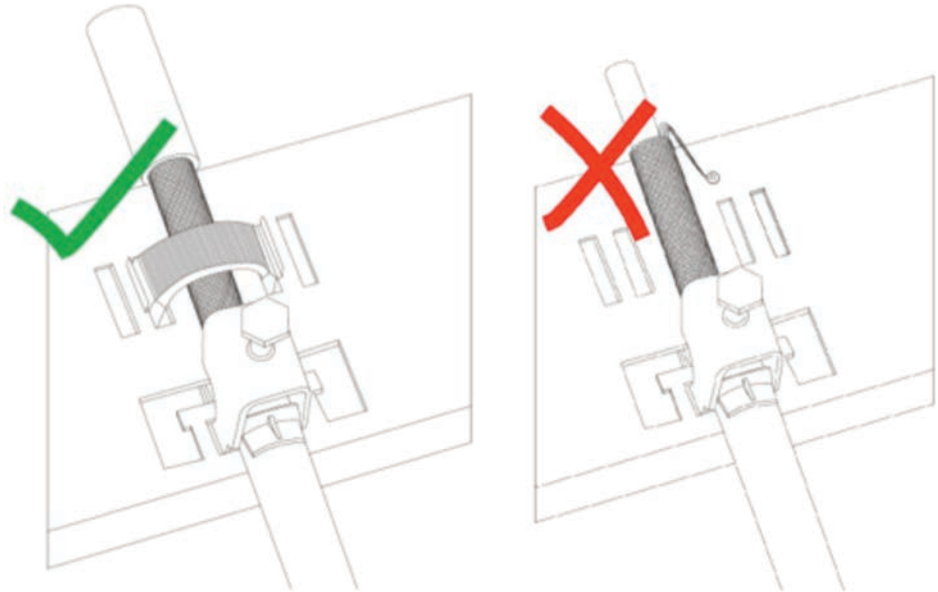

Figure 10
Correct (left side) and wrong (right side) connection of VSD Cable. Correct 360º connection of shielded cable requires cable clamps or metal fittings.

Typical Current Rating Table for VSD Cables

No cores x cross sec mm^2	Power ratings with 3 loaded cores in Amperes
3 x 1,5 + 3 G 0,25 4 G 1,5	23
3 x 2,5 + 3 G 0,5 4 G 2,5	32
3 x 4 + 3 G 0,75 4 G 4	42
3 x 6 + 3 G 1,0 4 G 6	54
3 x 10 + 3 G 1,5 4 G 10	75
3 x 16 + 3 G 2,5 4 G 16	100
3 x 25 + 3 G 4,0 4 G 25	127
3 x 35 + 3 G 6,0 4 G 35	158
3 x 50 + 3 G 10,0 4 G 50	192
3 x 70 + 3 G 10,0 4 G 70	246
3 x 95 + 3 G 16,0 4 G 95	298

Current quoted in ambient temperature conditions.

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