Robust Motor Design

Submersible motors are designed for a wide range of applications, such as deep well water supply, irrigation and pressure boosting. To have a robust insulation system, the insulation shall be designed to withstand the peak voltage levels during operation.

Many applications require a long cable between the motor and power supply. Long cables increase the peak voltage level when the motor is driven by a Variable Frequency Drive (VFD), also known as a frequency converter.

The primary components of a motor insulation system shall withstand the following voltages: **Phase-to-phase, phase-to-ground and turn-to-turn** voltages as shown in Figure 1.

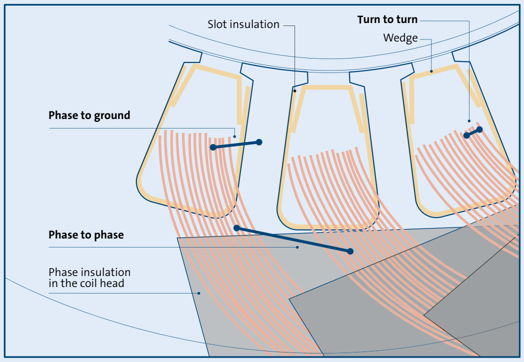

Figure 1: Typical stator insulation system

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Stator Design Of Submersible Motors

In submersible motors, the space between the stator and rotor is typically filled with a motor liquid, typically a glycol and water mixture. These motors are called wet runners. Figure 2 shows the two main stator types for a wet runner motor: Wet-wound stators and potted stators (sometimes referred to as canned stators.)

In potted stators, a can is inserted in the stator bore. The space around the copper wire is filled with a potting material. The potted stator is hermetically sealed, and the copper wire is not in contact with water. The phases can be insulated from each other by phase paper and the wires are fixated by the potting material.

The copper wires of a wet-wound stator are in direct contact with the liquid inside the motor and a special copper wire with thicker insulation e.g., PE2PA, and higher mechanical durability is therefore used. The stator windings are accessible, and it is possible to re-wind the stator in case of an electrical failure. The electromagnetic performance and robustness of a wet-wound stator is generally lower compared to a potted stator.

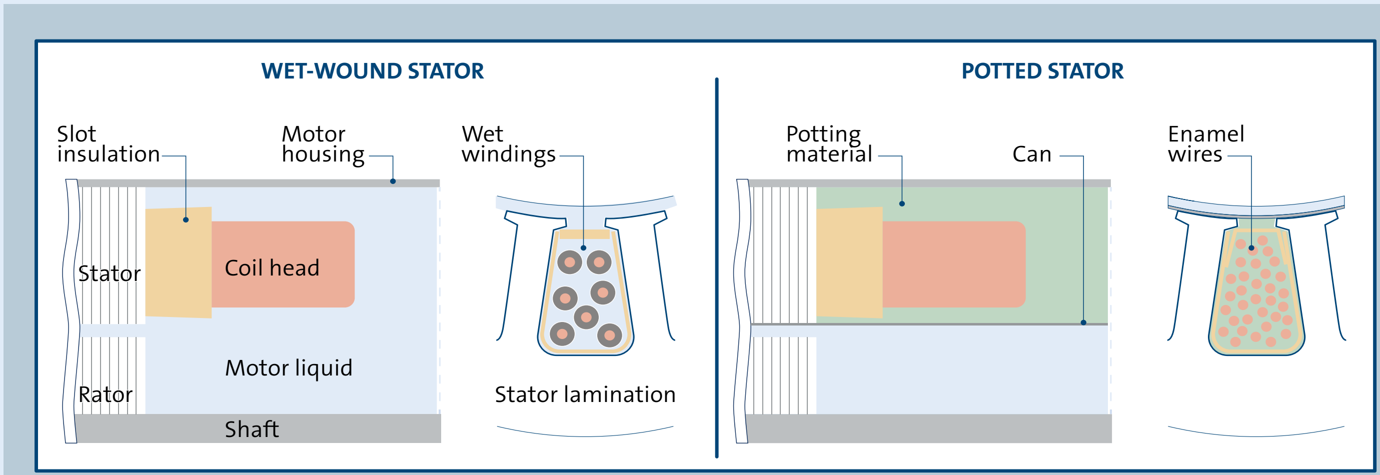

Figure 2: Axial and radial views of wet wound and potted stators

Application Of Sine Wave Filter

The sine wave filter is placed between the VFD and motor, as shown in Figure 3, to protect the insulation system of the motor from the transient voltages related to PWM voltage generation from the VFD.

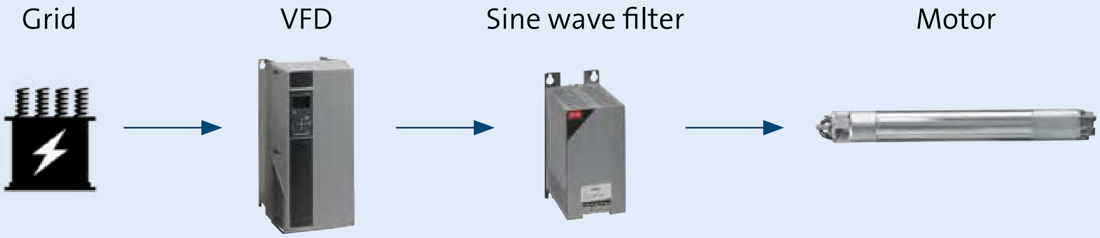

Figure 3: Components of a variable speed motor and pump system.
Refer to product manufacturer for proper sizing, voltages, and settings.

A VFD with a built-in passive diode rectifier bridge, a DC link and a three-phase inverter, as shown in Figure 4, is the most commonly used topology in pump applications as of today.

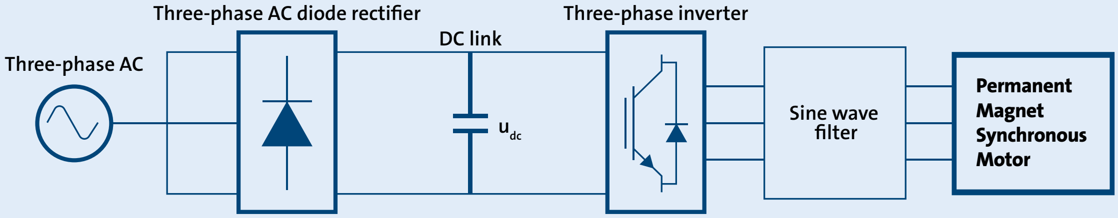

Figure 4: Electrical system diagram of a variable speed motor and pump system

The 3 phase AC grid voltage is rectified into a DC link voltage by the diode rectifier as shown in Figure 5. The DC link voltage is chopped into a series of rectangular voltage pulses, with a variable width and frequency but fixed amplitude, by turning on and off transistors at a high frequency in the inverter. The switching pattern of the transistors is controlled by a PWM strategy enabling variable speed control of the motor.

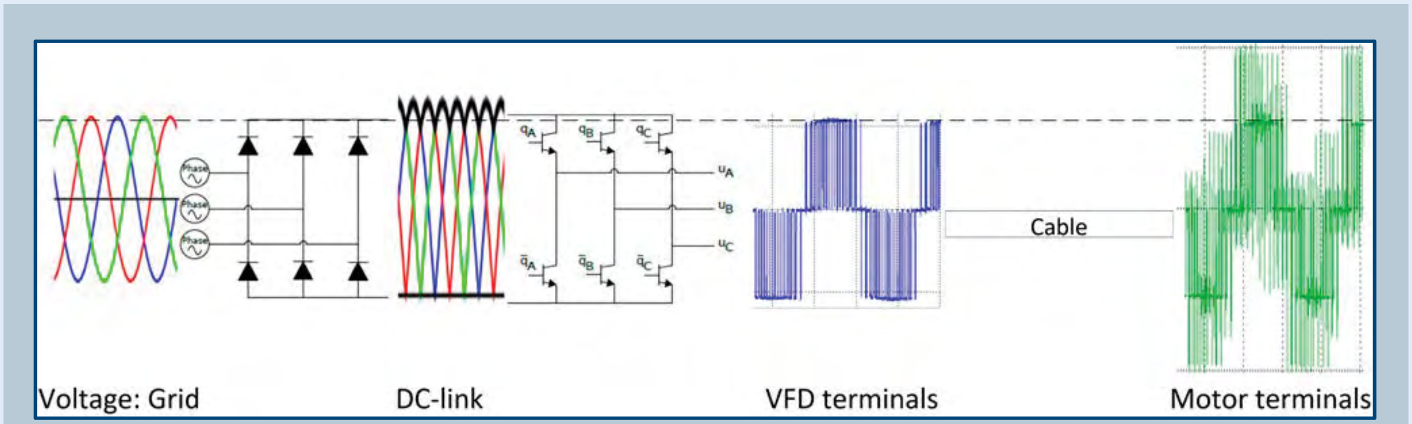

Figure 5: Voltage waveforms without sine wave filter

The rectangular pulses from the inverter, shown in Figure 6 (blue signal), propagate through the drop cable until it reaches the motor terminals (green signal). Overshoot and ringing occur at the motor terminals due to reflections caused by mismatch between the cable and motor impedances. The peak voltage at the motor terminals is typically twice the peak voltage at the inverter terminals but it can be much higher dependent on the output of the inverter, cable length and impedance mismatch.

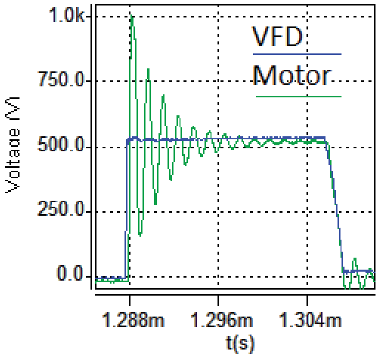

Figure 6: Voltage waveforms measured at the output of the inverter and motor terminals. The VFD was fed from a 3 phase 400V grid.

The purpose of the sine wave filter is to filter the PWM voltages at the output of the VFD. Figure 7 shows the sinusoidal voltage output from the filter. The sinusoidal waveform does not generate overshoot and ringing with long cables and the peak voltage is therefore reduced.

The sine wave filter eliminates detrimental voltage spikes and also reduces the high frequency radiated electromagnetic noise generated by the VFD and transmitted by the cable but that must be handled separately as it depends on the application, local requirements, and electrical installations on the site.

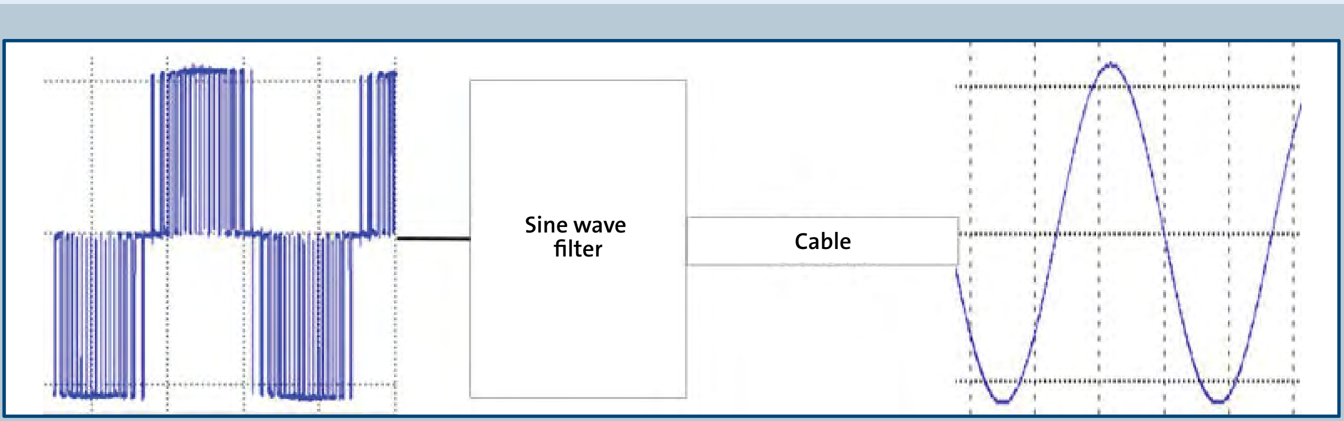

Figure 7: The sine wave filter with PWM voltage input (left) and sinusoidal voltage output (right)

Damages On Motors Not Designed For Vfd Operation

Motors not designed to be driven by a VFD without a sine wave filter are likely to experience electrical failure of the insulation system after a short period of operation.

If the peak voltage in the motor exceeds the partial discharge level of the insulation material, the insulation material starts to deteriorate. Partial discharges cause degradation and ultimately failure of the insulation system by both chemical and mechanical wear of the insulation material. Figure 8 shows the degradation of copper wire (left) and insulation paper (right). The erosion of the copper wire starts at lower voltage levels compared to the insulation paper and therefore phase insulation paper is often required between two phases in a stator.

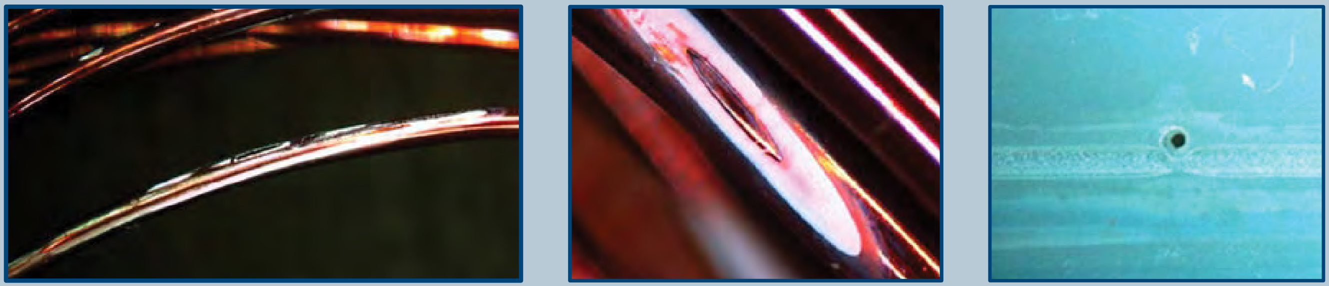

Figure 8: Damages to copper wire enamel and insulation paper after partial discharges caused by high voltage peak levels.

Motors Designed For Variable Frequency Drives

The insulation system in motors designed for variable frequency drives are designed with materials and a construction that can withstand the increased peak voltage level from the VFD. The design and materials of the insulation system are qualified for the peak voltage levels and temperatures during operation. When the system is qualified and validated, the manufacturing processes shall be able to maintain a high standard to secure a converter robust motor design.

The Grundfos 6-inch MS6000P permanent magnet motor is, as one of the few submersible motors, designed and qualified to be operated without a sine wave filter within the limits described in Table 1 (see next page). The converter robust design of the MS6000P motor reduce the cost, complexity, and size of the system by the possibility of removing the sine wave filter.

Motor requirements	Value	Unit
Media temperature	≤ 60 / (140)	°°C / (°F)
Peak voltage at motor terminals (VLL)	< 1500	VLL
dU/dt at motor terminals	< 6	V/ns

Grid requirements	Value	Unit
Line-Line voltage (nominal)	≤ 460	V RMS
Phases	3	[-]

VFD requirements	Value	Unit
DC voltage	< 620	Vdc
Peak voltage at inverter terminals (VLL)	< 650	VLL
Rise time at VFD terminals (10-90% VDC)	> 100	ns
dU/dt at VFD terminals	< 5	V/ns
Switching frequency	≤ 4	kHz
Grid voltage rectification	Passive rectifier bridge	

Cable requirements	Value	Unit
Length	≤ 300 / (1000)	m / (ft)

Table 1 System requirements for operation of the Grundfos MS6000P permanent magnet motor without sine wave filter Local and national requirement for safety, EMI etc. must always be followed and can demand filtering due to e.g., noise suppression. Cables and other system components must be properly rated for VFD use. Cable lengths over 300m or 1,000ft should use a Sine Wave Filter

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