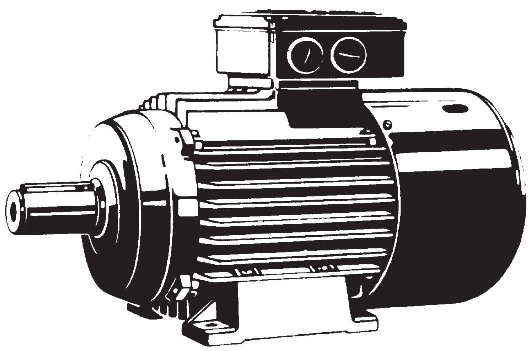
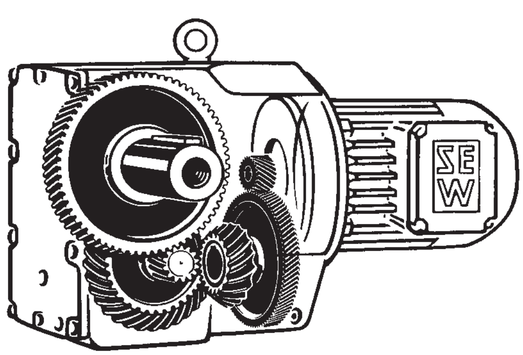




Engineering Note

Reflected Wave Phenomenon

Motors for Inverter Operation

SEW
EURODRIVE

Reflected Wave Phenomenon

Variable frequency drives are being used in today's industries for a wide range of reasons. Variable frequency controllers have increased the flexibility and efficiencies of a large number of manufacturing processes. Also the variable frequency drive has itself been evolving with the use of high performance digital microprocessors and advanced output devices such as IGBT's (insulated gate bipolar transistor). These newer high performance drives are much faster in their internal control and calculation which has allowed for an improvement in motor control. The newer IGBT output devices are also much faster with typical rise times in the order of 0.1µS where as older output devices had a rise time of between 1µS and 4µS. This means that an improvement of between 10 and 40 times has been accomplished. Figure 1 shows the output waveform of a PWM variable frequency drive.

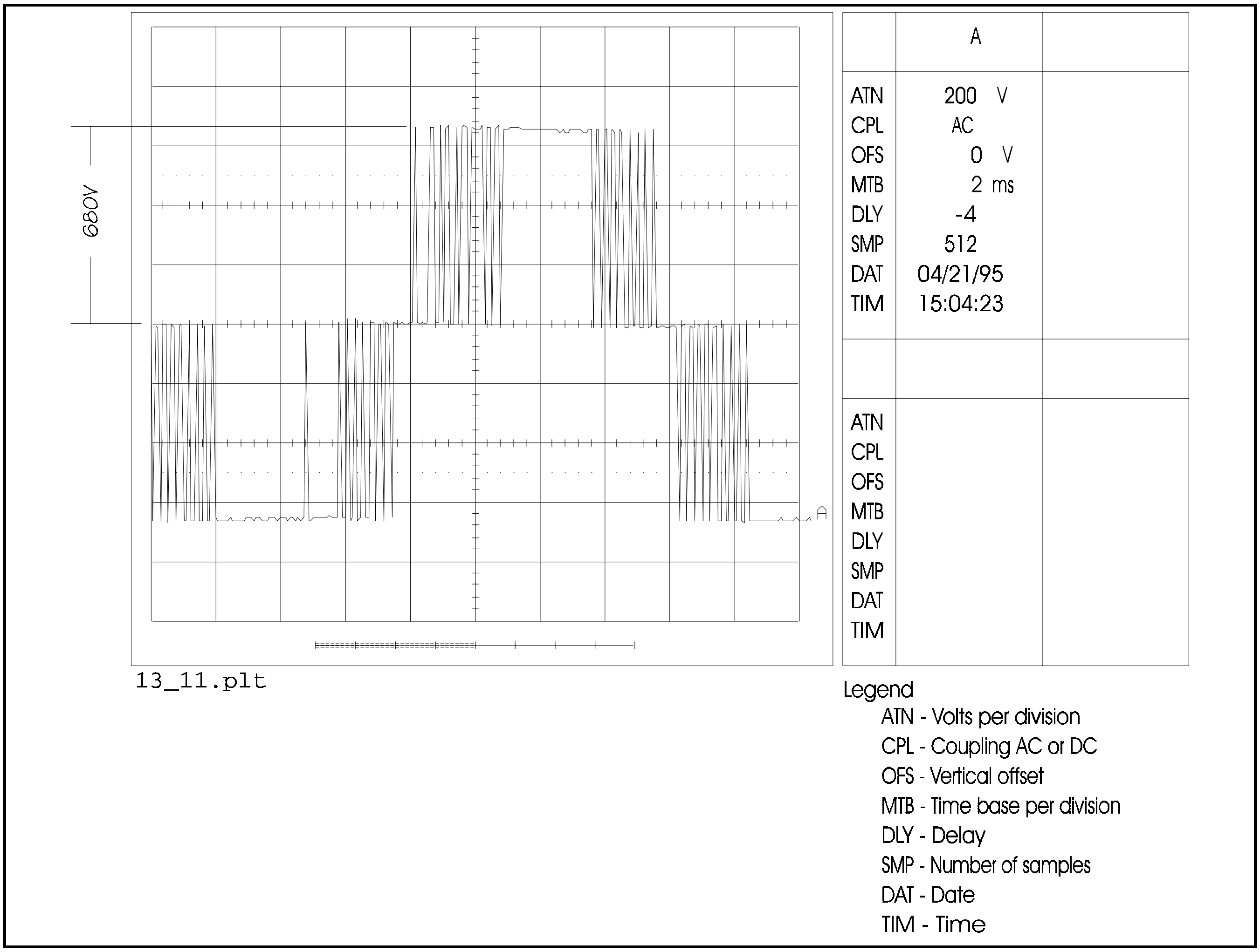


Figure 1

The output waveform shown in Figure 1 is measured at the output of an inverter with no motor or supply cable leads connected. Figure 1 is the best possible PWM waveform that this inverter can produce.

The wave form shown in Figure 1, even at its best, is still very different than a real sine-wave supply as shown in Figure 2. Figure 2 shows a 480Vrms wave and its peak voltage of 680V.

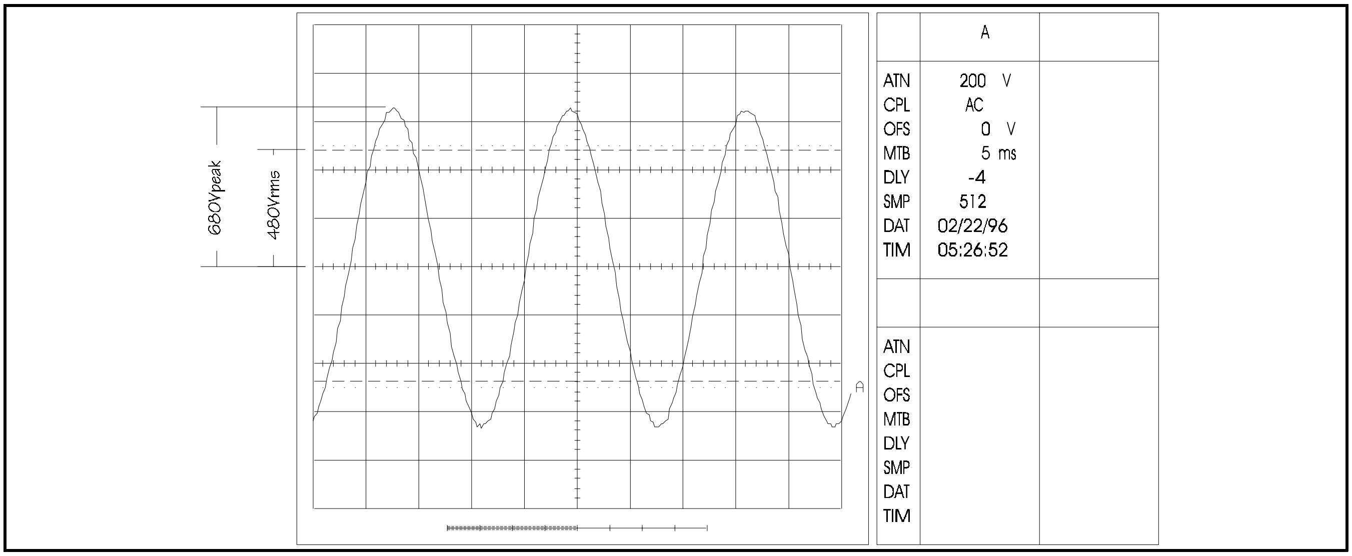


Figure 2

Figure 3 shows the leading edge (turn-on) of one of the of the positive going pulses.

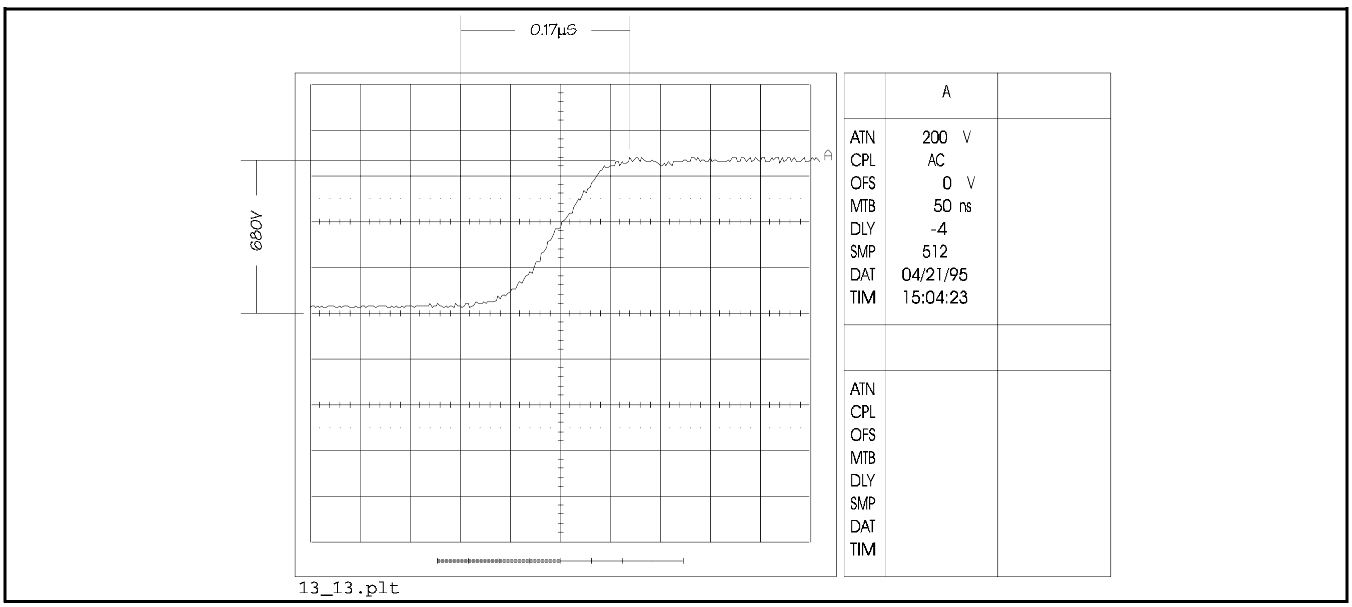


Figure 3

The rise time of the waveform in Figure 3 is slightly over 100ns (0.1µs). This is the time it takes for the output transistor to switch from 0 volts to the peak voltage of 680V. The 680V is the voltage level of the DC-bus. Figure 3 is also measured at the output of the inverter with no load (motor or cable) connected.

When a load is connected to the output of the inverter the measured waveform can look quite different. Figure 4 shows the output voltage waveform measured at the motor terminals with 250 feet of cable between the motor and the inverter.

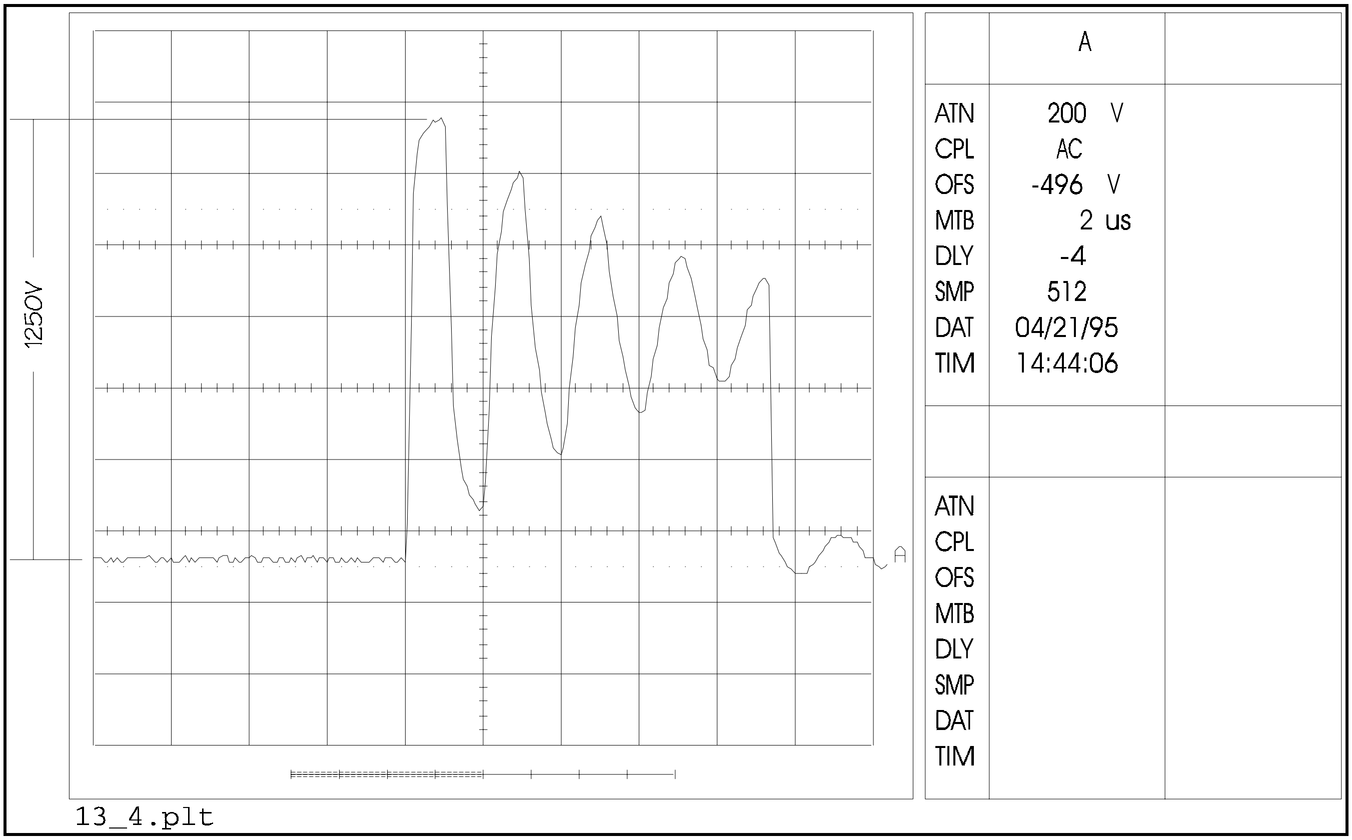


Figure 4

Figure 4 shows the positive going turn on of the transistor measured at the motor after 250 feet of cable. This waveform looks very different than in Figure 3. The waveform in Figure 4 has been shifted down by 496V volts so that the top of the waveform is not cropped by the scope. Figure 4 shows a peak voltage of approximately 1260 volts instead of the expected voltage level of 680 V (the DC-bus level). This wave also shows a damped ringing until the transistor turns off. The waveform is quite different than the ideal square wave a PWM source should produce.

The distortion of the waveform as shown in Figure 4 is caused by the impedance mismatch between the motor and the cable feeding the motor. When there is an impedance mismatch between a source and its load, some of the energy reflects back from the load to the source. The easiest way to think about this is to imagine a flashlight shining into a body of water. When the flashlight beam is pointed towards the water most of the light passes into the water, however, some of the light is reflected from the water surface back towards the flashlight (the source). Figure 5 illustrates this point.

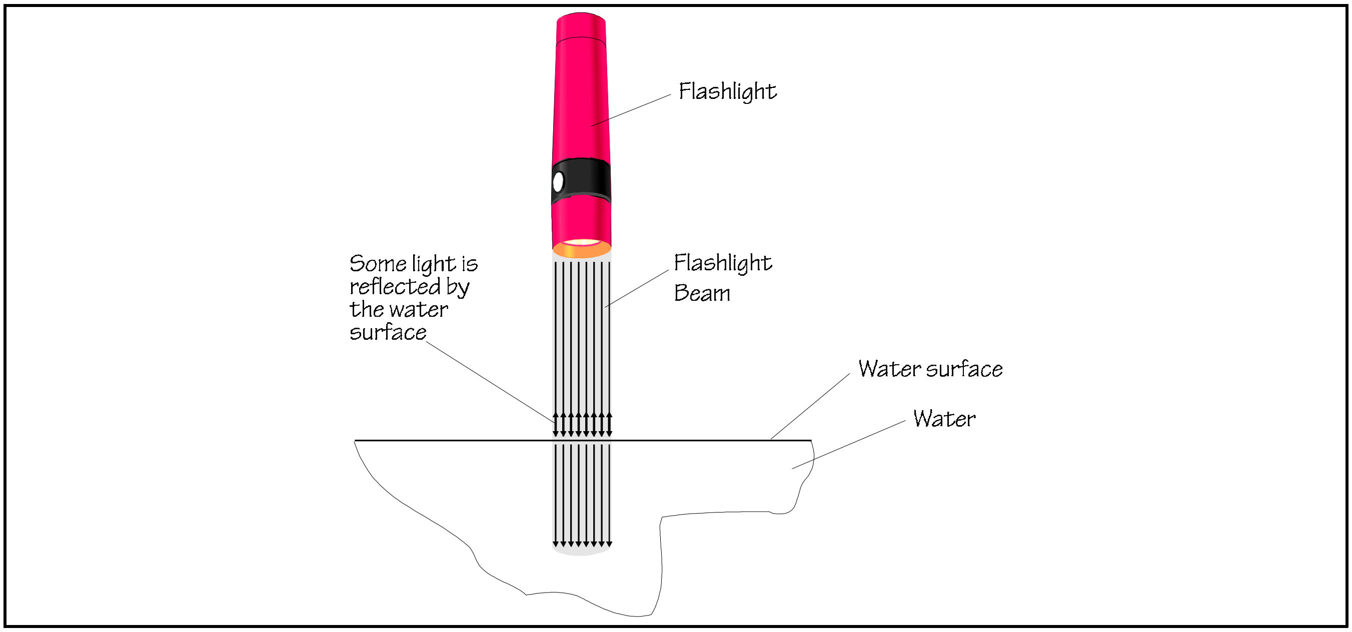


Figure 5

The light reflecting off of the water surface is very similar to voltage reflecting at an impedance mismatch. The reflecting of voltage waves is a very well understood phenomenon in the communications and networking industries. The reflected voltage phenomenon is exaggerated by two factors: the first is long motor cable runs, the second is the higher frequency content (faster turn-on times) of the voltage waveform with the use of newer faster switching IGBT inverter output devices.

Reflected Wave Phenomenon and Motors

The high peak voltage that is shown in Figure 4 can have a detrimental effect on the electric motor. Typical electric motors are designed for use on a 3 phase power supply of either 230, 460 or 575Vrms power supply. A 460 V rms power system will have a peak voltage of 650 volts. The peak voltage in Figure 4 is approximately 1260 volts. This high peak voltage is also repeated every time the power transistors are switched on. With a PWM inverter this may be turned on 3000 times a second. The motor must be able to handle the high peak voltage very frequently.

High voltages can breakdown the insulation systems inside the motors. The insulation system inside a three phase electric motor can consist of the following — see Figures 6 and 7:

Magnet wire insulating jacket (typically enamel or similar)
Varnish dip impregnation
Slot liners
Phase separator
Top stick wedge (or paper)
Phase paper
Connecting wire sleeves

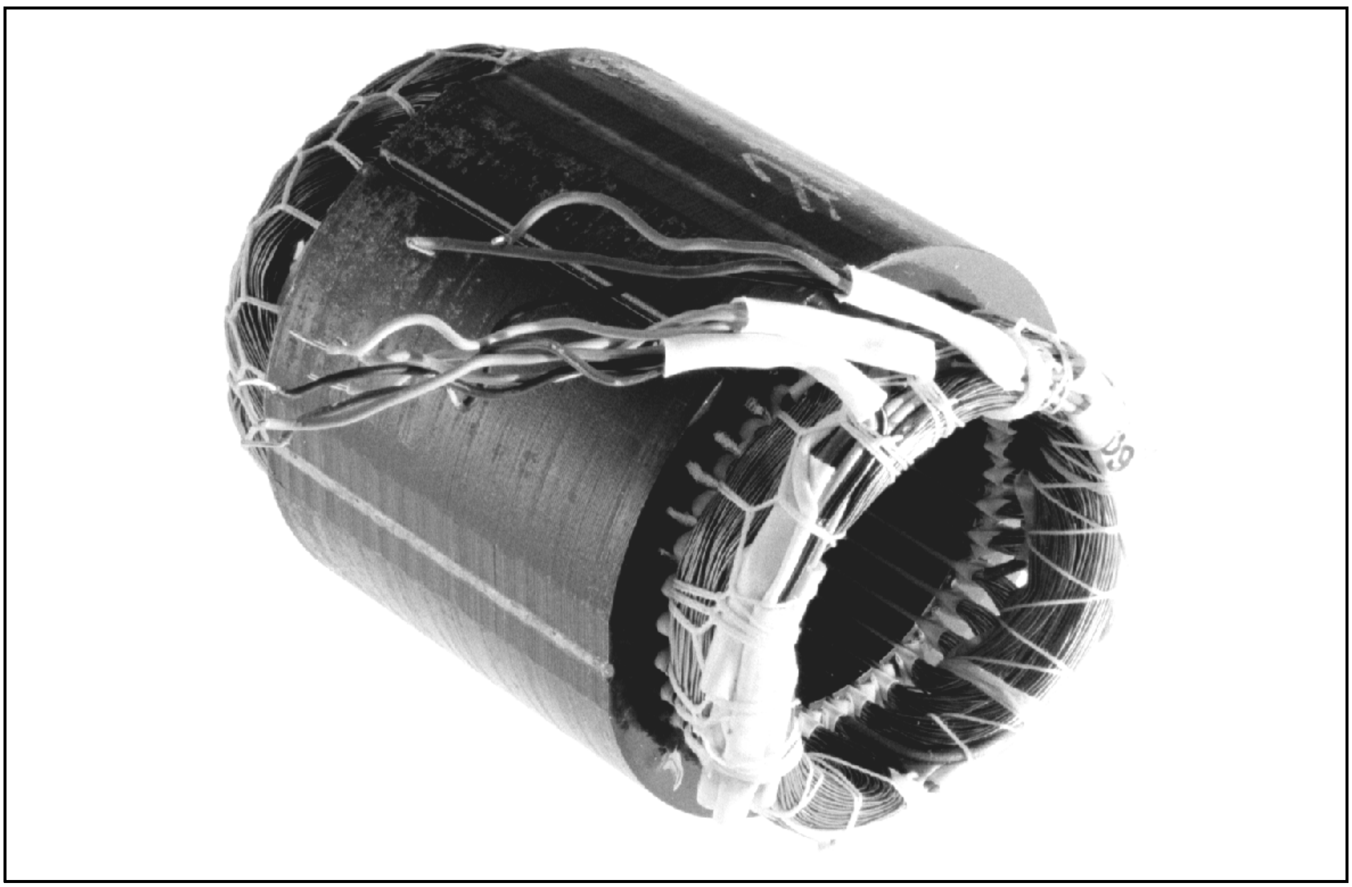


Figure 6

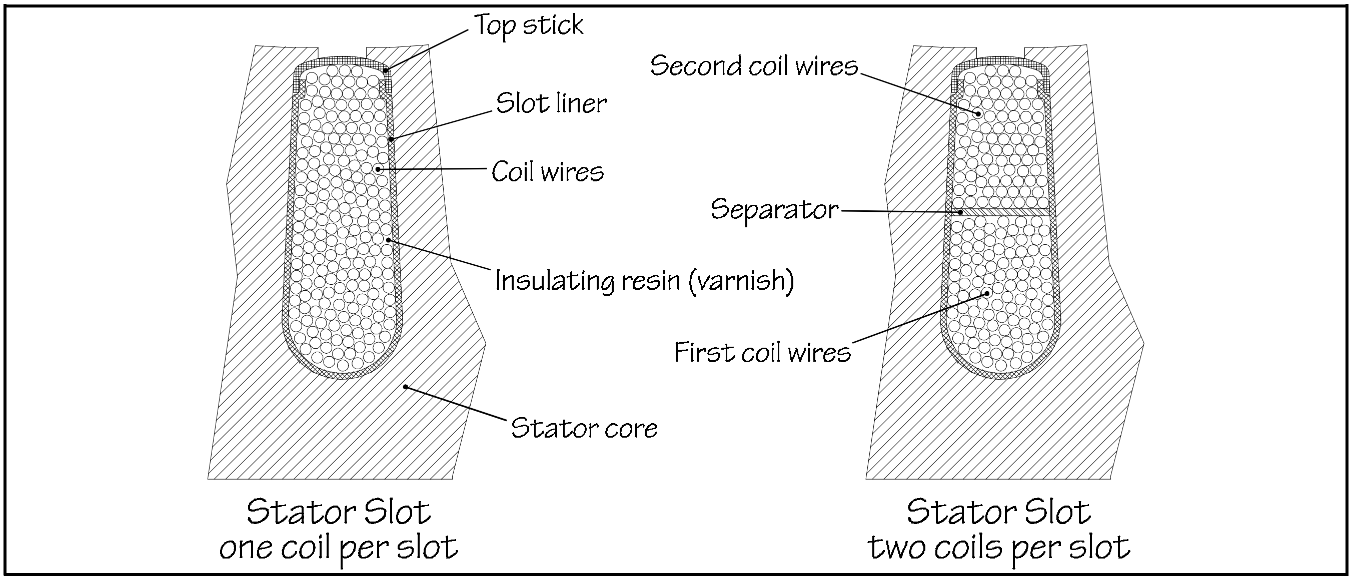


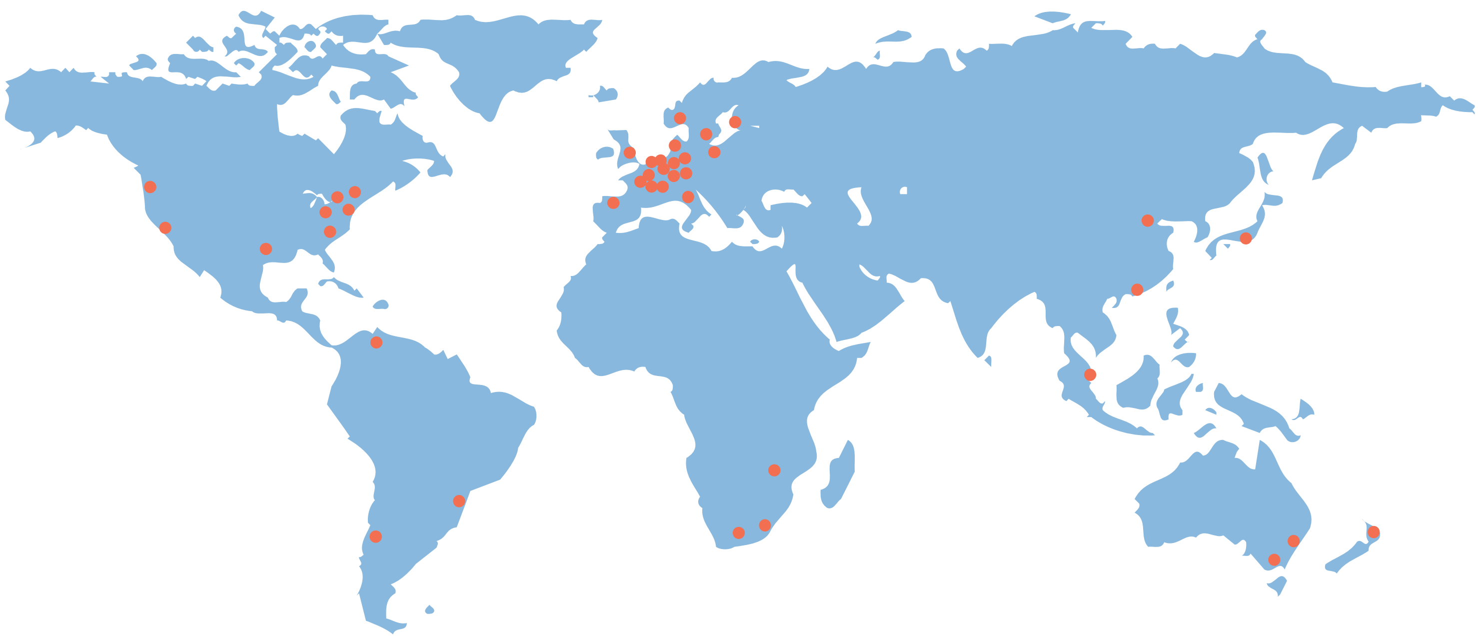
Figure 7

The job of the insulating system is to prevent items at different voltage potentials from shorting together. The motor's insulating system becomes even more important when large peak voltages are being applied to the motor.

SEW uses all of these insulating techniques. This is very unusual, particularly in motors of 5 HP and below. Most manufactures in this power range do not use phase paper. Some manufacturers also do not use slot liners. Instead of slot liners they use a paint coating to line the slot steel for additional insulation. Special magnetic insulating wire is used to ensure insulation integrity is maintained even with high peak voltages. A number of other construction techniques also enhances the insulating characteristics including vertical dipping, optimized dip times for different wire gages and the use of class H insulation varnish. All of these factors add together to provide a superior insulation system.

NEMA has recently introduced a more complete specification for motors to be used with variable frequency inverters. MG 1 Parts 30 and 31 contain some detailed concepts for motors used with variable frequency inverters. Most notable on this topic is 31.40.4.2 *Voltage Spikes*. This specification indicates that motors ($V_{in} \leq$ 600VAC) for use on VFD drives should be able to withstand 1600V_{peak} at a risetime of $\geq$ 0.1µS. This voltage level and rise time are produced by the new faster IGBT's and at a voltage input of 575V. SEW motors are designed to meet or exceed this specification.

Even more important than meeting a specification, SEW motors have also shown their reliability in real field installations. For over 10 years, motors with the same design and construction have been used on variable frequency drives. Since 1985 SEW has been a manufacturer of variable frequency inverters. Since 1990 SEW has been manufacturing inverters with IGBT output devices. SEW was one of the pioneers in using fast IGBT devices in production inverters and has conducted extensive research into motor reliability on inverter driven systems. History has shown that SEW motors are extremely reliable when used with inverters — even the newest technology drives.



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