SC9000
Output Quality Guide

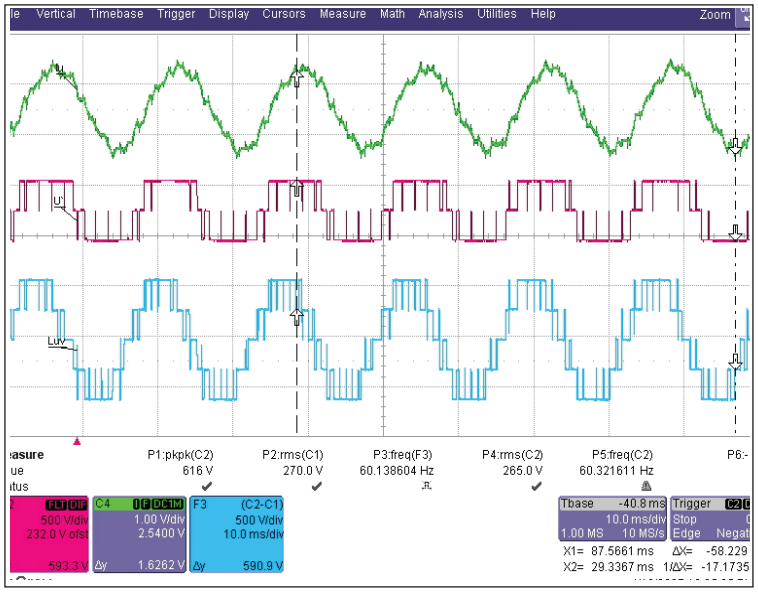

Figure 1. SC9000 Output Waveform

This guide is focused on the SC9000 output and is intended to help the reader understand the output quality of the three-level voltage source inverter, and the dv/dt or sine wave filter are also discussed. It is important to know the motor and application to ensure a successful installation. For simplicity 4160 VAC is used as nominal throughout this discussion.

Eaton SC9000 Motor Output

The SC9000 uses an isolation transformer to prevent coupling of the power system to the connected motor. The AC line voltage is converted to DC and voltage is stored in DC link capacitors. The neutral is hard grounded in a method known as Neutral Point Clamp, NPC. The SC9000 uses 6500V IGBT's that are fully rated for the application. The design offers a three level voltage output with three distinctive steps in voltage above or below neutral. **Figure 1** is a scope shot of the output waveforms of the SC9000. The green trace is current, red trace is line to ground voltage and blue trace is the line to line voltage. The current is nearly sinusoidal.

The DC link is 1.414 x the applied line voltage, nominally 5883V. When the inverter switches on the DC link voltage is applied to the motor. The RMS value is based on the V/Hz curve programmed into the drive. The peak voltage at the drive terminals is the level of the DC bus. The peak voltage at the motor terminals is based on transmission line effect. Keep in mind that the DC voltage does sag during full load conditions to between 5300 and 5500 VDC.

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The output voltage is controlled by the insulated gate bi-polar transistors (IGBT). Pulse width modulation is used to vary the RMS of the output. The rise time of the voltage is determined by the length of time it takes to turn on the IGBT, this is about 1.2uS. The amplitude of the voltage step will be about 1400 volts. This gives the SC9000 a dv/dt of about 1200V/uS. This is a relatively low dv/dt value.

Industry guidance on dv/dt issues have been incorporated into the design of the SC9000. Solidly grounded drive, isolation transformer, and lower switching frequency are all features we provide.

Motor bearing current is caused by high dv/dt which produces circulating currents in the rotor. The SC9000 has a relatively low switching frequency, and its three level inverter design reduces voltage step for an overall low dv/dt. If the voltage to ground exceeds the insulation value of the bearing grease, bearing current can occur. This bearing current can lead to eventual bearing failure if not properly addressed. We recommend a ground brush or insulated bearing on the non drive end (NDE) to ensure long bearing life.

Transmission line effect and the disparity of impedance between the cables and motor create the voltage spikes at the motor terminals that everyone wants to avoid. Industry recommends that shielded cables that are tightly bundled with dedicated ground wire be used to interconnect the drive and the motor. Large motors have an advantage the larger the motor the lower the impedance.

Standard Three Phase Induction Motor

The SC9000 can be used on standard three phase electric motors up to 100 feet from the drive without the addition of an output filter. These standard motors are designed to handle +/-10% of nameplate voltage. It is good to have Class F insulation (220C). The service factor on standard induction motors is negated when the motor us powered by an Adjustable Speed Drive.

Inverter Duty Motors

NEMA MG1 part 31 has provided guidance to motor vendors in the construction of VFD rated motors the formula is shown below.

Motors with base rating voltage V rated >600 volts:

Vpeak ≤ 2.5 (√2/√3) V rated = 2.04*V rated

For 4160V motors = 8.49kV

We have studied many installations and have developed a high end number of 6 volts rise per foot from the drive to the motor. This is worst case. Depending on motor size and cable type we have seen as low as 4 volts/ft.

In the case of and inverter duty motor we recommend adding an output filter if motor cables exceed 300 feet. The standing wave peak voltage would climb no more than 1800V this number is added to the peak of the AC waveform at the drive terminals (1800V + 5883V). That is 7683V worst case. **Figure 2** shows the voltage peak climb over distance of an unfiltered SC9000 output. The Blue line is the MG1 Part 31 inverter duty voltage limit, the green line is the standard induction motor limit. The pink line is the standing wave peak voltage a given distance from SC9000 to motor.

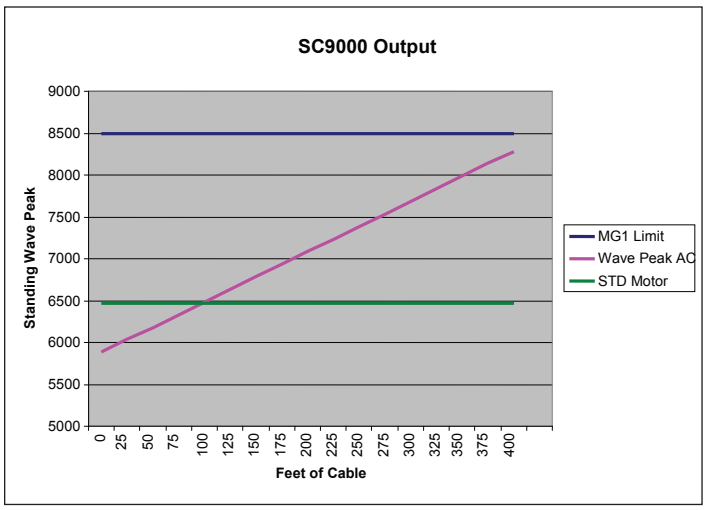

Figure 2. Standard SC9000 Output Voltage Rise Table

DV/DT Filter

The dv/dt filter design is intended to remove the steep wave front of voltage that creates the standing wave at the motor terminals. It uses a three phase reactor with damping resistors and a resistor capacitor shunt. These filters are sized by voltage and current.

The reduced rise time helps with motor insulation stress, reduces potential for circulating currents in the rotor and therefore reduces the risk of bearing current.

The dv/dt filter will increase the distance the drive can be from the motor to 500 feet for standard duty motor and to over 1000 feet for inverter duty motors. **Figure 3** has the addition of the dv/dt filter output voltage peak shown in red.

The output voltage waveform is shown in **Figure 4**. This was recorded 650 feet from the drive at the motor terminals. The voltage is in red and blue, current is green in the trace. The voltage peaks can be seen at the edges of transitions.

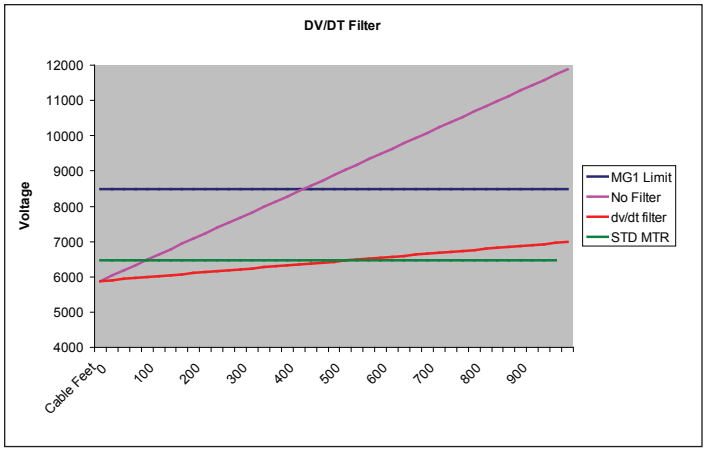

Figure 3. DV/DT Filter Increases Cable Distance

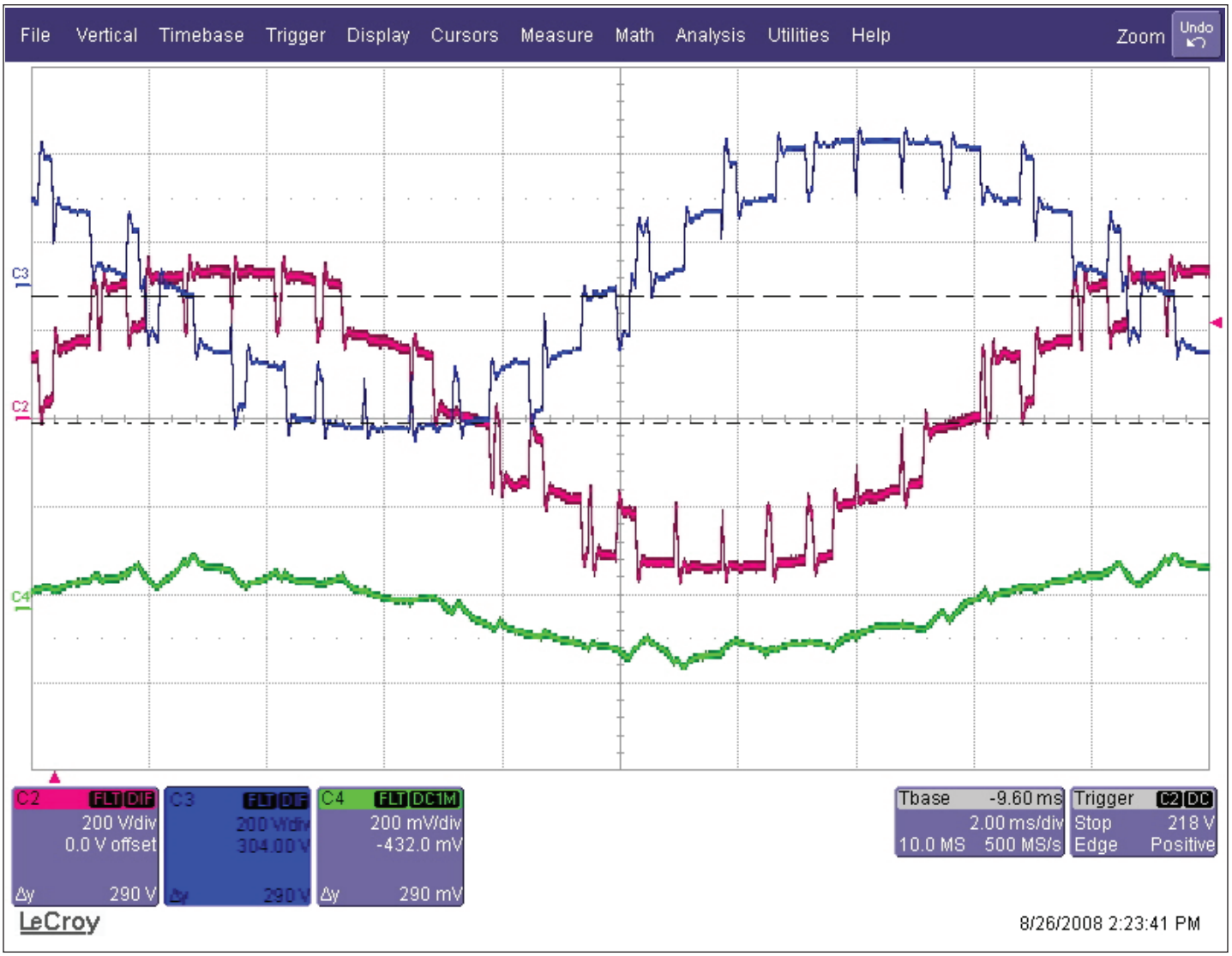

Figure 4. DV/DT Filter Voltage Waveform at 650 Feet

Sine Wave Filter

The SC9000 sine wave filter is designed to deliver an output with less than 5% THD on both voltage and current. The sine wave filter removes the steep rise time, eliminates the standing wave and prevents bearing currents. Dv/dt is reduced to less than 10v/uS.

The cable distance between motor and drive are now limited only to voltage drop over distance. The service factor of the motor can be used. **Figure 5** shows sine wave filter output. The purple is filter input voltage, the green is filter output voltage. The tan is output current.

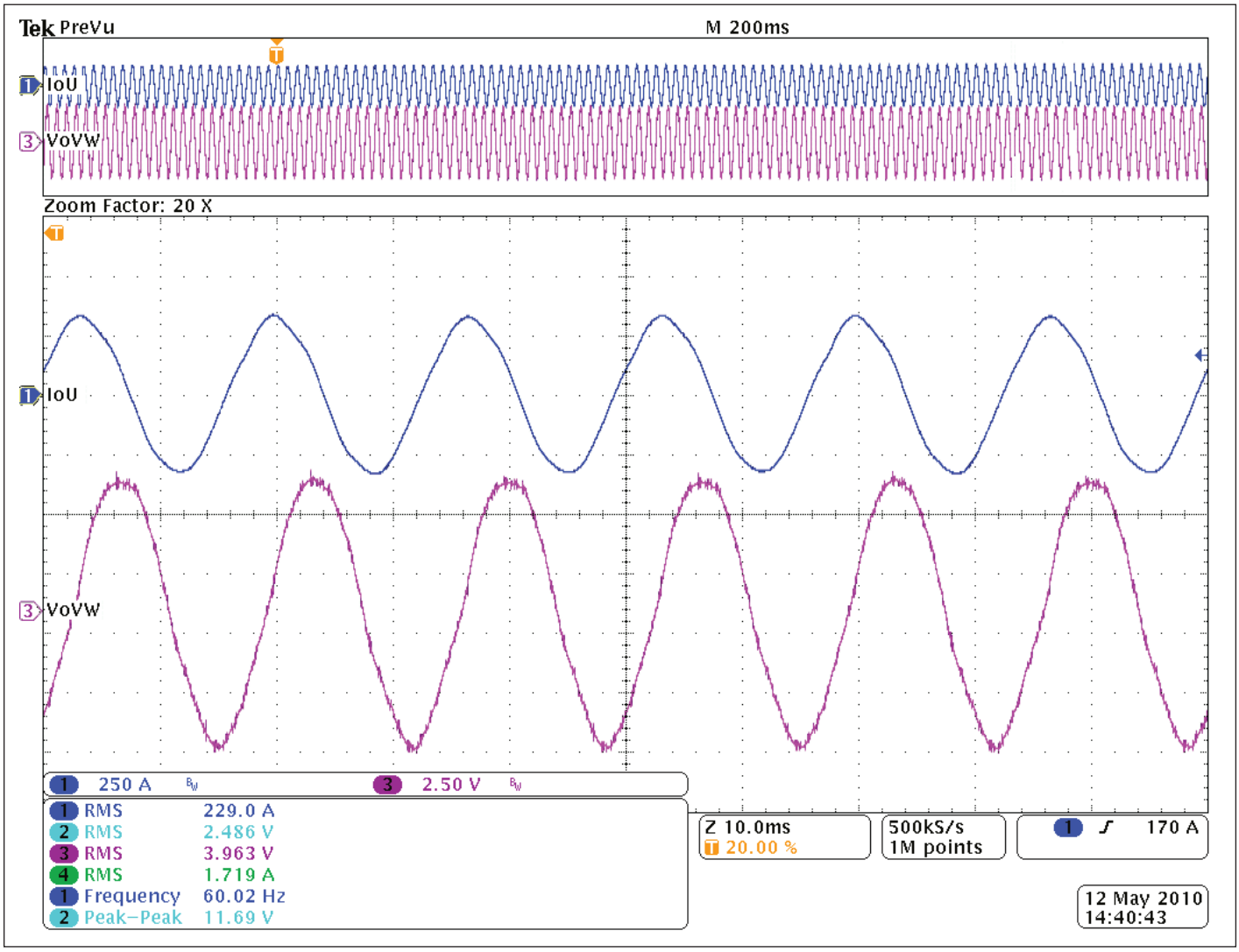

Figure 5. Sine Filter Output

Summary

The 3 level inverter of the SC9000 uses state of the art fully rated IGBT's. The inverter design takes into account industry guidance methods to reduce wear and tear on the motor. Using standard and accepted installation techniques will ensure a reliable installation for any process. Inverter duty motors are better suited to handle the voltage stress found on the output of an adjustable frequency drive. The dv/dt filter will extend the distance between motor and drive. The sine wave filter removes dv/dt from discussion and offers a low output THD.

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