Rockwell Automation
Standard Drives Business
6400 West Enterprise Drive
Mequon Wisconsin 53092 USA

Subject:

WWTP Motor Insulation Failure Investigation Trip Report

Date: April 18, 2013

To:

Company: Rockwell Automation

Copy: Steve Kubisch, Rockwell Automation

From: David Dahl, Senior Project Engineer, Rockwell Automation

Email: dldahl@ra.rockwell.com Telephone: (262) 512.8412 Fax: (262) 512.2222

This report summarizes RA Standard Drives Business Technical Support analysis of the electrical measurement data collected at WWTP. Voltage and current measurements were taken at 4 250HP US Motor that controls the speed of the IPS and is controlled by an Allen-Bradley Bulletin Power Flex 700H (PF700H) variable frequency drive (VFD). The measurements are part of a motor failure investigation.

Summary:

Three phase motor voltages and currents were measured and recorded at 4 IPS pump motors.

Oscilloscope plots are provided at the end of this report. All of the oscilloscope plots can be obtained by request.

motors were tested with the operation of a Rockwell Automation Model PowerFlex 700H VFD. The voltage and current rating is 480 VAC, 385 amps with 3% load reactor connected at the output of each VFD.

IPS motor manufacture, model, nameplate horsepower, voltage, current, and RPM are US Motor, Vertical Mount, 250HP, 460Volt, 346.5 Amps, 885 RPM, 5012P Frame, Type RUEI, WP-1 Enclosure, with electric heater.

The cable used to connect the VFD to the motor is 500 MCM/kcmils, three runs – one per phase, type THHN/THWN. The wire length from VFD to motor is approximately 23 feet. There is a motor disconnect box about 15 feet from VFD.

The ambient temperature on the day the measurements were taken was about 70 F.

The altitude of this site is about sea level.

Voltage and current measurements were recorded using a Tektronix Model MSO2024 four channel 200MHz digital storage oscilloscope. Tektronix P5210 High Voltage differential probes were used with the oscilloscope to measure motor terminal voltage and Power Electronic Measurement Rogowski current probes were used to measure motor current. A Fluke model 87V digital multimeter with Low Pass Filter feature was used to measure the RMS values of the motor terminal voltage.

The VFD's and motors were running and the following values were recorded:

1. At VFD from VFD parameters
   a. 213-227 Amps – fluctuating +/- 7 amps
   b. 51 - 52 Hz – fluctuating a little up and down
   c. 385-393 output volts – fluctuating a little up and down
   d. 630-636 volts DC bus

2. At motor:
   e. U to V volts – 385-393 output volts – fluctuating a little up and down f. V to W volts – 385-393 output volts – fluctuating a little up and down g. U to W volts – 385-393 output volts – fluctuating a little up and down

3. At motor current measuremennts:
   h. 213-227 Amps – fluctuating +/- 7 amps
   i. 213-227 Amps – fluctuating +/- 7 amps
   j. 213-227 Amps – fluctuating +/- 7 amps

Voltage measurements were taken at the motor terminals with the Tektronix digital storage oscilloscope and high voltage differential voltage probes. Current measurements were taken at the motor terminals with a Rogowski current probe. The voltage was measured from phase to phase and phase to ground. The oscilloscope was set up to capture the highest peak voltage phase to phase and phase to ground. The peak voltage recorded about 1100 volts phase to phase and 800 volts phase to ground. The voltage rise time recorded was about 1 micro second from zero voltage to peak voltage.

With a reflective wave reduction device (Terminator) installed on Pump #1 the motor peak voltage recorded was about 930 volts. The voltage rise time recorded was about 1 micro second from zero voltage to peak voltage. The voltage ringing or oscillation following the peak voltage was reduced.

The voltage waveforms captured shows high frequency ringing on the rising edge and at the peaks. The exact cause of the ringing on the rising edge is unknown. However, it is reasonable to believe that the winding configuration and electrical (inductance and capacitance) characteristics of the motor stator windings, cable and wire (inductance and capacitance) characteristics, and the rapid voltage rise time may be contributing to the ringing. The ringing after the peak waveform is caused by the winding configuration and electrical (inductance and capacitance) characteristics of the motor stator windings and cable and wire (inductance, resistance, and capacitance) characteristics.

With the installation of the reflective wave reduction device (Terminator) installed on Pump #1 the motor voltage pattern indicated less ringing and faster damping to DC bus voltage following the peak reflective wave voltage.

The oscilloscope plots are provided at the end of this report.

In all four pump motor measurements conditions the peak voltage measured from phase to phase was less than the peak voltage defined in NEMA MG1 Part 31.40.4.2, 1998. The rise time of the voltage recorded at the motor was > 0.2 micro seconds. This is greater than the voltage rise time defined in NEMA MG1 Part 31.40.4.2, 1998. **(FIGURE 1 is from NEMA MG1 Part 31.40.4.2, 1998.)**
Measurements with reflective wave reduction device connected to Pump #1 motor, the peak voltage measured from phase to phase was less than the peak voltage defined in NEMA MG1 Part 31.40.4.2, 1998. The rise time of the voltage recorded at the motor was > 0.2 micro seconds. This is greater than the voltage rise time defined in NEMA MG1 Part 31.40.4.2, 1998. **(FIGURE 1 is from NEMA MG1 Part 31.40.4.2, 1998.)**

Based on research it appears that from our experience the following conditions may apply:

1. The voltage measurements at the motor with and without a reflective wave reduction device show the peak voltage is less than the peak voltage defined in NEMA MG1 Part 31.40.4.2, 1998.
2. The rise time of the voltage recorded at the motor with and without a reflective wave reduction device is greater than the voltage rise time defined in NEMA MG1 Part 31.40.4.2, 1998.

The reflective wave reduction device, 1321-TFB2 (Terminator), does reduce the peak voltage from 1100 volts to less than 1000 volts. Rockwell Automation classifies 480 volt motors with additional slot, phase paper and VPI as at least 1200 volt rated motors. The terminator limits the peak voltage to less than 1200 volts. The reflective wave reduction devices, 1321-TFB2 (Terminator), does further reduce the peak voltage from 1100 volts to less than 1000 volts. However there is some unusual high frequency voltage ringing. Rockwell Automation does not know what effect the high frequency voltage ringing may have internally in the motor windings.

The high frequency ringing may be further reduced by the installation of resistors connected across the load reactor. The application of resistors across the load reactor provides damping to high frequency ringing voltages. (Figure 25)

Rockwell Automation requests the following information from the motor manufacture:

1. In the original manufacturing of the motors do they use VPI (Vacuum Pressure Impregnation).
2. Schematic of the stator winding.

Rockwell Automation requests the following information from the motor repair facility:

1. In the repair process of the motors do they use VPI (Vacuum Pressure Impregnation).
2. Schematic of the stator winding.

Rockwell Automation requests the following information from the site installation:

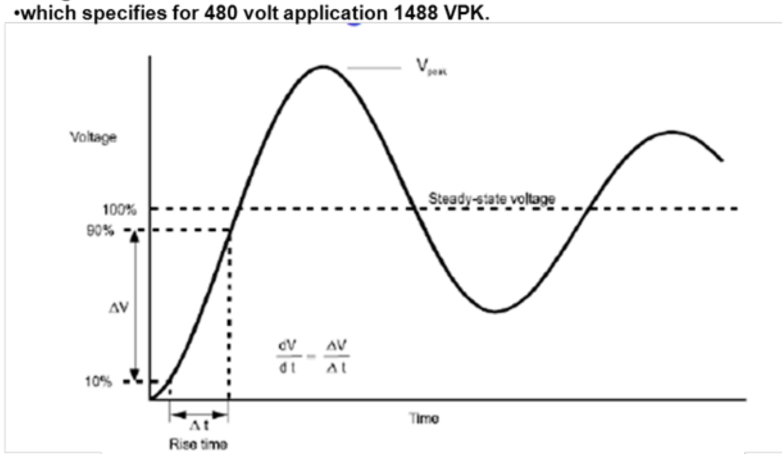
1. Each motor has an internal heater. How is this used in this application? Provide a copy of the control schematic to help determine when the heaters are used.

If you have any questions or comments please feel free to contact me.

Regards,

Dave Dahl
Senior Project Engineer Analyst
Rockwell Automation - Allen Bradley Standard Drives

•NEMA MG1 Part 31.40.4.2, 1998 "Insulation can withstand voltage spikes of up to 3.1 times motor rated voltage"
•which specifies for 480 volt application 1488 VPK.



Motors with base rating voltages $V_{rated} \leq 600$ volts:

$$V_{peak} \leq 1.1 * 2 * \sqrt{2} * V_{rated} = 3.1 * V_{rated}$$

Rise time $\geq 0.1\ \mu s$

Where: V_{peak} is a single amplitude zero-to-peak line-to-line voltage

V_{rated} is the rated line-to-line voltage.

Figure 1: NEMA MG1 Part 31

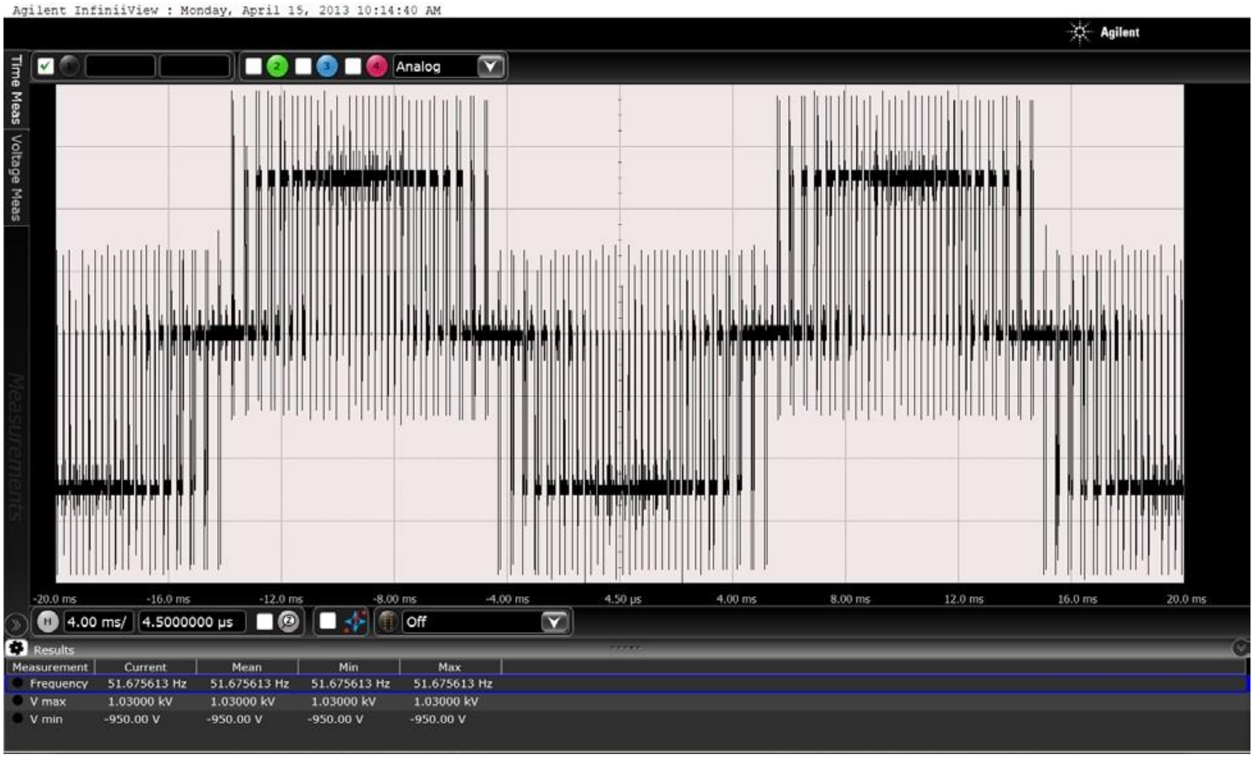


Figure 2: Pump #1 voltage phase to phase, 250 volts per div

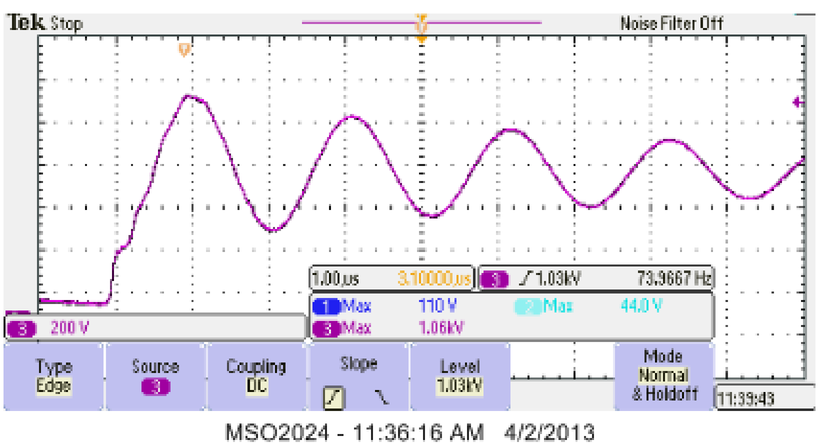


Figure 3: Pump #1 voltage phase to phase, 250 volts per div

Figure 4: Pump #1 Phase to ground voltage, 200 volts per div

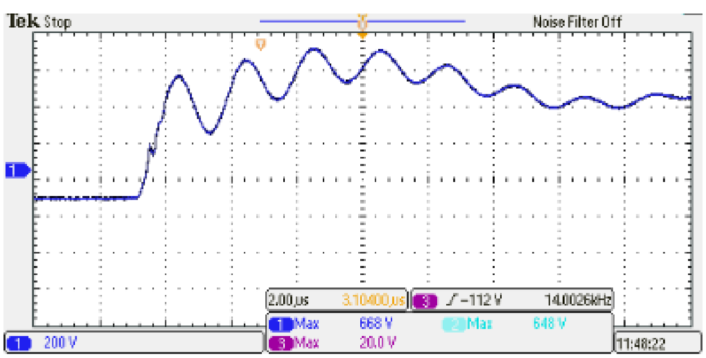


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Figure 5: Pump #1 Phase to ground voltage, 200 volts per div

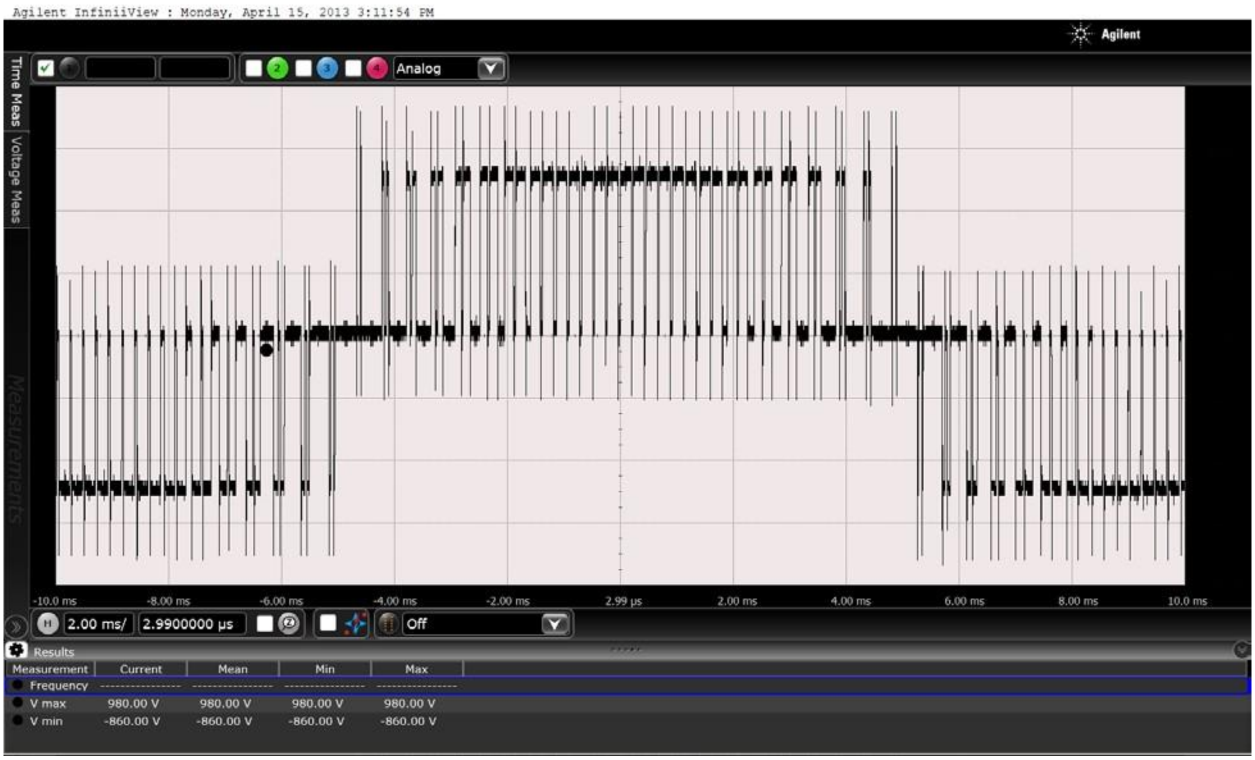

Figure 6: Pump #1 with reflective wave reduction device (terminator) phase to phase voltage. , 250 volts per div

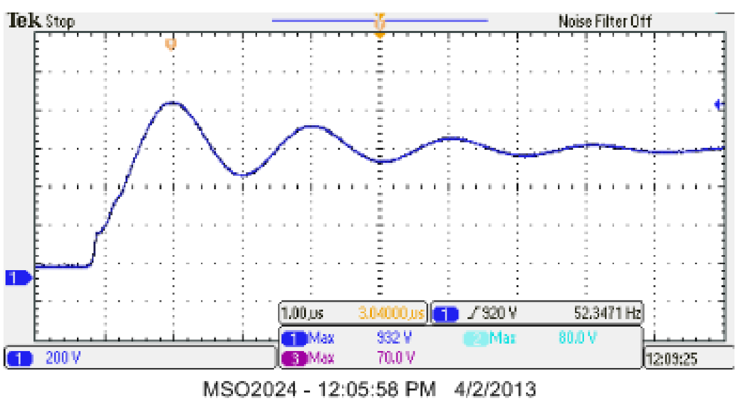

Figure 7: Pump #1 with reflective wave reduction device (terminator) phase to phase voltage. , 250 volts per div

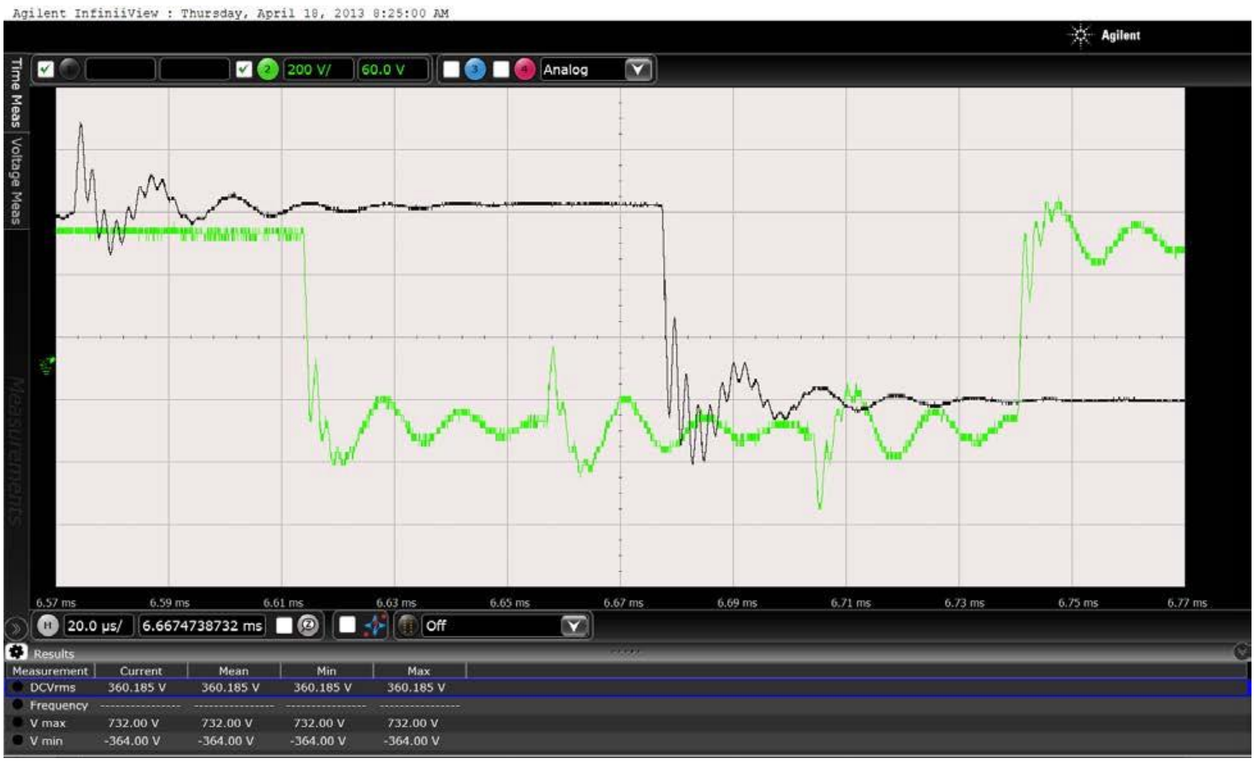

Figure 8: Pump #1 without CH1 and with CH2 reflective wave reduction device (terminator) phase to ground voltage. , 200 volts per div

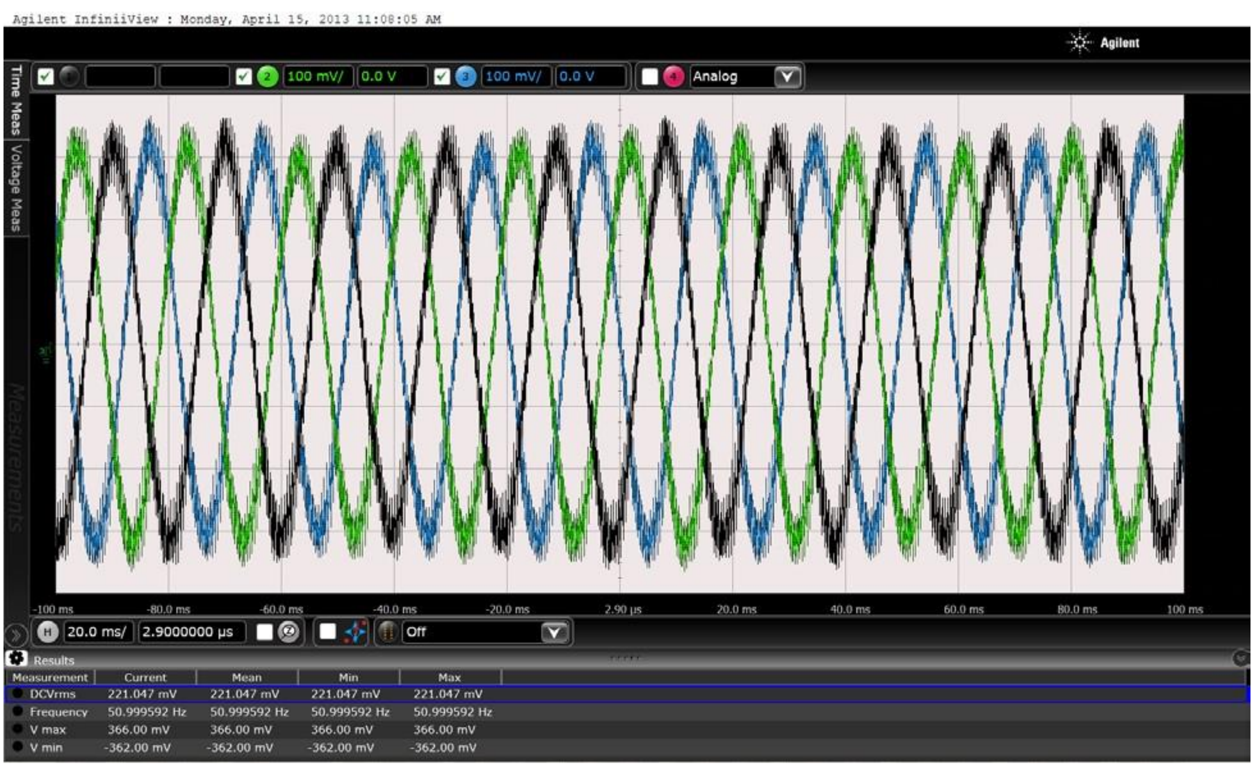

Figure 9: Pump #1 current, 100 Amps per div

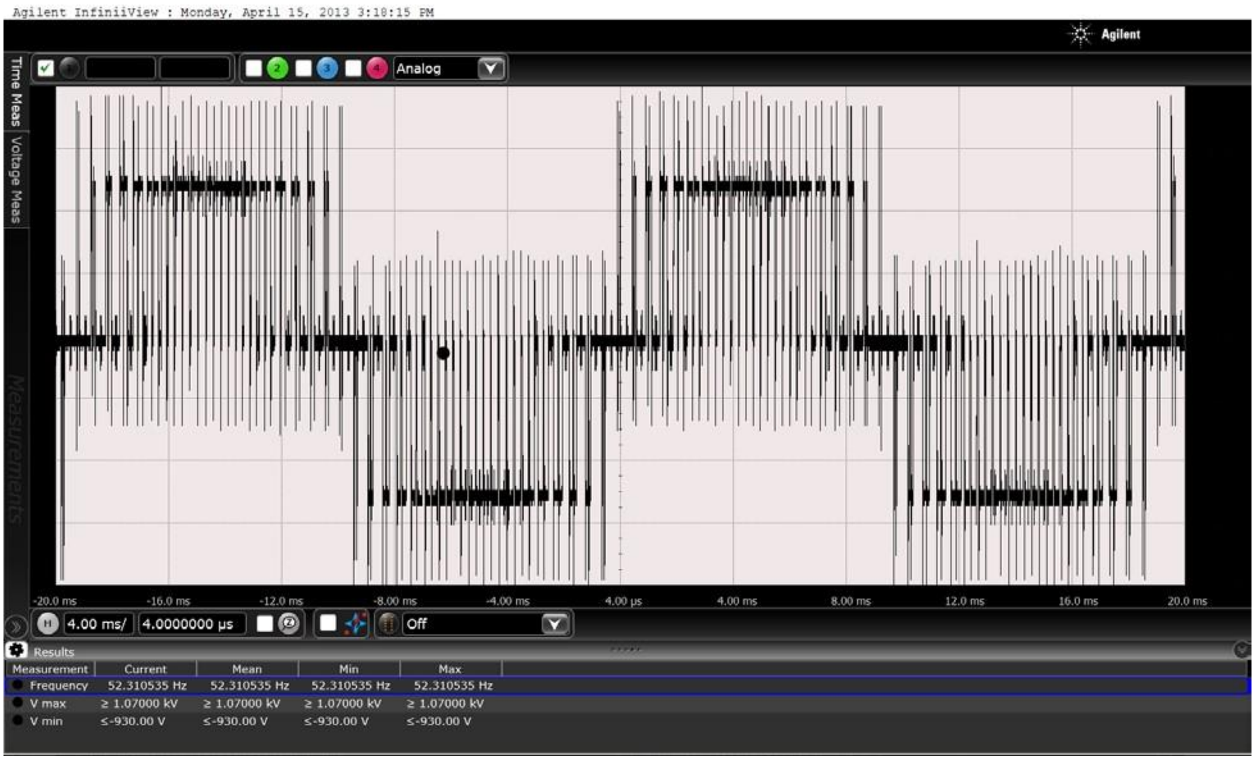

Figure 10: Pump #2 voltage phase to phase, 250 volts per div

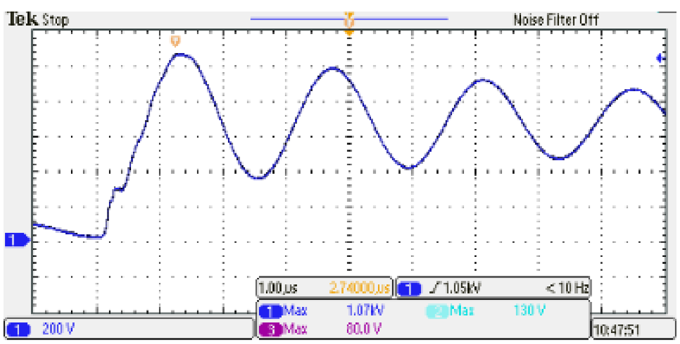

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Figure 11: Pump #2 voltage phase to phase, 250 volts per div

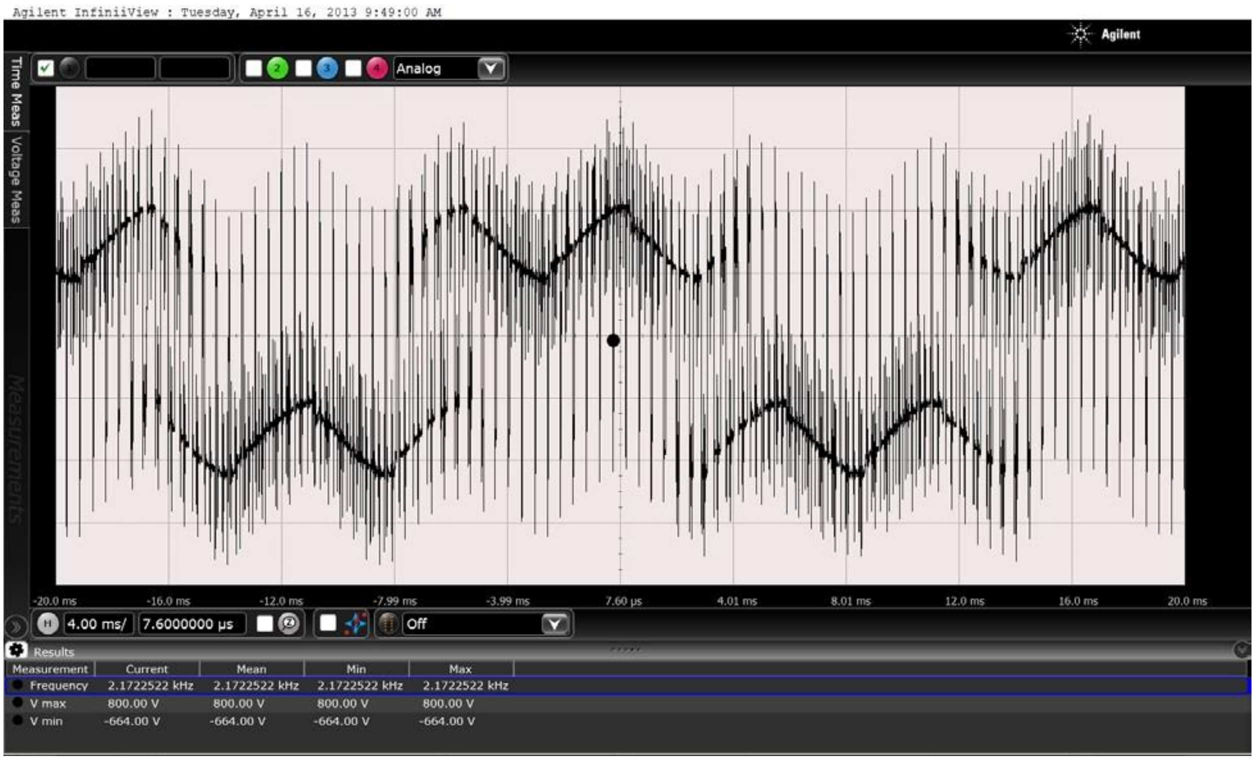

Figure 12: Pump #2 voltage phase to ground, 200 volts per div

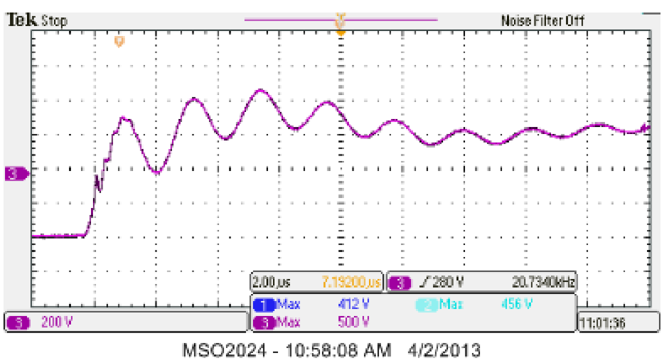

Figure 13: Pump #2 voltage phase to ground, 200 volts per div

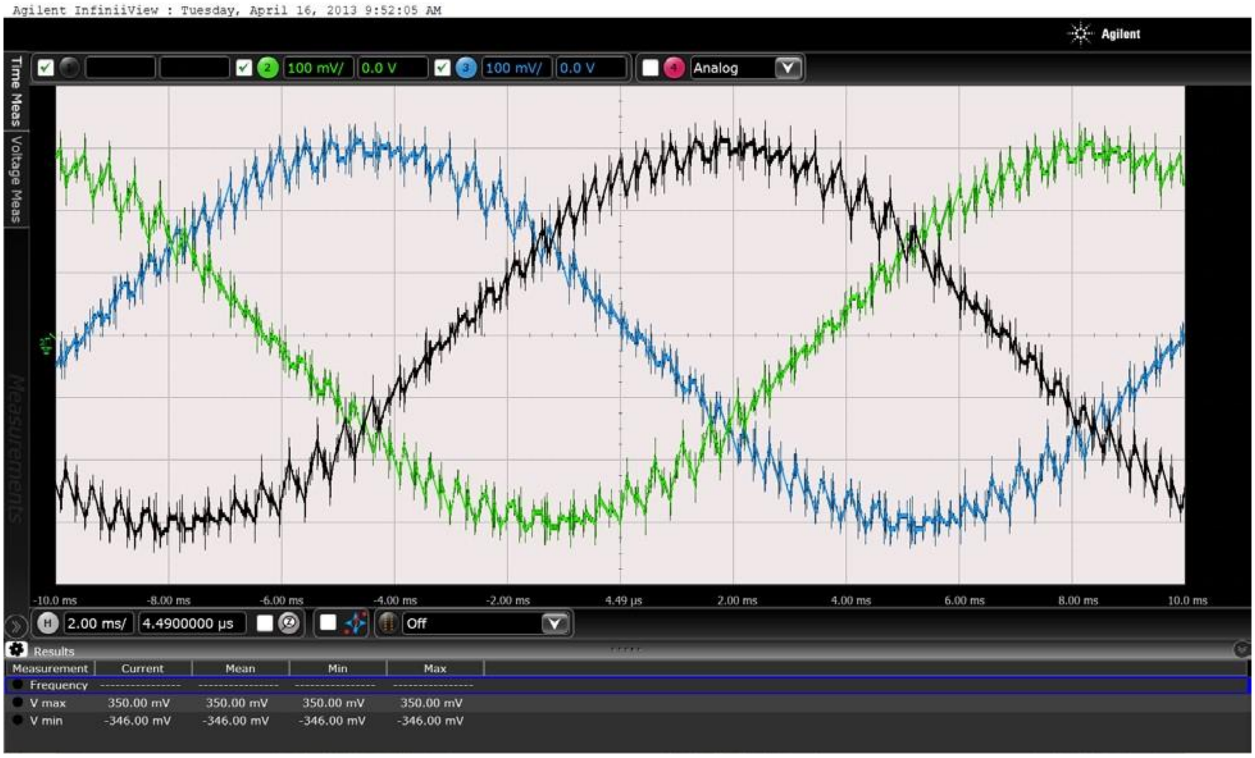

Figure 14: Pump #2 current, 100 Amps per div

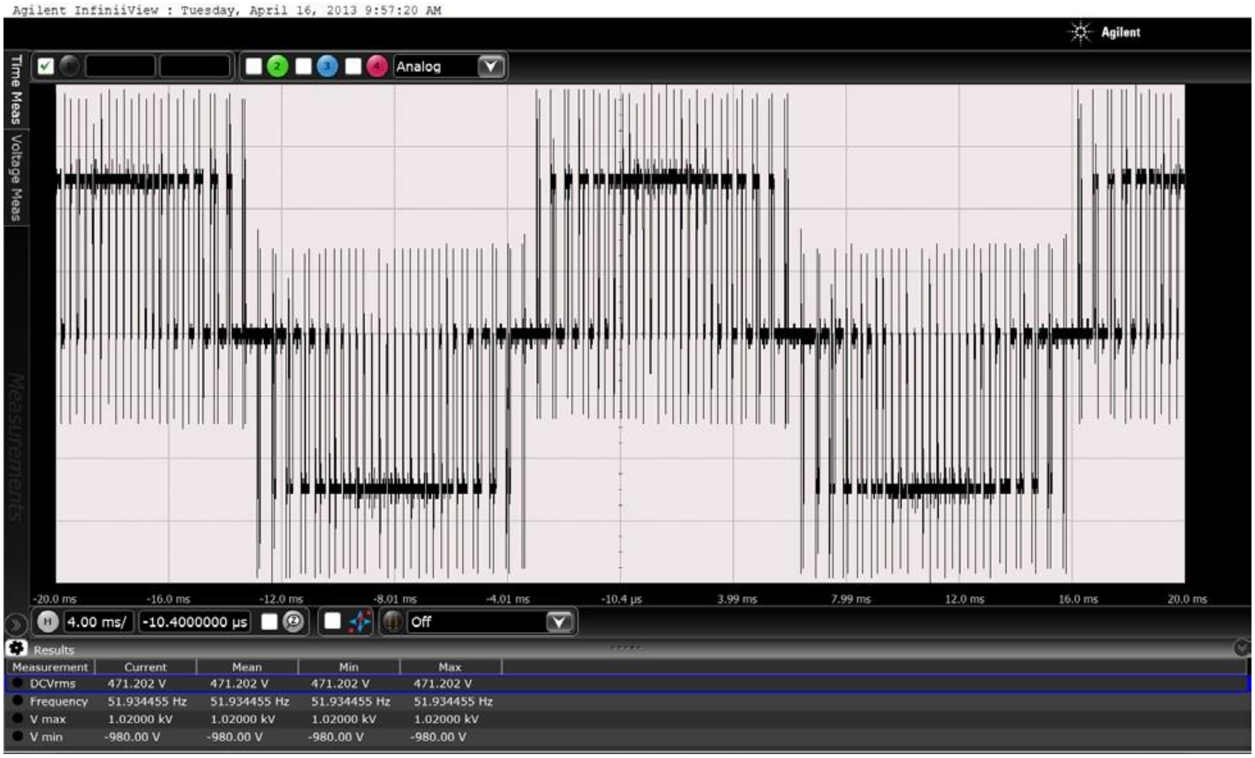

Figure 15: Pump #3 voltage phase to phase, 250 volts per div

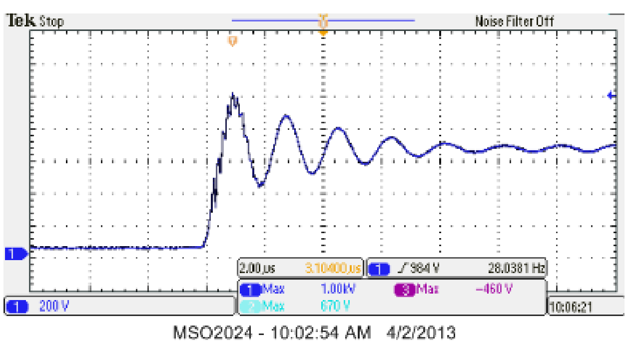

Figure 16: Pump #3 voltage phase to phase, 250 volts per div

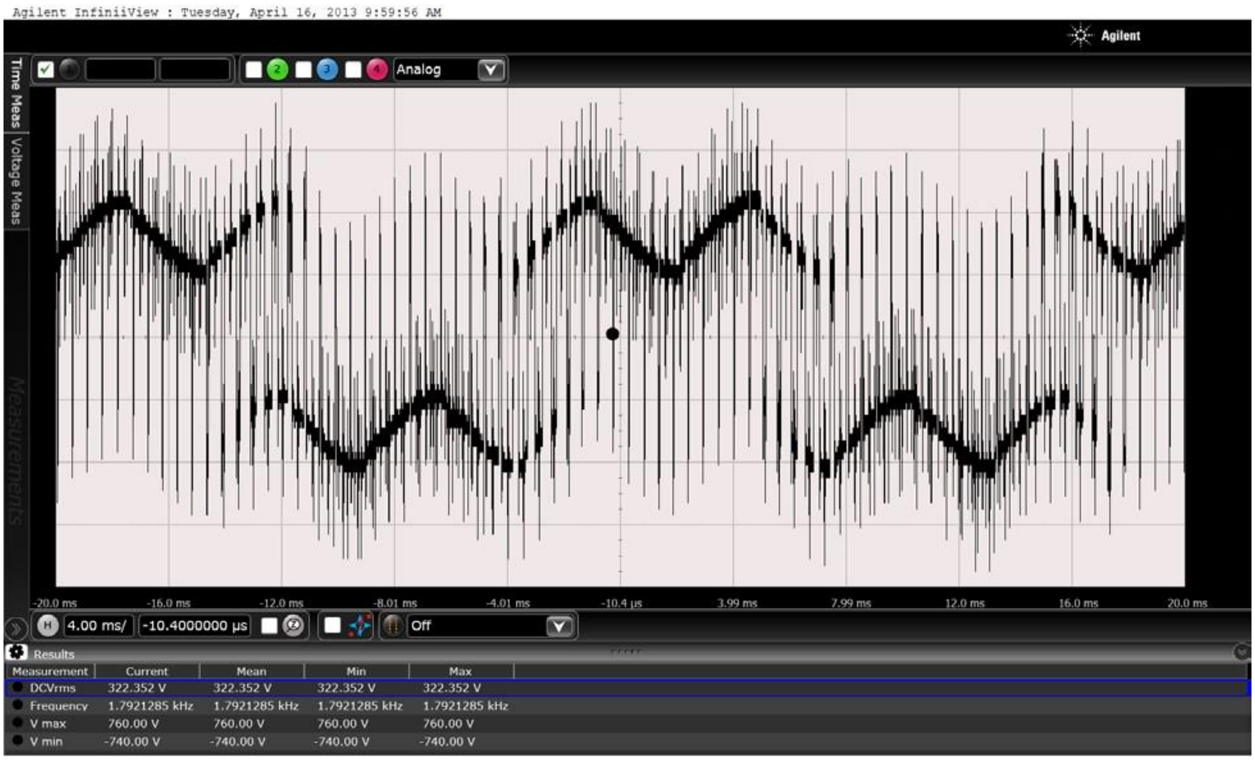

Figure 17: Pump #3 voltage phase to ground, 200 volts per div

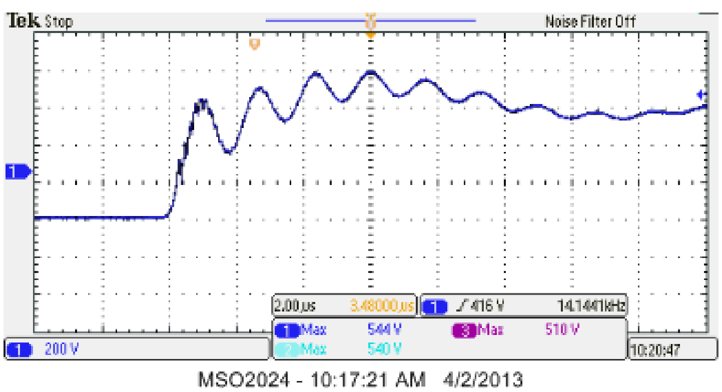

Figure 18: Pump #3 voltage phase to ground, 200 volts per div

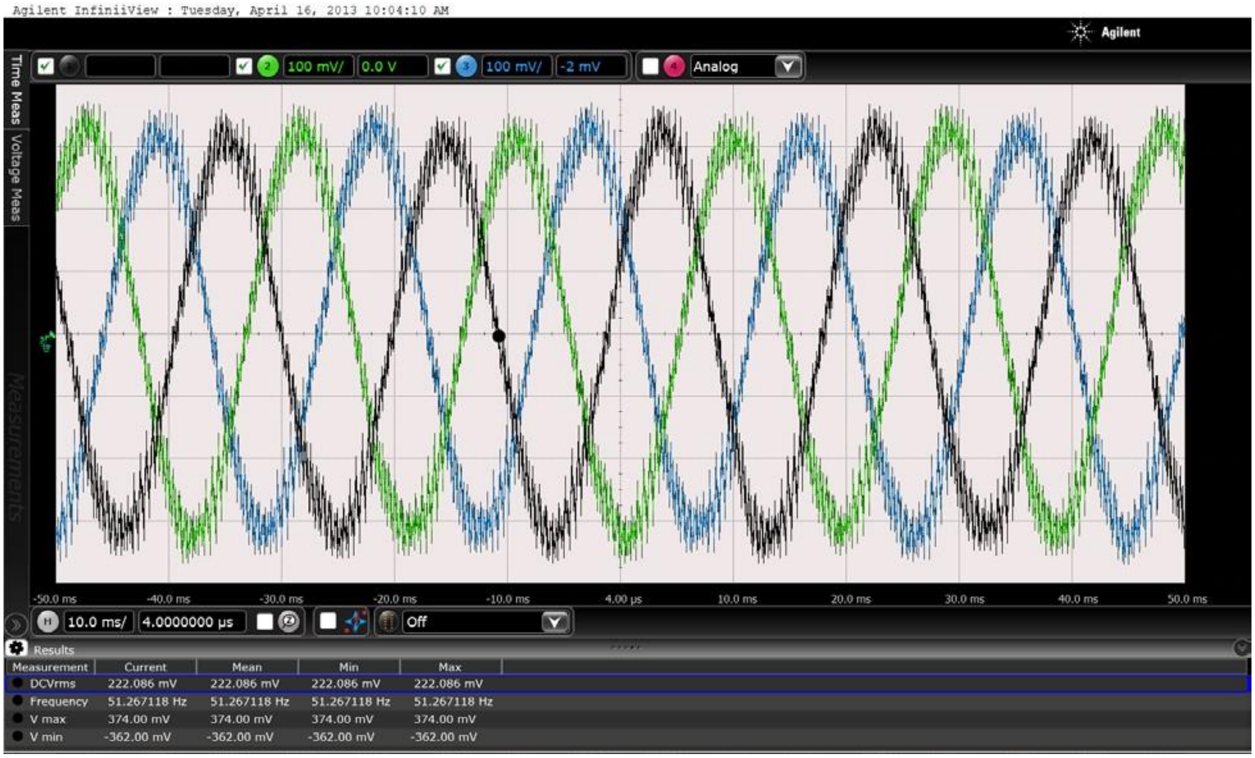

Figure 19: Pump #3 current, 100 Amps per div

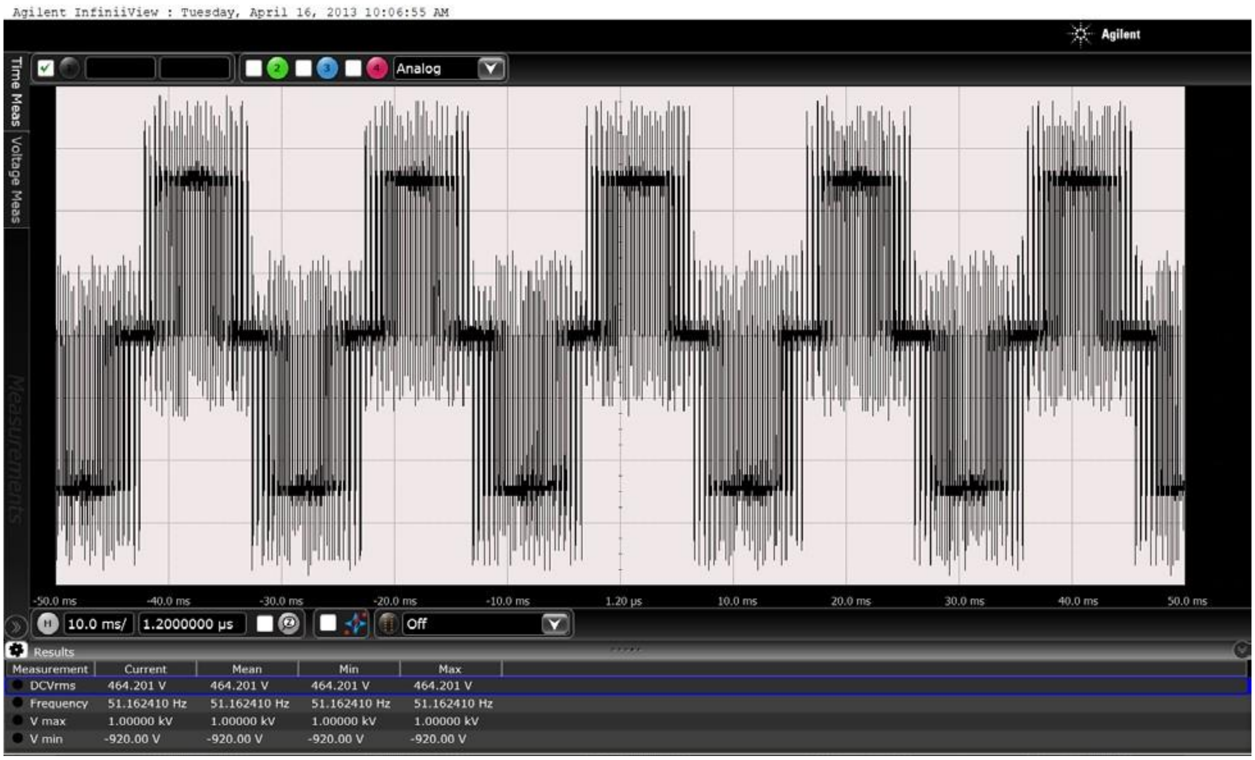

Figure 20: Pump #4 voltage phase to phase, 250 volts per div

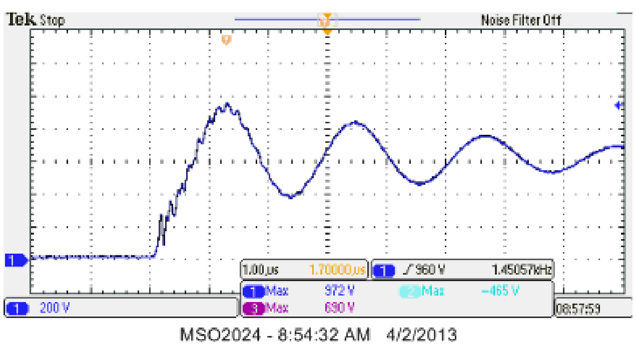

Figure 21: Pump #4 voltage phase to phase, 250 volts per div

Figure 22: Pump #4 voltage phase to ground, 200 volts per div

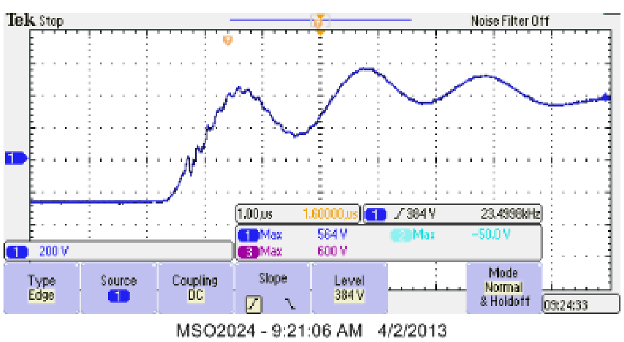

Figure 23: Pump #4 voltage phase to ground, 200 volts per div

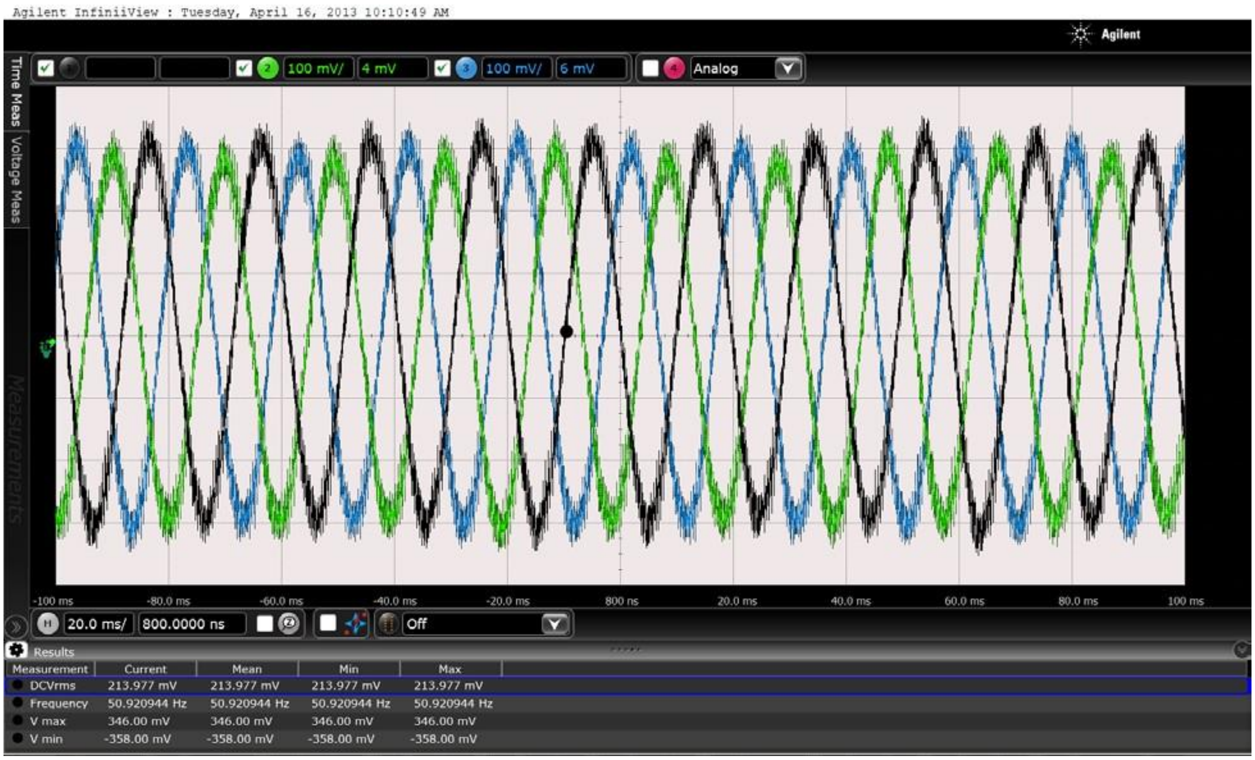

Figure 24: Pump #4 current, 100 Amps per div

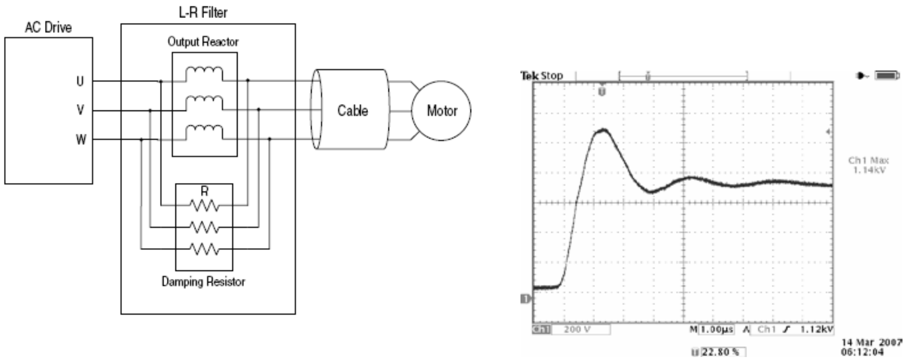

Figure 25: Load Reactor with damping resistors. The voltage waveform shows one large overshoot with rapid decay to nominal DC bus. Damping resistor contributes to the reduction in ringing.