EPRI Solutions Case Study
2004 Program 97 – Number 6

Induction Heater Investigation at a Gas Cylinder Manufacturing Plant

Background

A gas cylinder manufacturer wanted to add a single-phase induction heater to its production line but was concerned that the heater might cause an imbalance loading issue on the utility delivery transformer. This transformer also fed other equipment in the plant, and the customer wanted to make sure that the heater would not cause any problems. The single-phase heater was to replace a three-phase unit in the necking process line because it operated at a lower frequency. The lower frequency would give the customer a more uniform heat pattern for the cylinders that it was producing. Because one of its West Coast plants had a spare heater and was also using a single-phase unit, it decided to test the heater before putting it into operation. Being one of the world leaders in the development, production, and supply of seamless extruded aluminum and composite high-pressure cylinders for the storage of gases, the company had to make sure that its product met its customers' standards.

The account manager and the customer requested assistance with a power quality study to determine whether the single-phase induction heater would cause any voltage imbalance on its system. A power quality (PQ) engineer from the local utility company was asked to help with the study. The study confirmed that the induction heater would not cause any significant voltage imbalance on its system, so it was put into operation. Shortly thereafter, the company began to experience problems with other equipment in the plant that was fed from the same delivery transformer as the induction heater. The problems included uninterruptible power supplies (UPSs) cycling to battery, relays dropping out, and adjustable-speed drives (ASDs) tripping off on overvoltage error codes. The PQ engineer helped the customer with follow-up monitoring to determine why the induction heater was impacting the company's equipment and to develop a solution.

Investigative Approach

For the voltage imbalance study, the PQ engineer set up a demonstration test to determine whether the heater would cause a significant voltage imbalance on the utility transformer. The test was set up by temporarily powering the heater and monitoring the delivery voltage. A sophisticated PQ monitor was installed at the 1000-kVA delivery transformer feeding the induction heater to measure the voltage impact it would have on the supply voltage.

After the test confirmed no significant voltage imbalance issues, the customer put the induction heater into operation. Additional monitoring on the customer's electrical system was performed in response to problems experienced with other equipment in the plant that was fed from the same delivery transformer as the heater. The PQ engineer monitored the heater to determine why it was causing problems for other equipment in the plant.

Observations/Findings

A portion of the customer's plant was fed from a 1000-kVA, 480/277-V delivery. The input specifications of the induction heater are: 480 V single-phase, 184 kVA, 400 A, and 60 Hz. The initial test conducted by the PQ engineer was to determine whether the induction heater would cause any significant voltage imbalance on one of the delivery transformers. He recorded the effects of the new heater on the voltage and current during the limited heating-cycle tests that were performed (see Figure 1). The monitor was set up to record voltage, current, and load. A storage interval of one second was programmed into the monitor. The monitor was not set up to record transient voltage or current waveform events. The heat cycle was when the heater was turning on and off as the bottles passed through the production line. For a typical heating cycle, Table 1 shows the changes in the voltages and currents recorded over a one-second period. Results proved that the current imbalance caused by the single-phase induction heater would not result in a significant voltage imbalance. Based on the data, the PQ engineer and the customer did not find any problems with the operation of the single-phase induction heater.

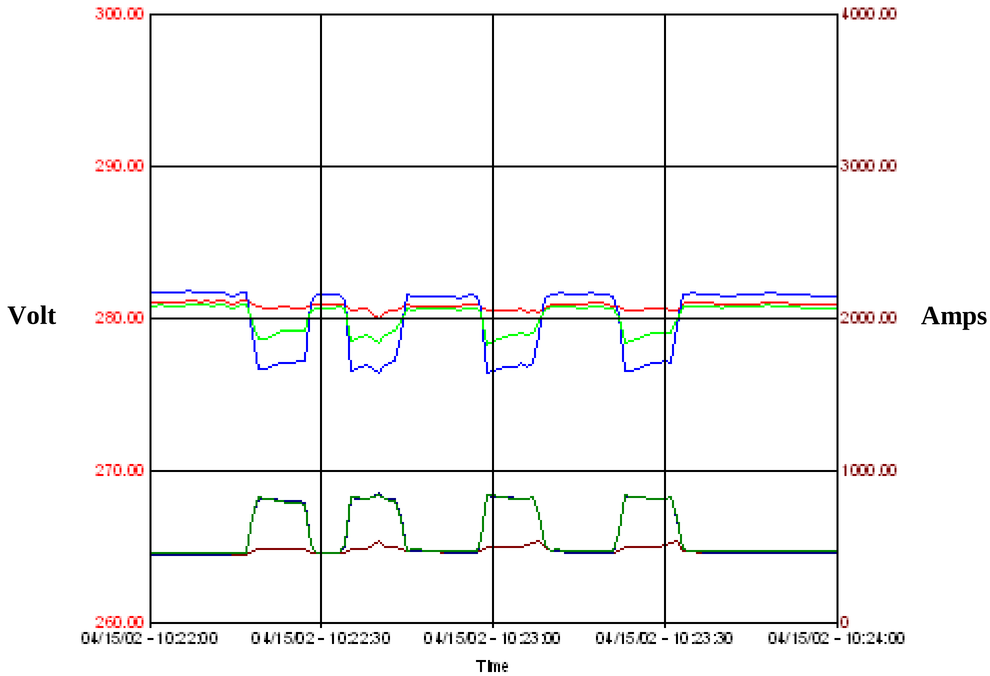

Figure 1. RMS voltages and currents—line-to-neutral (initial test).

Table 1. Voltage and current measurements before and after heat cycle.

Just Before Heat Cycle		
3-Phase Voltages:	281 V/282 V/281 V	$V_{Imbalance}$: 0.3%
3-Phase Currents:	451 A/454 A/460 A	$I_{Imbalance}$: 1.1%
During Heat Cycle		
3-Phase Voltages:	281 V/277 V/279 V	$V_{Imbalance}$: 0.7%
3-Phase Currents:	485 A/816 A/816 A	$I_{Imbalance}$: 31.3%

The customer then decided to put the induction heater into operation. Immediately the customer began experiencing problems with the UPSs, ASDs, and relays fed from the same delivery transformer as the heater. Based on the problems that the customer was experiencing, the PQ engineer suspected a transient event. By reviewing previously monitored data, the PQ engineer correlated the problems to the operation of the new single-phase induction heater. The customer was able to switch the UPS load to another delivery transformer. Further monitoring and investigation was needed to determine whether transient events were indeed causing the problems.

A sophisticated PQ monitor was set up to record the voltage and current at the 1000-kVA delivery transformer feeding the heater (see Figure 2). The storage interval for the monitor was setup to capture high-speed data with an interval of one cycle. The data showed three-phase voltage and current for seven heat cycles of this equipment. The RMS profile graphs do not show any significantly long-duration voltage drops or excessive current inrushes during the heat cycle of the equipment except for the moment when the induction heater turns on.

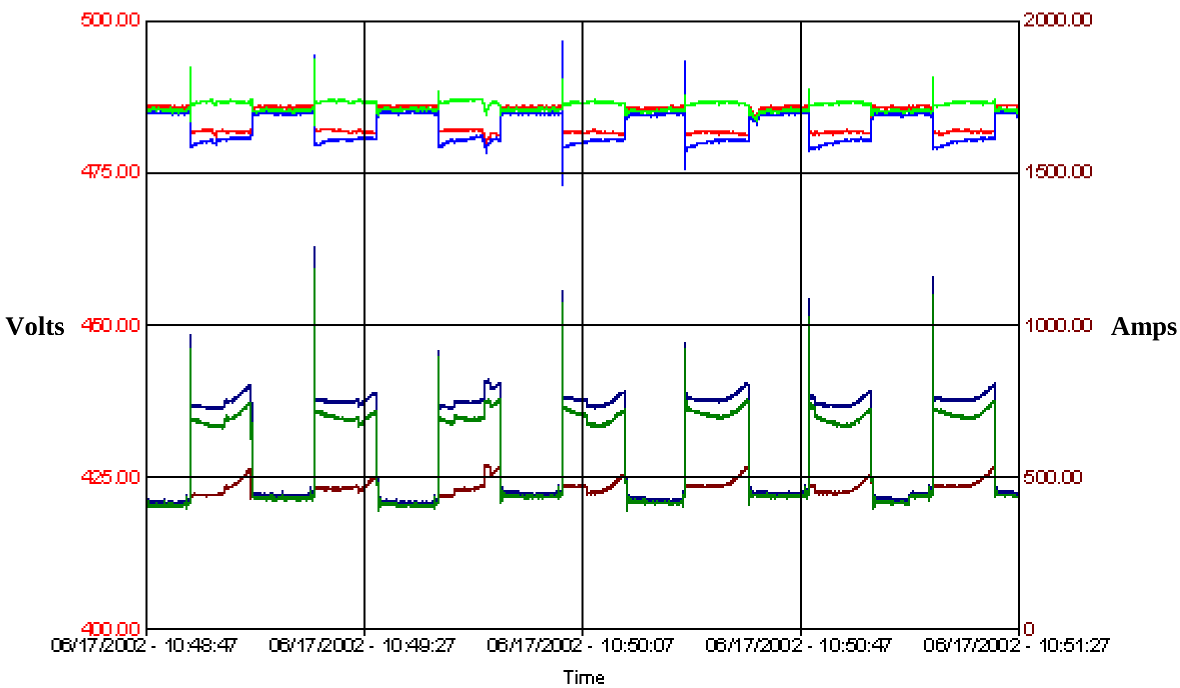

Figure 2. RMS voltage and current, phase-to-phase (after heater was placed in operation).

To get a closer look at the moment the heater is turned on, the monitor was set up to capture transient voltage and current waveform events by triggering on the current inrush (see Figures 3 and 4). The monitor was programmed to capture two electrical cycles prior to the equipment start and six electrical cycles after the start. The current waveform shows two large sub-cycle current pulses during the first electrical cycle. This current inrush resulted in a voltage notch towards zero. The initial voltage disturbance then resonated with the electrical system, resulting in an overvoltage transient. These voltage and current transients lasted about one-half of an electrical cycle.

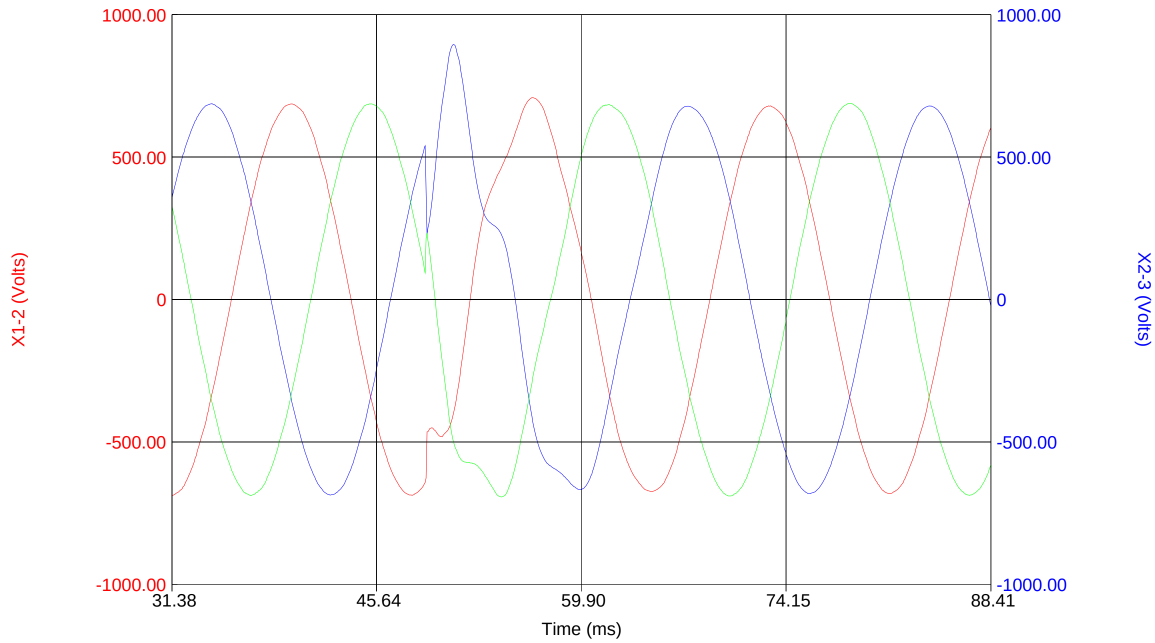

Figure 3. Voltage waveform—induction heater start (zoomed in on initial transient).

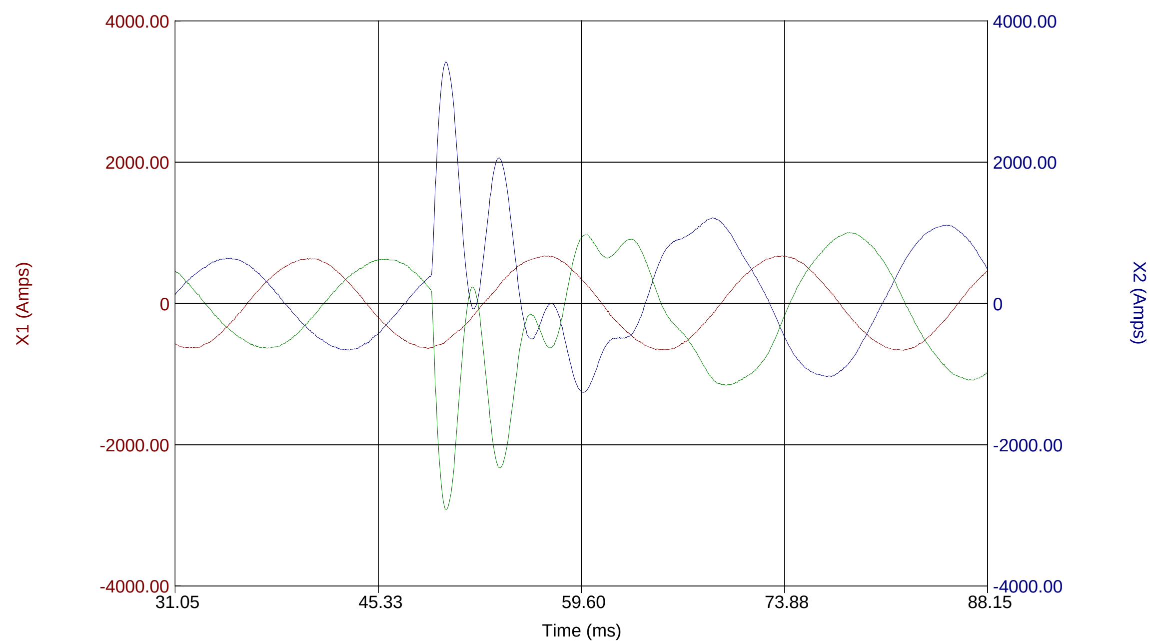

Figure 4. Current waveform—induction heater start (zoomed in on initial transient).

Other plant equipment was being affected by this voltage transient, which was created by the current inrush when the induction heater started. The UPSs sensed the voltage notch, interpreted it as a start of a power outage, and switched to battery. Relays were also impacted by the momentary voltage notch and dropped out. The overvoltage portion of the voltage transient overcharged the DC link capacitor of the ASDs, and they shut down on overvoltage in order to prevent damage to the inverter section of the drives.

Recommendations/Solutions

The PQ engineer considered that a possible solution to this problem would be to provide some isolation between this induction heater and other equipment fed from the same electrical system. This solution could be achieved by adding some electrical impedance at the input of the induction heater. The customer also contacted the manufacturer of the induction heater about its recommendations to resolve the problem. Reactors were recommended by the PQ engineer, and the manufacturer helped with the sizing of the reactors.

The customer installed a reactor on the input of the induction heater, and follow-up monitoring was done by the PQ engineer to quantify the benefits of the reactor. Based on the data, the reactor did reduce the severity of the voltage transient and current inrush, but it did not eliminate the problems of ASDs tripping (see Figures 5 and 6). The problems with relays were eliminated, and the UPS issue was resolved by switching the office load (location of UPSs) to another delivery transformer. A 15-HP ASD fed from the same delivery transformer would trip only when the company ran the induction heater with the largest heater coil. The PQ engineer noted that a means to prevent the overvoltage on the DC link within the drive would prevent its tripping. Therefore, he recommended a clamping circuit. A clamping circuit is designed to absorb the extra energy from a voltage transient and thus prevent an ASD from tripping for an overvoltage transient.

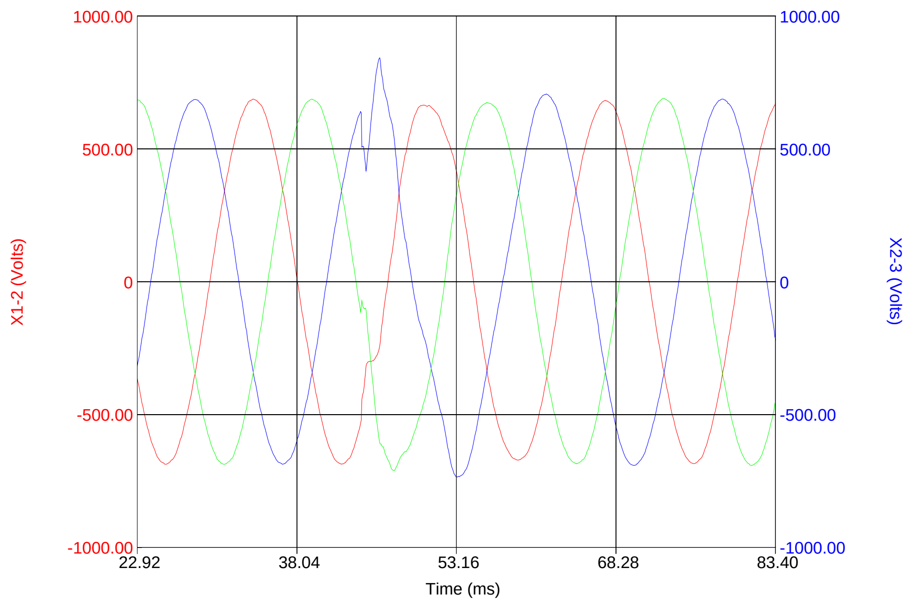

Figure 5. Voltage waveform after reactor installation.

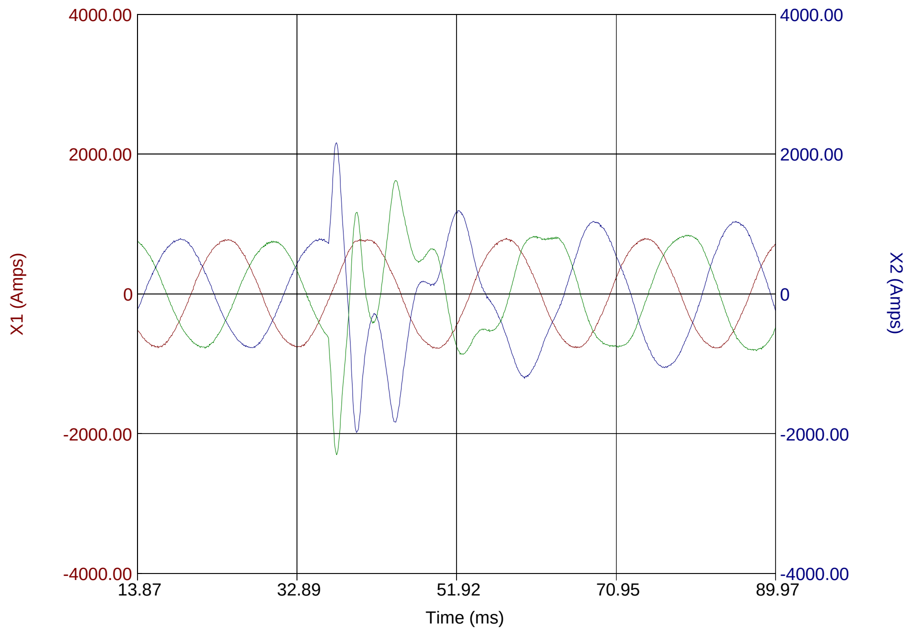

Figure 6. Current waveform after reactor installation.

A clamping circuit acts to reduce excess voltage transferred to the DC link during a voltage transient. These voltage transients are normally caused by capacitor bank switching but can be created by other switching operations. In this case, the switching on of the induction heater generated a voltage transient. The clamping circuit contains a resistor and a solid-state switch, which are connected across the DC bus of the ASD. Once the voltage reaches a certain level, the switch closes, reducing the excess voltage to keep it from overcharging the DC bus. To apply the clamping circuit, the resistor must be sized so that it can carry rated current for the DC bus. For example, the resistor is equal to DC bus voltage divided by the rated current. The line reactor in front of the drive is sized based on the current rating of the drive.

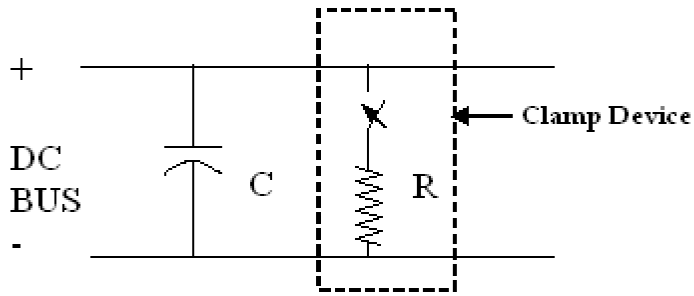

Figure 7. Clamping circuit.

A clamping circuit was installed on two different process lines where ASDs were tripping. The PQ engineer first performed a test of the DC bus clamping circuit on a 15-HP ASD in the first process line by setting a sophisticated PQ monitor to record the voltage waveforms. The monitor was set up to monitor the three-phase AC input and the DC bus voltage of the ASD. It was programmed to trigger on the voltage transient that was created by the induction heater. The ASD already had a 3% line reactor in place (see Figure 8). Figures 9 and 10 are graphs of an overvoltage transient before and after the installation of the clamping circuit. The ASD tripped with a recorded DC bus overvoltage of 830 V without the clamping circuit. With the clamping circuit in place, the highest DC bus voltage recorded was 78 0V. There were no ASD trips during a 1.5-hour period with the clamping circuit installed.

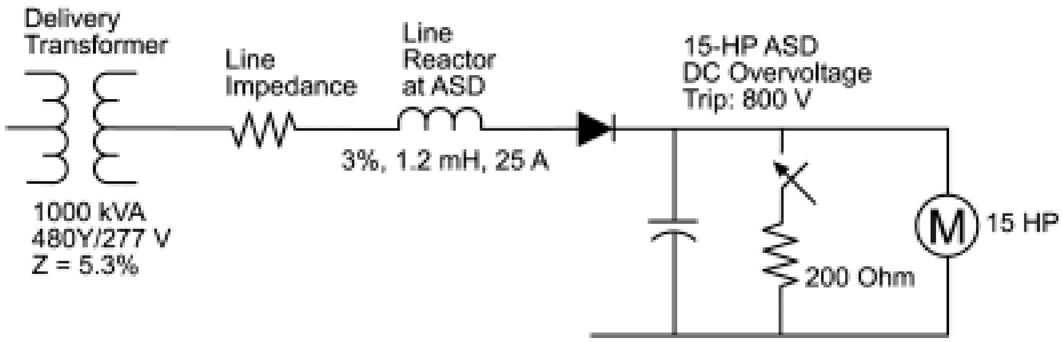

Figure 8. 15-HP ASD with 200-ohm clamping circuit.

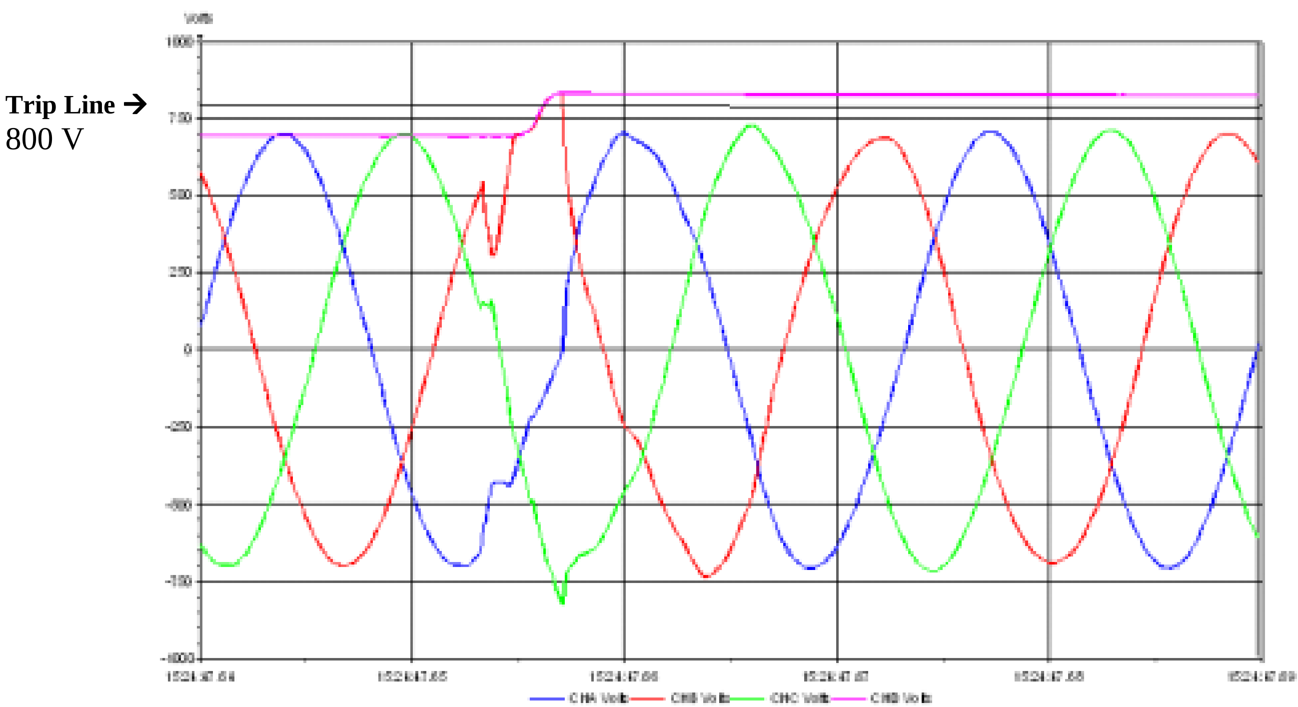

Figure 9. Without clamping circuit.

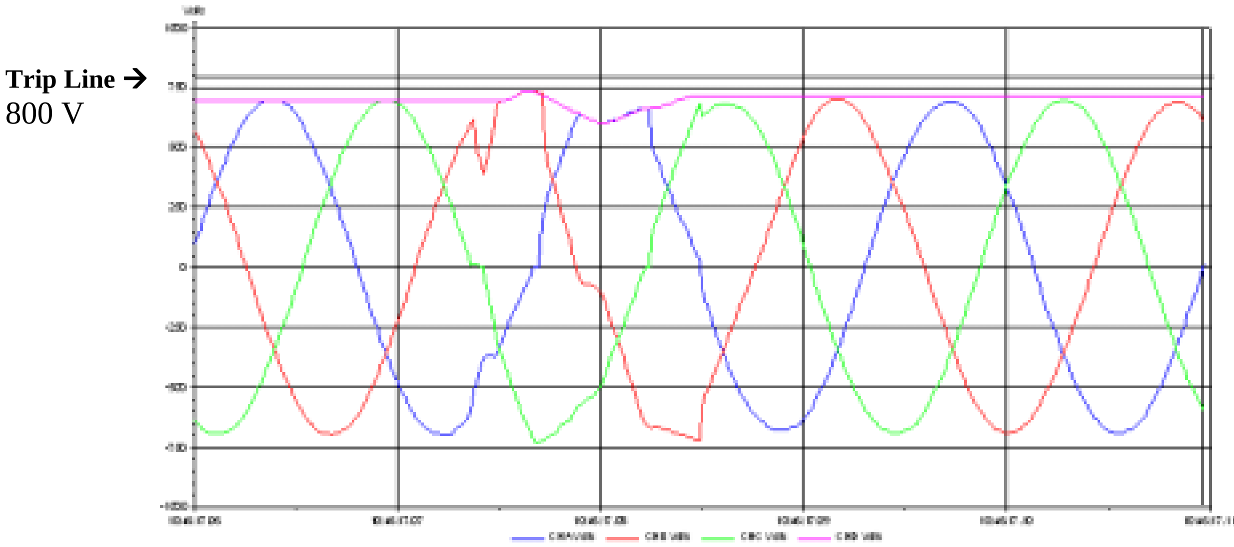

Figure 10. With clamping circuit.

For the next process line, a clamping circuit was installed on a 1.5 hp ASD which had no input line reactors. The ASD still tripped repeatedly even with the claming circuit installed. Since the 15 hp ASDs had line reactors installed, the PQ engineer suspected that line reactor might help in this case. A 3% line reactor was added to each phase of the 1.5 hp ASD (Figure 10). Monitoring was performed with a sophisticated PQ monitor to verify the results of the clamping circuit and line reactors (Figures 11a and 11b). For the second process line, an input line reactor was required to add some impedance in order to drop some voltage for the clamping circuit. Figure 11b shows the performance of the clamping circuit with the input line reactors. From testing and recorded data, the addition of the line reactors prevented the 1.5 hp ASD from tripping.

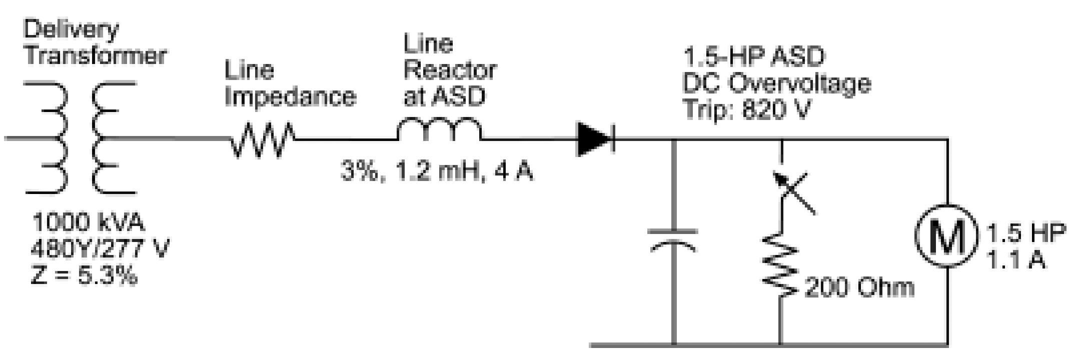

Figure 11. 1.5 hp ASD with 200 ohm clamping circuit.

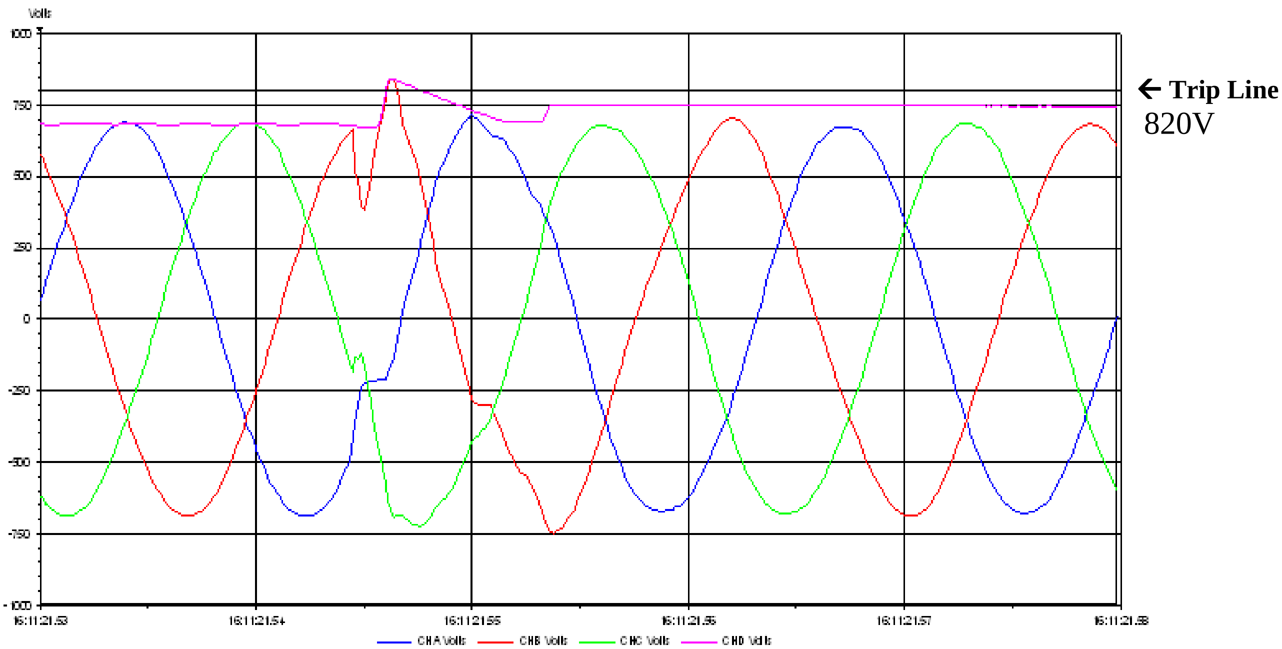

Figure 12. DC bus voltage with clamping circuit and no line reactor (ASD trips).

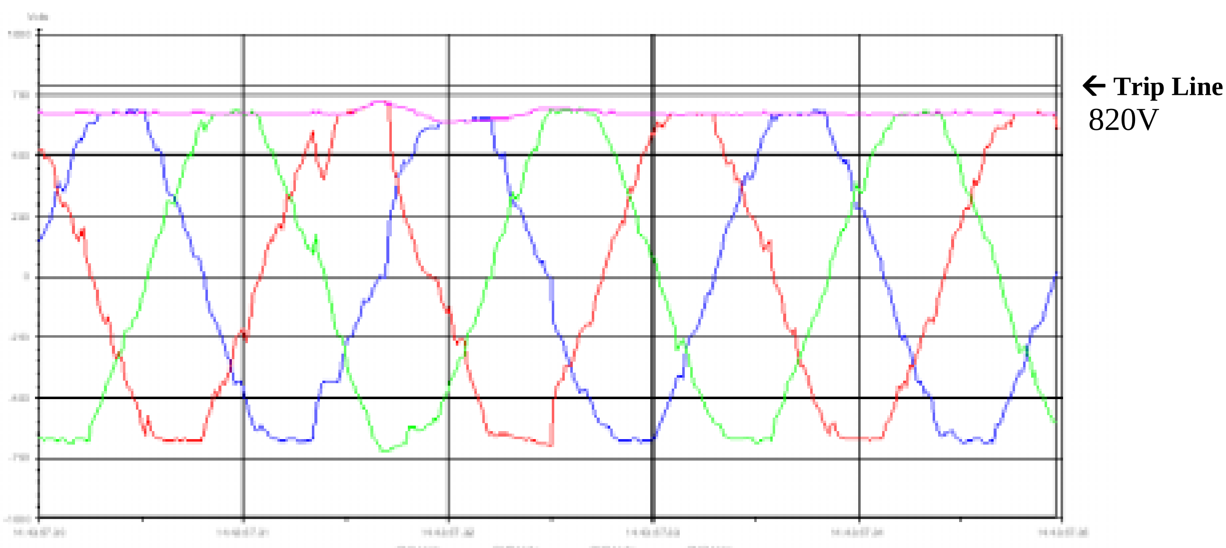

Figure 13. DC bus voltage with clamping circuit and line reactors (no ASD trip).

In conclusion, the PQ engineer did not find any voltage imbalance problems but did find that the induction heater created high overvoltage transients that were affecting other equipment in the plant. To eliminate the problems caused by these transients, he added line reactors to the heater and added clamping circuits and line reactors to the ASDs that were tripping. The UPS loads were moved to another delivery transformer to isolate them from the induction heater. The clamping circuits and line reactors kept the ASDs from tripping by removing excess energy from the DC bus before the trip level was reached. Line reactors on the heater prevented relays from dropping out in the plant, while isolating the UPSs from the induction heater solved the problem of frequent transfer to battery. These solutions allowed the customer to keep the single-phase induction heater in operation without impacting other equipment in the plant.