

AC SYSTEM MONITORING DEVICE

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OVERVIEW

The alternating current (AC) system monitoring device is used to monitor voltages on AC power systems. These devices are also known as programmable logic controllers (PLCs), and are used in industry for power distribution control and system automation. The AC system monitoring device will use digital processing to monitor and control AC systems. Digital processing removes the need for the traditional electro-mechanical controls used throughout industry for the last 60 years, resulting in improved system reliability.

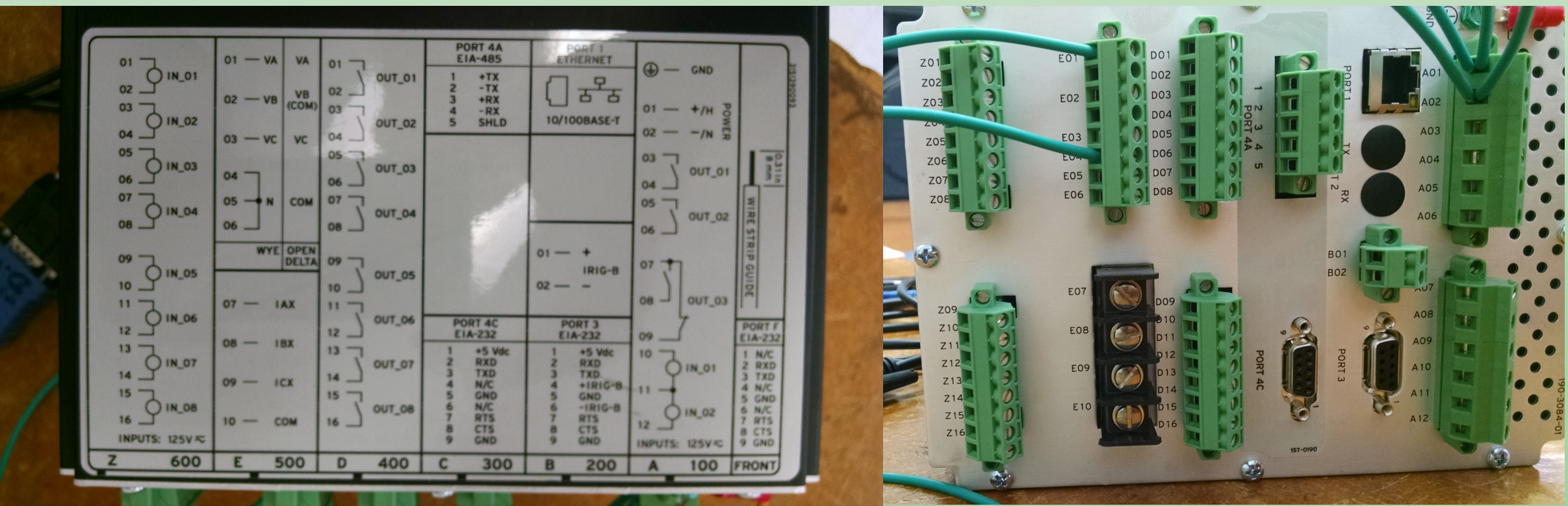
OBJECTIVE

The project will cover the design of a device to monitor an AC power system and provide power factor correction. Specifically this project will have the objective of building a device that will monitor AC voltage, AC current, and power factor. Additional functionality of the device would include power factor correction by adding capacitors in parallel with inductive loads.



SEL-2411 PROGRAMMABLE AUTOMATION CONTROLLER

The SEL-2411 programmable automation controller is also referred to as a programmable logic controller in industry. Programmable logic controllers allow the user to define logic to be easily programmed into the device for the desired application. This controller has the ability to customize the inputs and outputs as required for a particular application. Utilizing a three-phase power card for the SEL-2411 permits obtaining AC voltage and AC current data. The device also includes electrical-mechanical switches to control the relays used in the switching of capacitors for power factor correction.

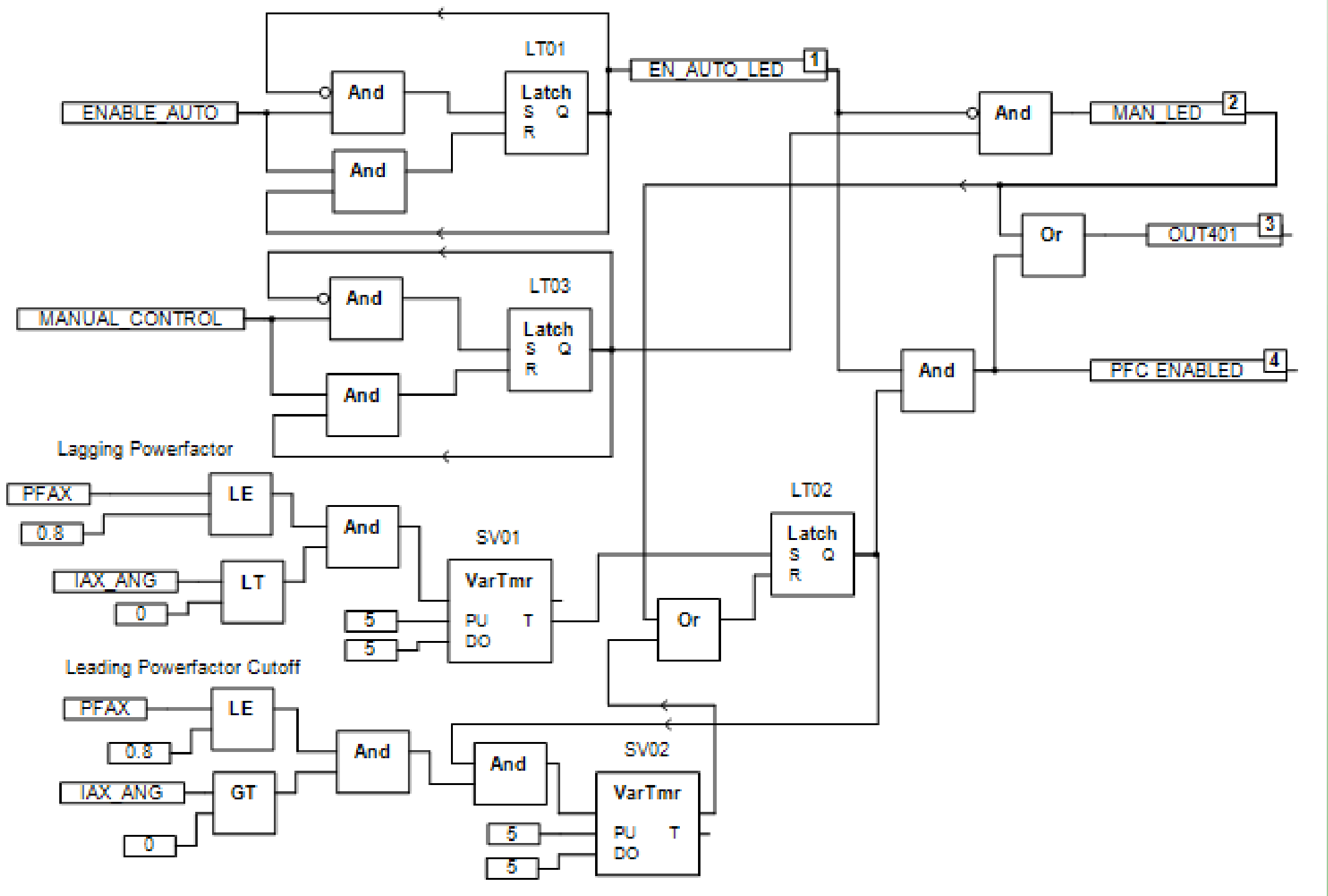
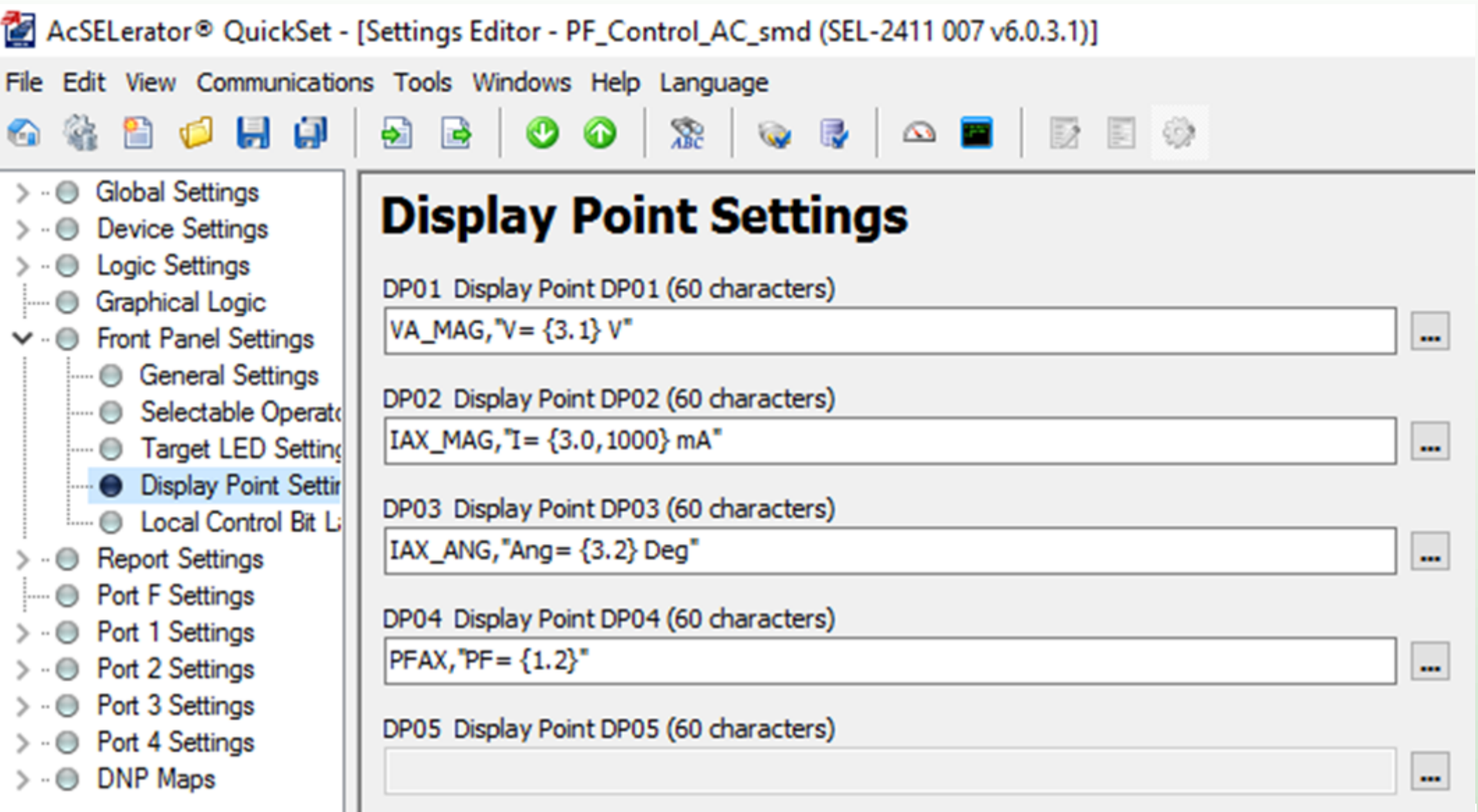


RESISTIVE INDUCTIVE LOAD

A resistive and inductive load was used in the testing of the device to provide the need for power factor correction. In this design motors or dynamometer systems were avoided because the dynamometers available in lab were intended to be run only for short periods and were therefore unsuited for long term testing.

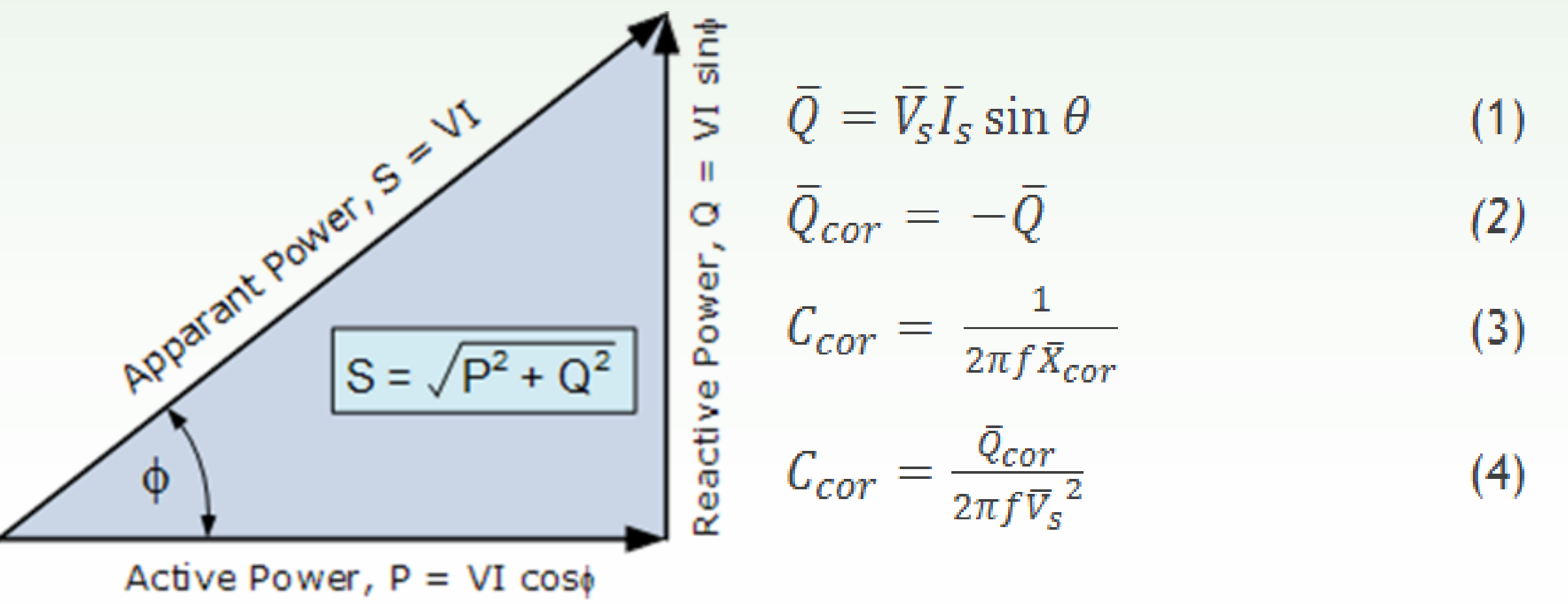
MONITORING AC SYSTEM

The monitoring of the AC system was performed by the SEL-2411 programmable automation controller. The logic control for the SEL-2411 programmable automation controller utilizes SEL's own proprietary software to program the device. The software to be used in the programming of the device is called AcSElerator QuickSet® and can be downloaded and installed for no license fee. The software allows users to simply program logic "settings" to produce personal logic schemes. One of the key tools used was the graphical logic designer to convert a visual logic scheme to the logic "settings" registers of the controller.

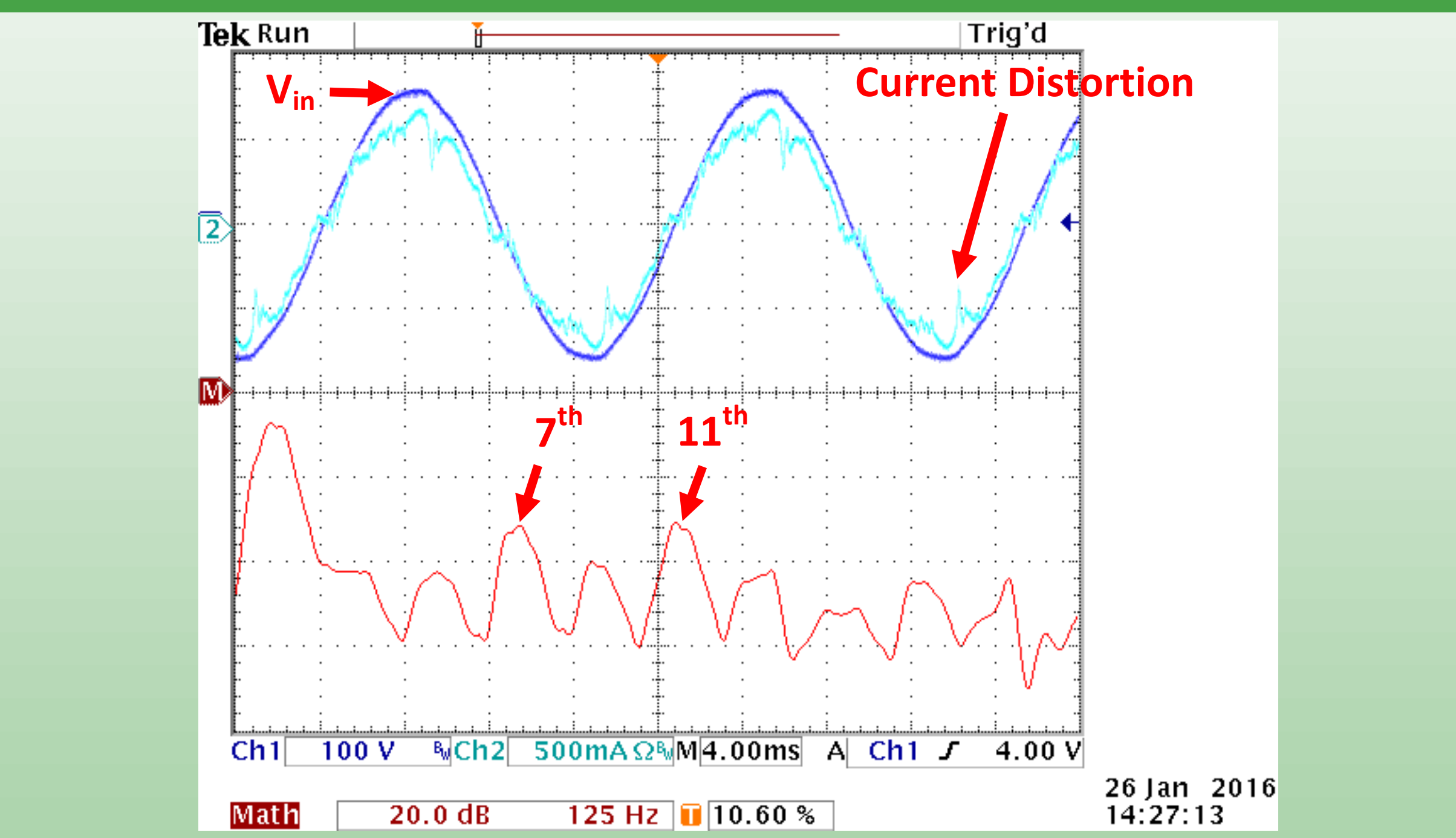
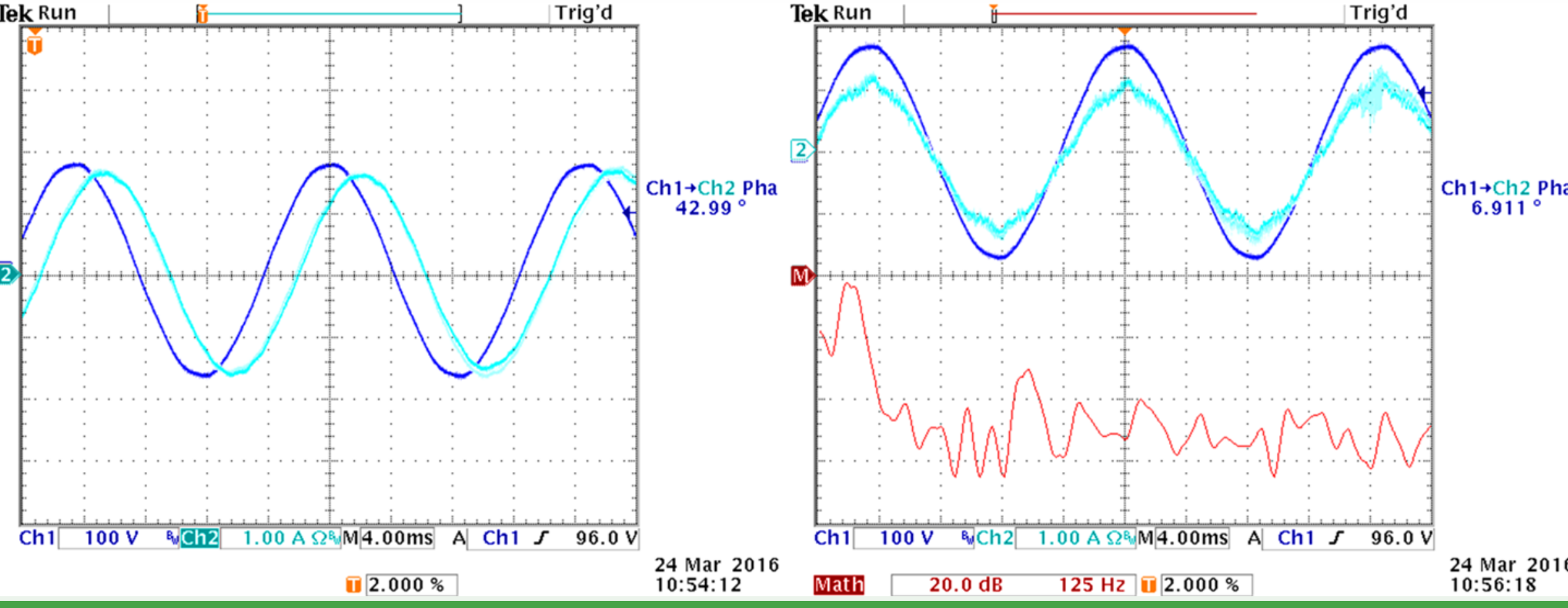


POWER FACTOR CORRECTION

The power factor correction utilized capacitor banks connected to relays to be switch them off and on across the AC system. This was controlled by the SEL-2411 programmable automation controller with outputs to the relays. Sizing of the capacitor banks required calculation of the initial load and power factor of the circuit being used. To find the capacitance required for power factor correction, the reactive power of the load needed to be calculated. Equation 1 was used to find the reactive power using the apparent power and the phase shift between the voltage and current. The corrective reactive power will be equal and opposite to the inductive reactive power as shown in equation 2. The required capacitive reactance then will be used to solve for the needed capacitance using equation 3 (which simplifies to equation 4).



Testing of the power factor correction shows that the source current is reduced and the source voltage and current are in phase. The active power consumed was reduced from the original 125 watts to 39 watts.



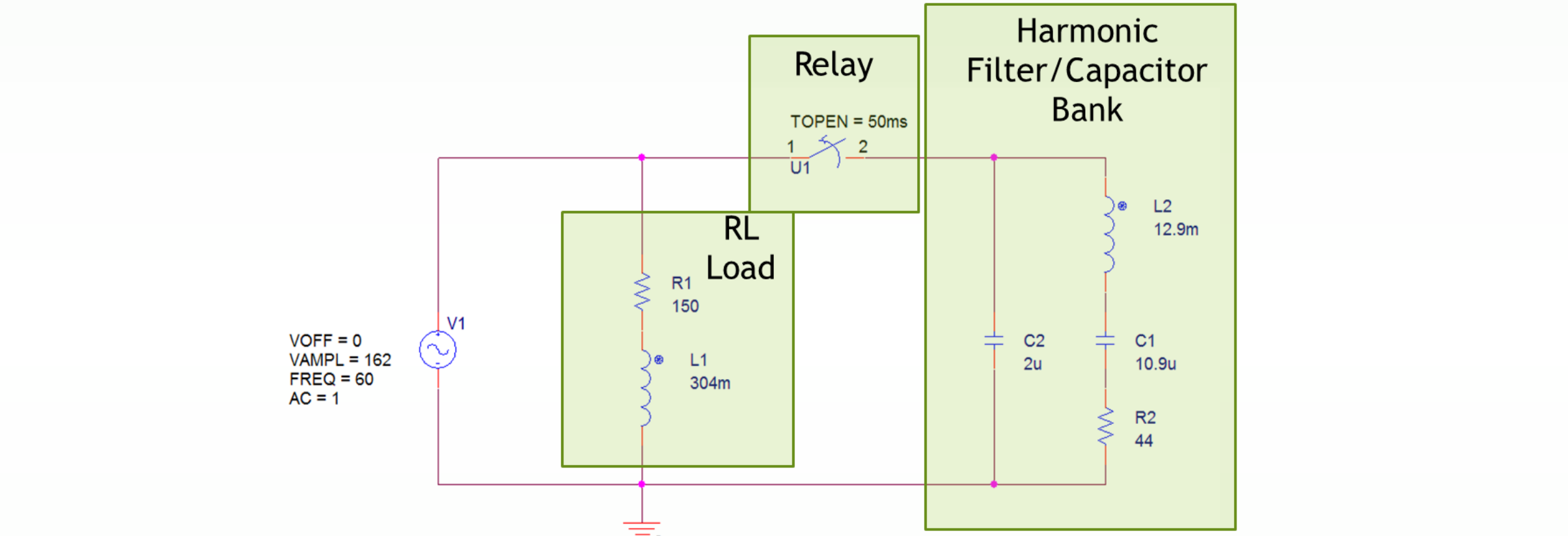
UNEXPECTED CURRENT DISTORTION

Current distortion was introduced by performing power factor correction on the RL Load. Analysis determined harmonic distortion was introduced by the power factor correction system. The most prominent harmonics were the 7th and 11th.

DESIGN FOR HARMONIC FILTERING

Excessive amounts of current distortion introduced in to the AC system would not be ideal as it could result in stability issues of equipment used on the line. A common solutions used in industry is to use harmonic filters to provide a lower impedance at specific tuned frequency so the harmonics can be filtered out of the system. The design selected for the harmonic filter was an RLC circuit tuned to the 7th harmonic. Using the resonance frequency for RLC circuit shown in equation 5, it was tuned to the 7th Harmonic (420Hz). The capacitors available in the laboratory were used to compute the required inductance. The bandwidth of the filter was controlled by a 44Ω variable resistor. Equation 8 was used to determine the pass band of the harmonic filter.

$$\omega = \sqrt{\frac{1}{LC}} \Rightarrow L = \frac{1}{\omega^2 C} \quad (5)$$
$$\omega = 2\pi f_0 h = 2\pi(420\text{Hz}) = 2639 \frac{\text{rad}}{\text{s}} \quad (6)$$
$$L = \frac{1}{\left(2639 \frac{\text{rad}}{\text{s}}\right)^2 10.9 \times 10^{-6} \text{F}} = 13.19 \text{mH} \quad (7)$$
$$Q = \sqrt{\frac{L}{C}} \rightarrow \delta = \pm \frac{1}{2} Q = \pm \frac{1}{2} \cdot \frac{\sqrt{\frac{0.01319 \text{H}}{10.9 \times 10^{-6} \text{F}}}}{44 \Omega} = \pm 39.5\% \rightarrow (252\text{Hz}, 588\text{Hz}) \quad (8)$$



Testing of the harmonic filter frequency response with low voltage indicated that the filter was tuned to the designed frequency. Testing with the RL load showed that the harmonics were reduced. The harmonic filter in this testing showed that the source current increased with the harmonic filter, but provided power factor correction. The increased source current resulted in an increase in the active power usage, but reduced the reactive power in the system.

