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DESIGN AND IMPLEMENTATION OF MICROCONTROLLER-BASED CONTROLLING OF POWER FACTOR USING CAPACITOR BANKS WITH LOAD MONITORING

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In this research work, an automatic power factor correction (APFC) technique is presented to improve power factor of industrial loads to the desired value. Power factor is corrected to provide relief to utility by supplying required reactive power demand of load locally. The improvement of power factor of industrial customer will reduce customer monthly bill as well as will escape from financial penalty being imposed by utility owing to his low power factor. Different power factor correction (PFC) techniques exists, however we have proposed a new scheme of PFC using PIC microcontroller (18F452) chip. A microcontroller based algorithm is developed to measure power factor of load and examine the similarities or differences with the set referenced value of power factor to switch in required value of capacitors to correct the power factor of load to desired value. The developed scheme in perspective of controlling the power factor has a main advantage of choosing the direct value of capacitor that is needed to correct the necessitate amount of reactive power in order to cater the current utilization by the load. The prevailed results have affirmed that the developed scheme is able to yield a desirable power factor and can be furthermore pursued in practical applications.

Keywords: Power Factor Correction, Zero Cross Detection (ZCD), Microcontroller, Capacitor bank, Inductive load.

Nomenclature

ACPF	Automatic controlling of Power Factor
PFC	Power factor correction
ZCD	Zero-cross detection
ZC	Zero crossing
ADC	Analog to digital converter
PIC	Programmable Interface Controller
LCD	Liquid Crystal Display

1. Introduction

Low Power Factor in the power distribution system induces the energy crisis in the supply voltage. Most of industrial electric loads have a low power factor not transcending from 0.8 and thus imparts to the distribution losses [1-4]. There are different methods of low power factor correction [1]. One of the approaches is to use a fixed capacitor as a source of reactive power for compensating local reactive power demand [5-6]. This approach is more reliable because it implies the count of lagging current in the power factor with very precise step setting in term of calculating the phase angle in power factor correction schemes [7].

Power factor correction is an old practice and different researchers are working hard to design and develop new system for the power factor correction. Fuld et al. developed a combined power factor control with buck and boost technique applied at three phase input supply, which present necessitate vantages at high AC voltage, desired output voltage, e.g. 400 V, wide input voltage varieties and no extra inrush current required [8]. Freitas et al. developed a dynamical study corresponding to the effects of AC generators (induction and synchronous machines) and distribution static synchronous compensator devices on the dynamic behavior of distribution networks [9]. Jones and Blackwell developed a technique for sustaining a synchronous motor at unity power factor (or minimum line current) from no-load to full-load conditions, assuring peak efficiency. This concept stemmed from an adaptation of Energy Saver Power Factor Controller for induction motors [10]. Kim et al. proposed a high-efficient line conditioner with excellent performance. The line conditioner comprises of an indirect type ac-ac converter, which functioned as a boost converter and a buck

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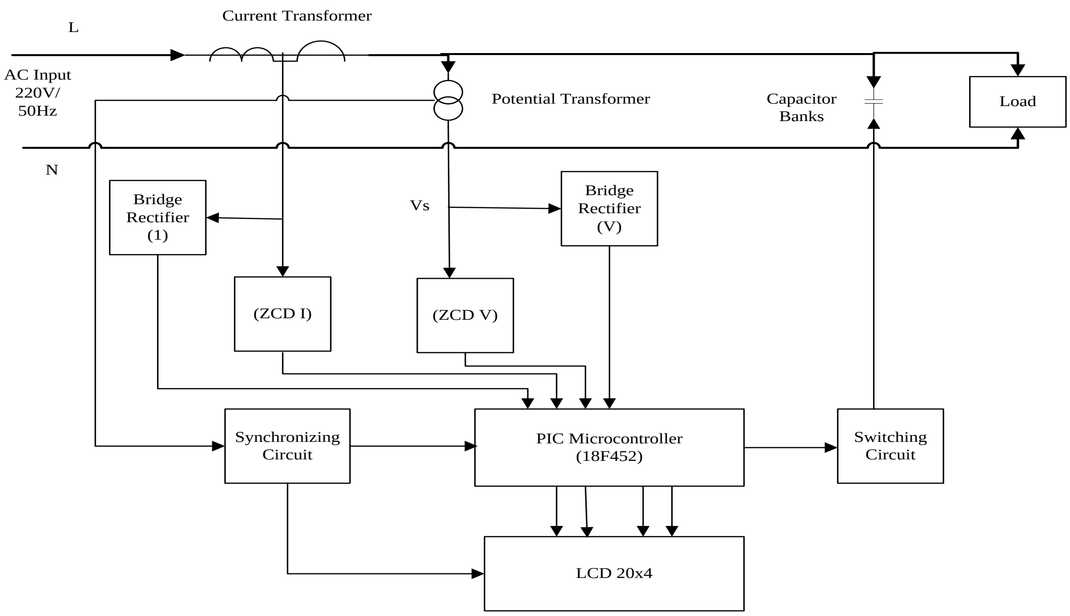

Figure 1. Block Diagram of Automatic Controlling of Power Factor (ACPF).

converter [11]. Kiprakis and Wallace proposed the entailment of the enhanced capability of the synchronous generators at the distant ends of rural distribution networks where the line resistances were high and the (cosφ) or the power factor ratios were small. Local voltage variation was specifically analyzed [12].

Above described research work and much more has been presented in the area of power factor improvement of inductive load. However, we have proposed a new algorithm for automatic detection and controlling of Power Factor for an inductive load comprising of both induction motors as well as resistive load. Proposed algorithm alongwith developed hardware setup works efficiently. Moreover, detection and correction of power factor is very fast. Microcontroller manipulates the developed algorithm to measure the needed reactive power that will be supplied through automatic switching of capacitor banks for the improvement of power factor of the load.

2. Proposed System of ACPF

Microcontroller based automatic controlling of power factor with load monitoring is shown in Figure 1. The principal element in the circuit is PIC Microcontroller (18F452) that runs with 11MHz crystal in this scheme. The current and voltage signal are acquired from the main AC line (L) by using Current Transformer and Potential Transformer. These acquired signals are then passed on to the zero crossing detector IC(ZCD I & ZCD V) individually that transposed both current and voltage waveforms to square-wave to make it perceivable to the Microcontroller to observe the zero crossing of current and voltage at the same time instant. Bridge Rectifier for both current and voltage signals transposes the analog signal to the digital signal. Microcontroller read the RMS value for voltage and current used in its algorithm to select the value of in demand capacitor for the load to correct the power factor and monitors the behavior of the enduring load on the basis of current depleted by the load. Synchronizing circuit is developed to synchronize the zero cross detection circuit, Microcontroller and LCD with incoming supply voltage. In case of low power factor Microcontroller send out the signal to switching unit (relay) that will switch on the in demand value of capacitor. The tasks executed by the Microcontroller for correcting the low power factor by selecting the in demand value of capacitor and load monitoring are shown in Liquid Crystal Display (LCD).

Figure 2 represents the zero crossing detector circuit utilized for the detection of zero crossing behavior of line voltage and current.

The output of the zero crossing detector circuit is shown in Figure 3.

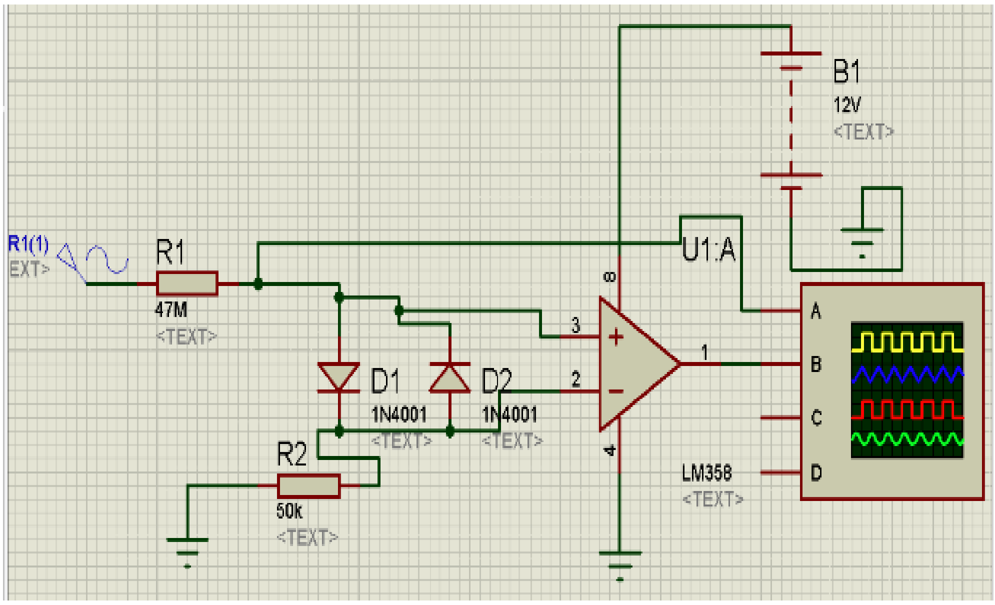

Figure 2. Zero crossing detector.

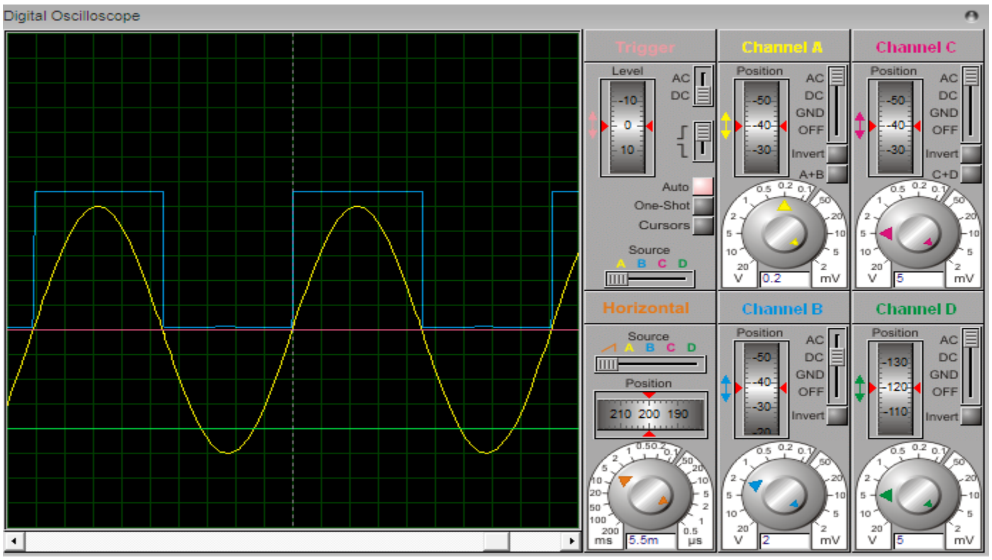

Figure 3. Zero crossing detector circuit output.

3. Microcontroller Algorithm Scheme

Microcontroller pretends as brain of the Automatic Controlling of Power Factor using Capacitor Banks with Load Monitoring circuit. For the analysis of voltage and current signals, Microcontroller through microcontroller's capture module ccp1(for voltage ZC) and ccp2 (for current ZC) measure the phase delay between the voltage and current square-waves yielded by the zero crossing detector IC. Microcontroller observes the rising edge of the square-waves of both the signals at same time instant. The time lag evaluated by the Microcontroller is in terms of power factor of the enduring load. After the evaluation of power factor of the load, the RMS value of current and voltage signals is read by the Microcontroller. The low power factor included with current and voltage signals are corrected in the algorithm of the Microcontroller. Microcontroller automatically select the in demand value of capacitor to amend the power factor of the load to desired value. The instructions of the Microcontroller monitor the behavior of the running load on the basis of current depleted by the load and the results were shown on LCD.

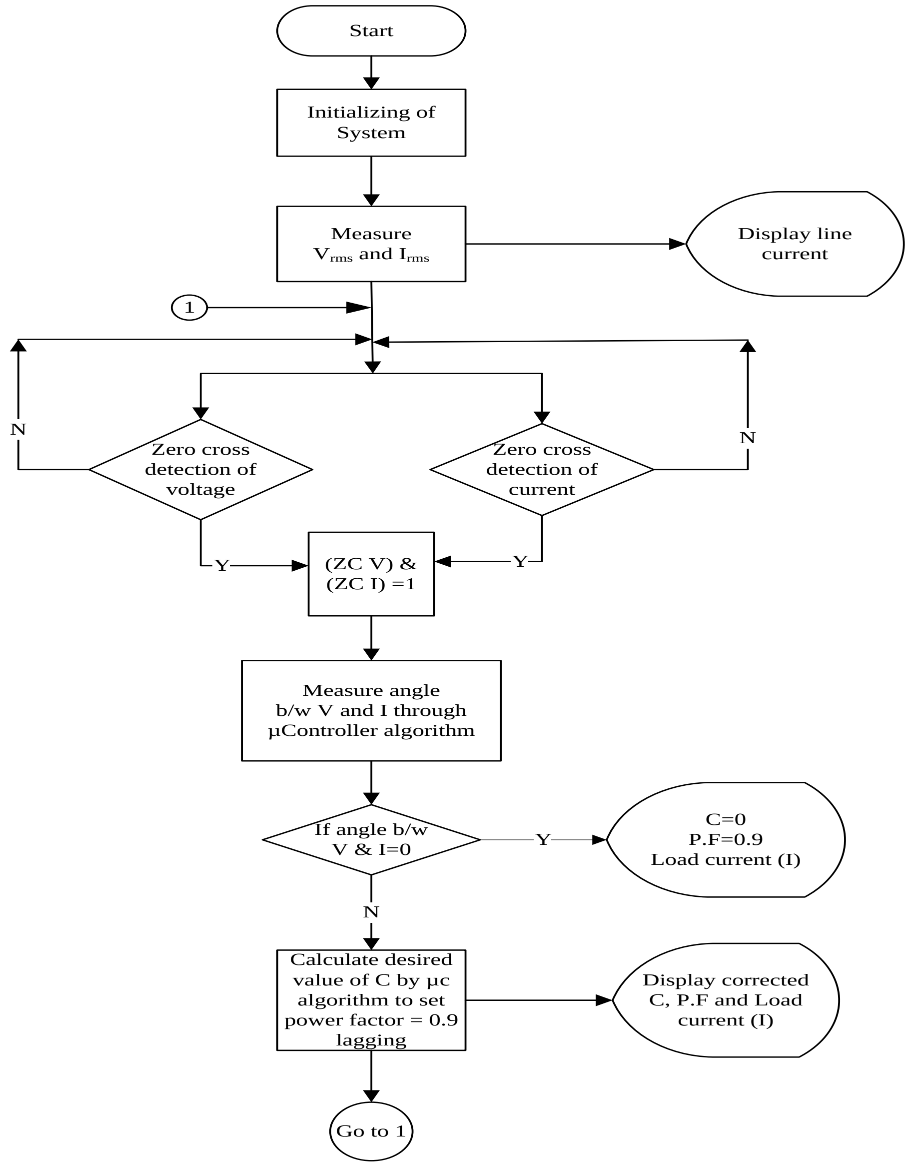

Figure 4. Flow Chart of the proposed ACPF.

Figure 4 shows the flow chart of the proposed automatic power factor controlling and load monitoring of the load. In the flow chart, the first step is about the initializing the ACPF circuit. Microcontroller measures the line voltage V_{rms} an I_{rms} through ADC pins (AN_0 and AN_1) on real time basis. The voltage and current signals which have been converted into square waves after zero crossing are provided to Microcontroller input pins (RC_1 and RC_2) that are fundamentally the input of capture module of the Microcontroller. If the zero crossing of voltage and current signals acquired by the Microcontroller points out that V and I signals are not in phase and power factor of load is less then set referenced value of 0.9 lagging then Microcontroller instructs for switching action to involve the required value of capacitor to counterbalance the power factor of running load through developed Microcontroller algorithm to set reference value. Microcontroller does not execute any action if both the voltage and current square-waves provided to capture module of the Microcontroller's pin are in phase or the measured power factor is 0.9 set as referenced value. LCD displayed the measured values of low power factor, corrected power factor, required value of capacitor to correct the power factor.

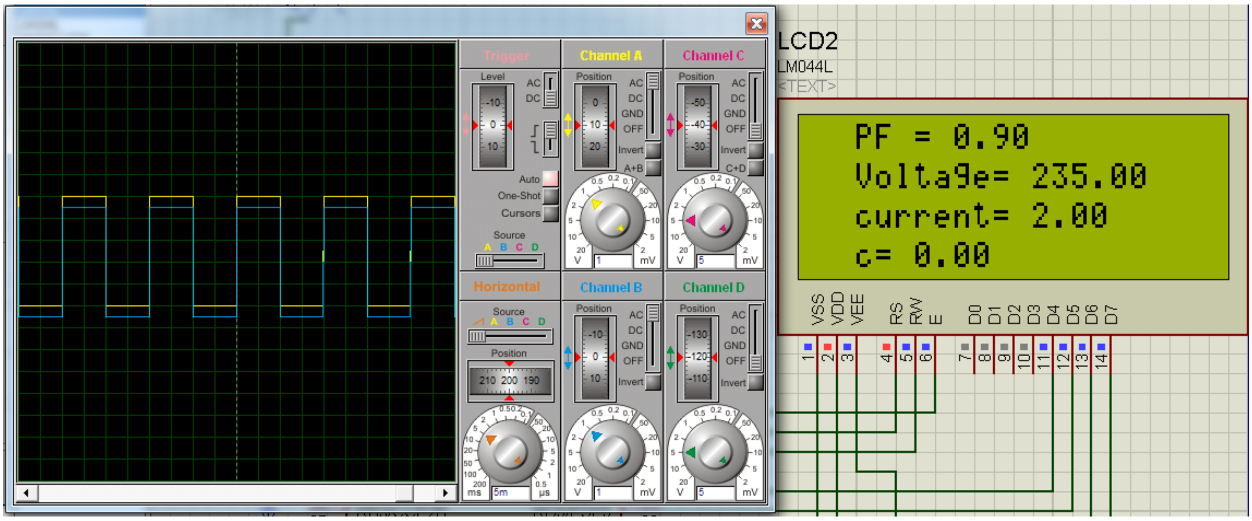

Figure 5. Simulation results with resistive load (400W).

In the above flow chart of the proposed ACPF:

V_{rms} and I_{rms} are read by the Microcontroller using ADC ports.

After the zero crossing of voltage and current signals, which are converted to square-waves, are provided to Microcontroller.

Power Factor is measured by the Microcontroller by the manipulation of capture module for V and I signals.

Real Power is measured as

$$P = I_{rms} V_{rms} \cos\varphi \tag{1}$$

Phase angle (θ_1) detection is done by taking the cos inverse of quantities'/ terms used in equation 1.

Set the cos θ_2 as a reference value of power factor equal to 0.9 and take the cos inverse of 0.9 to get reference value of (θ_2).

From the power angle diagram, the reactive power (VAR) utilized in circuit is given as:

$$VAR_1 = P \times \tan\theta_1 \tag{2}$$

Reference VAR are calculated as

$$VAR_2 = P \times \tan\theta_2 \tag{3}$$

Required reactive power of the load is:

$$VAR = VAR_1 - VAR_2 \tag{4}$$

Current required for new VAR by load is:

$$I_{required} = \frac{VAR}{V_{rms}} \tag{5}$$

Required value of impedance X_c is:

$$X_C = \frac{V_{rms}}{I_{required}} \tag{6}$$

Required capacitor to improve the power factor for Inductive load is given as:

$$C = \frac{1}{2\pi f X_C} \tag{7}$$

4. Simulation Results and Discussion

Automatic controlling of power factor is completely tested on Proteus software in which simulation result are based on the lagging power factor of the load. Following are the simulations results which includes different cases of resistive and inductive load.

Case 1: When resistive load (400W) is ON:

When a resistive load of 400W is ON, both the current and voltage signals are in phase as shown in Figure 5. In this case the power factor would be 0.9 as the set referenced value, so there is no insertion of capacitors. By the developed Microcontroller algorithm, this 0.9 power factor shows unity power factor in actual.

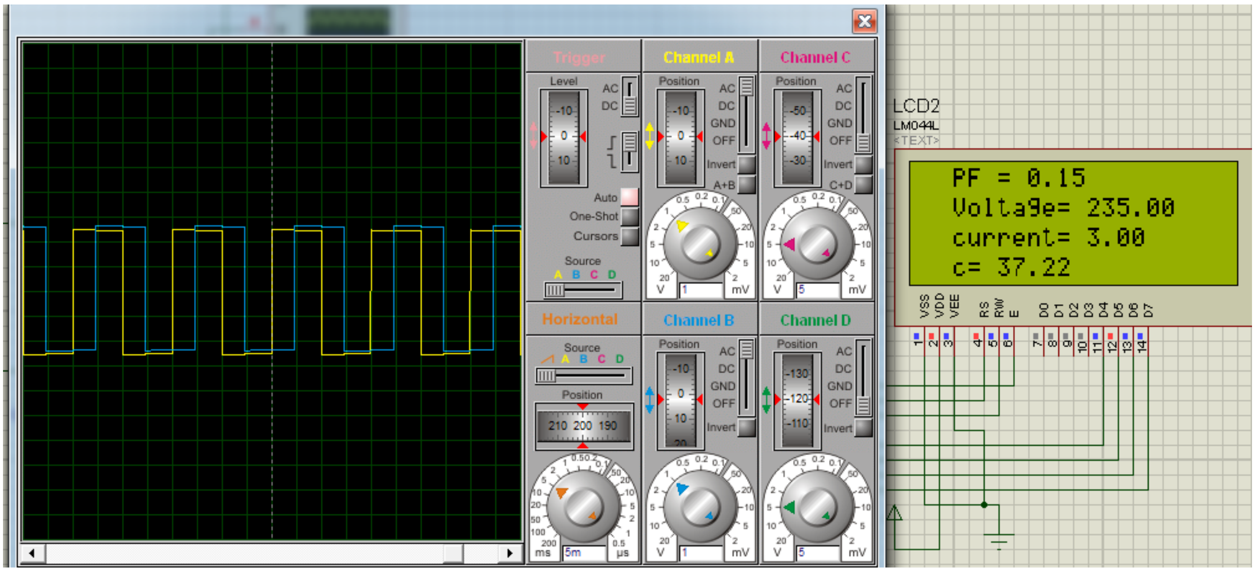

Figure 6. Simulation results with low inductive load (0.5 hp induction motor).

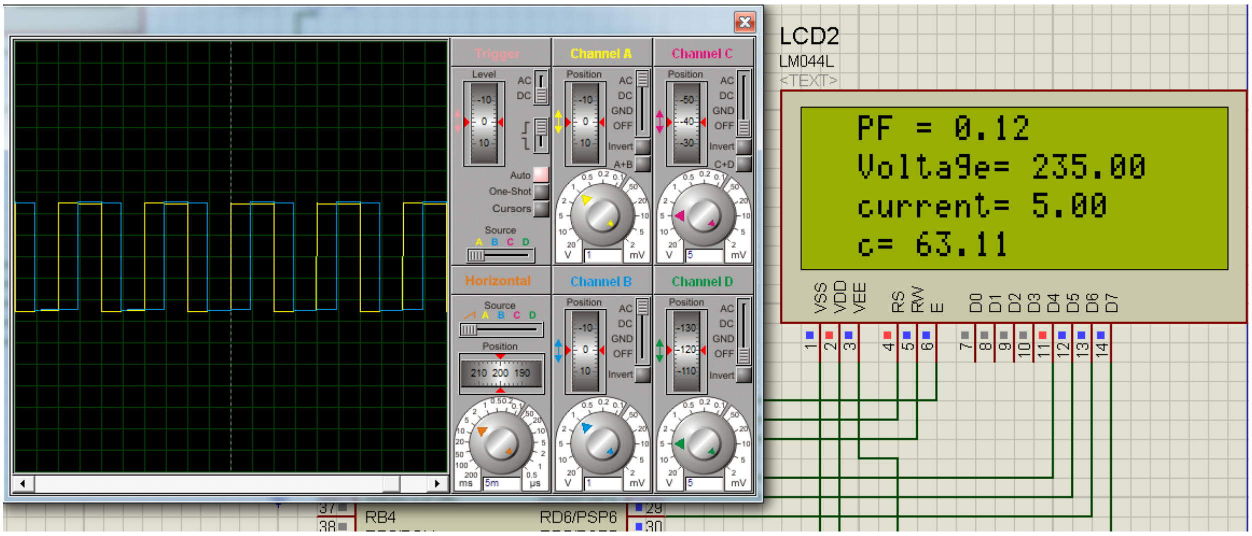

Figure 7. Simulation results with increased inductive load (1 hp induction motor).

Case 2: When 0.5hp induction motor is ON:

When an inductive load of 0.5hp induction motor is ON, there is phase delay in between current and voltage signals as shown in Figure 6. Microcontroller senses the delay produced by the load, and according to the delay, it inserts the desired value of capacitor by the developed Microcontroller algorithm to improve the power factor of the system to desired value.

Case 3: When 1hp induction motor is ON

When an inductive load of 1hp induction motor is ON, there is large phase delay in between current and voltage signals as shown in Figure 7. Microcontroller senses the delay produced by the load, and according to the delay, it inserts the desired value of capacitor by the developed of Microcontroller algorithm to improve the power factor of the system to desired value.

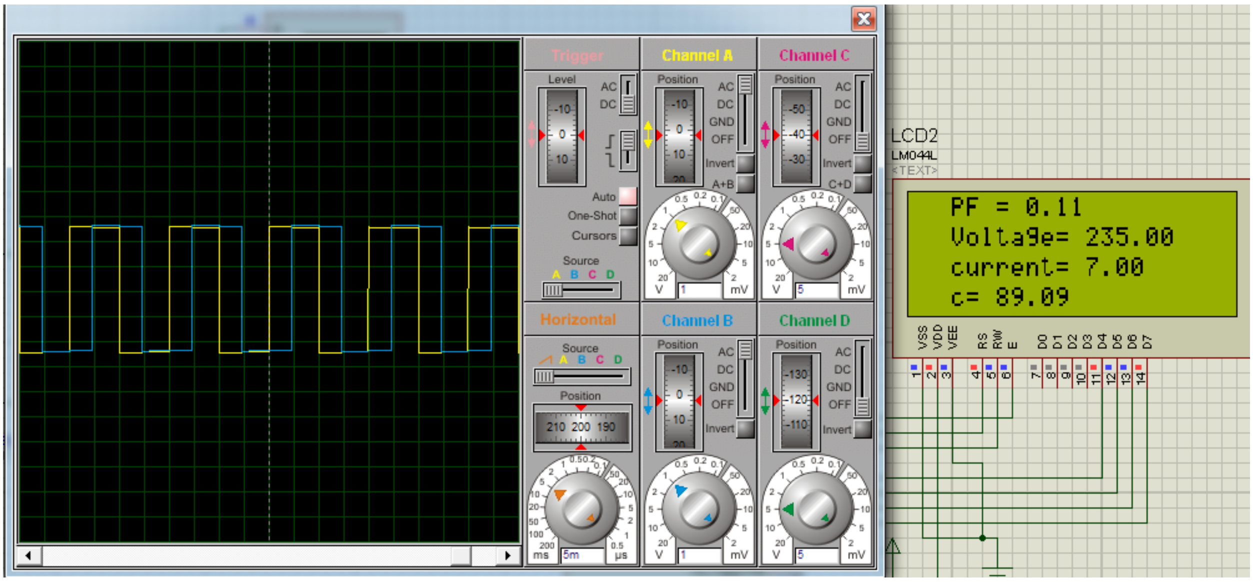

Figure 8. Simulation results with increased inductive load (1.5 hp induction motor).

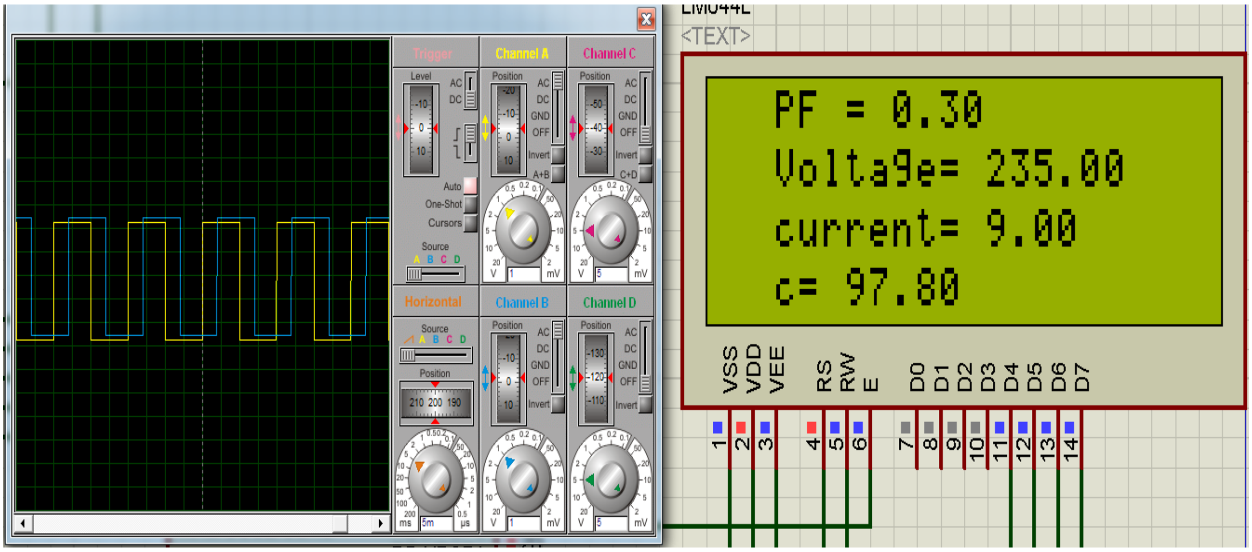

Figure 9. Simulation results with both resistive and inductive load (400W and 1.5 hp induction motor).

Case 4: When 1.5hp induction motors are ON:

When an inductive load of (1.5hp) is ON, there is an increased large phase delay in between current and voltage signals as compared to 1 hp induction motor load and is shown in Figure 8. Microcontroller senses the delay produced by the load, and according to the delay, it inserts the desired value of capacitor by the developed Microcontroller algorithm to improve the power factor of the system to desired value.

Case 5: When both resistive and inductive load are ON:

When both resistive (400W) and inductive load (1.5hp) is ON, phase delay between current and voltage signals is shown in Figure 9. Microcontroller senses the delay produced by the load, and according to the delay, it inserts the desired value of capacitor by the developed Microcontroller algorithm to improve the power factor of the system to desired value.

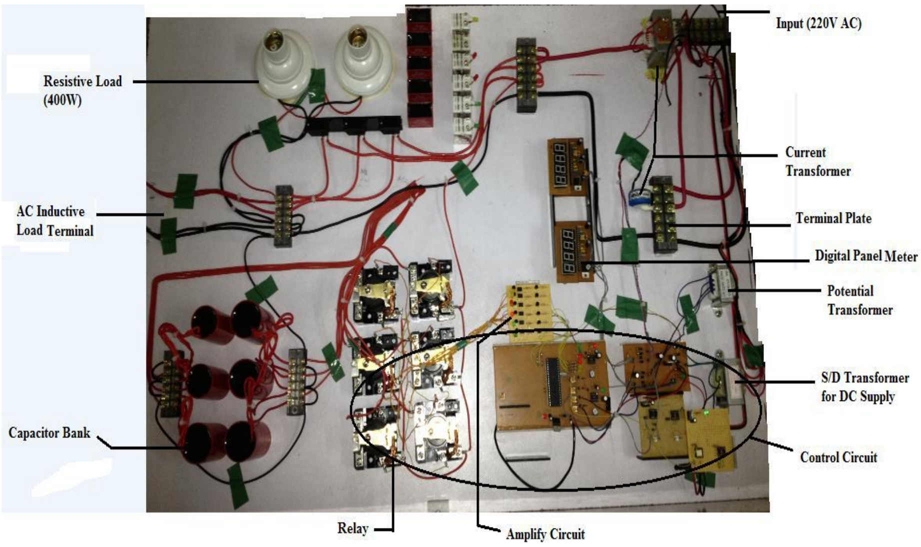

Figure 10. Hardware Prototype.

5. Hardware Results and Discussion

Main prototype model of the hardware is shown in Figure 10.

Whole system may be divided into three stages.

First stage is of concern with the step down arrangement of the incoming voltage and current signals into the PIC voltage level (e.g. 5V). Here we have used the step down arrangement of the transformer.

Second stage is concerned with zero crossing level detection by using an IC (LM358) for voltage and current, the incoming signals. Voltage signal can be acquired by using Opto-coupler (IC # 4N25) at the output of Potential Transformer for detection. Current signal can be acquired by using Current Transformer connected at main AC line.

In the third stage, Automatic power factor control with continuously load monitoring of the system is done using hardware prototype of Figure 10. The main part of the circuit is Microcontroller (18F452) with crystal of 11MHz.

After acquiring voltage and current signals, they are then passed through the zero cross detector block (ZCD V and ZCD I), that converts both voltage and current waveforms in square-wave that are further provided to microcontroller to detect the delay between both the signals at the same time instant. Two bridge rectifier circuits are utilized to convert both AC voltage and current signals into pulsating DC signals that are further provided to ADC pin of Microcontroller for their conversion into digital signals, so that the microcontroller performs its further necessary task. After this, the checking of RMS value for voltage and current is performed, these values are used in the algorithm of Microcontroller to select the capacitor of desired value to counteract the effect of low power factor of the load and monitor continuously which load is operated on the basis of current consumed by the load. Results of corrected power factor, selected capacitor value to correct the low power factor to desired value are shown on the LCD.

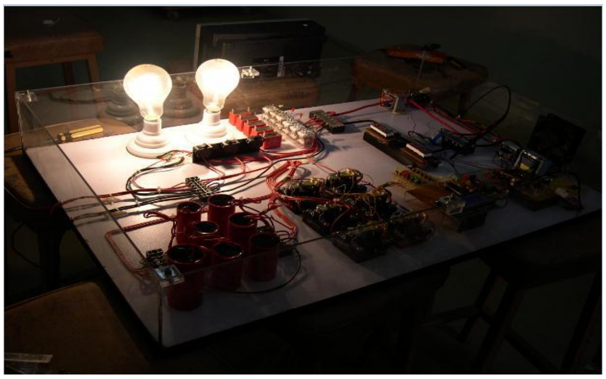

Figure 11. Hardware model with resistive load.

Case 1: When resistive load (400W) is ON:

When resistive load is ON, as shown in Figure 11, there is no phase delay between current and voltage signals and they are in phase as shown in Figures 12 and 13.

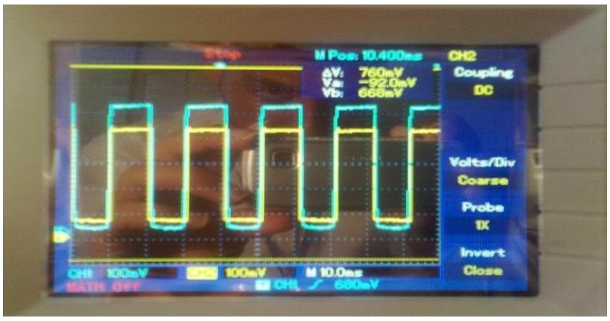

Figure 12. Zero crossing detection for resistive load.

In case of resistive load , as both V and I are in phase so there is no insertion of capacitors to improve power factor as shown in Figure 13. In this case the power factor would be 0.9 as referenced value.

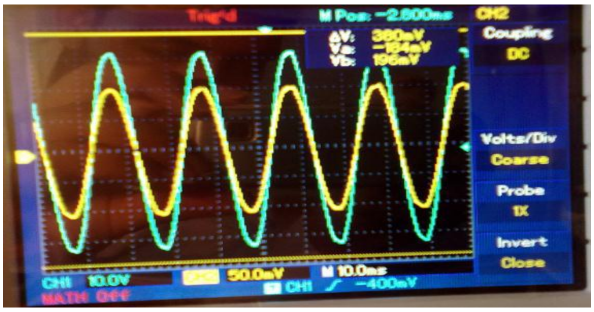

Figure 13. V and I behavior for resistive load.

The load monitoring of resistive load by microcontroller is shown on LCD in Figure 14.

Figure 14. Load monitoring for resistive load.

Case 2: When 0.5hp induction motor is ON

When an inductive load of 0.5hp motor is ON, there is phase delay between voltage and current signals, as shown in Figure 15. Microcontroller senses the delay produced by the load, and according to the delay, it inserts the desired value of capacitor to improve the power factor of the system as shown in Figure 18.

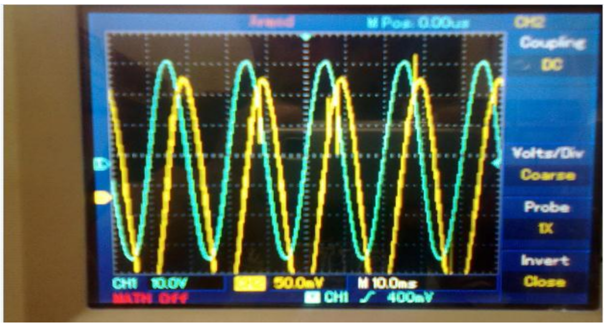

Figure 15. V and I behavior before correction with 0.5hp inductive load.

The zero-crossing detection of V and I signals for 0.5hp induction motor is shown in Figure 16.

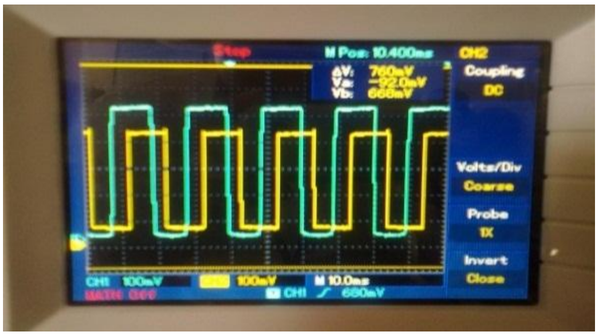

Figure 16. Zero crossing detection before correction with 0.5hp inductive load.

The load monitoring of 0.5hp induction motor is shown in Figure 17.

Figure 17. Load monitoring for 0.5hp inductive load.

According to the phase delay in signals, microcontroller takes the intelligent decision and adds the desired value of capacitor (35.842µF) as shown in Figure 18.

Figure 18. LCD showing selected value of ‘C’ for desired PFC.

When the desired value of the capacitors added the required reactive power to the system, the current and voltage waveforms are in phase, as shown in Figure 19.

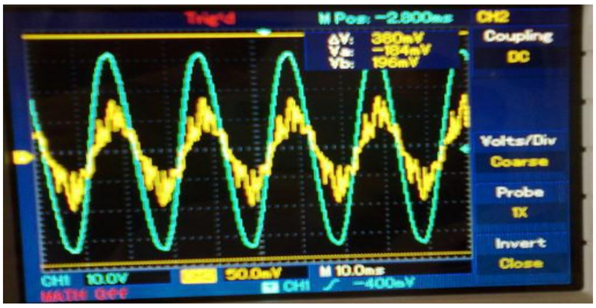

Figure 19. V and I behavior after PFC with 0.5hp inductive load.

After the insertion of required value of capacitor, the V and I zero cross detector signals are also in phase in accordance with the set referenced value of power factor (0.9 lagging).

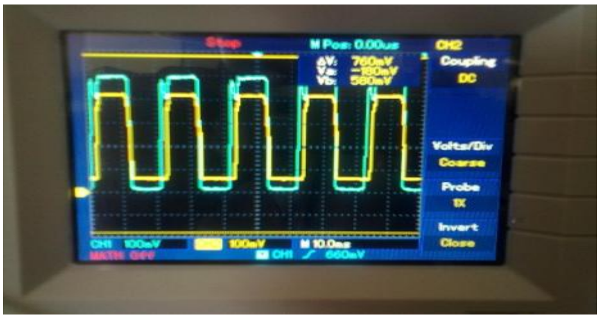

Figure 20. Zero crossing detection after correction with 0.5hp inductive load.

Case 3: When 1hp induction motor is ON

When an inductive load of 1hp motor is ON, there is phase delay in between current and voltage signals, as shown in Figure 21. Microcontroller senses the delay produced by the load, and according to the delay, it inserts the desired value of capacitor to improve the power factor of the system.

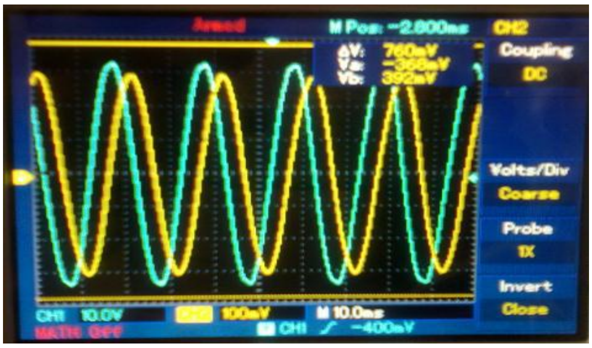

Figure 21. V and I behavior before correction with 1hp inductive load.

The zero-crossing detection of V and I signals for 1hp induction motor is shown in Figure 22.

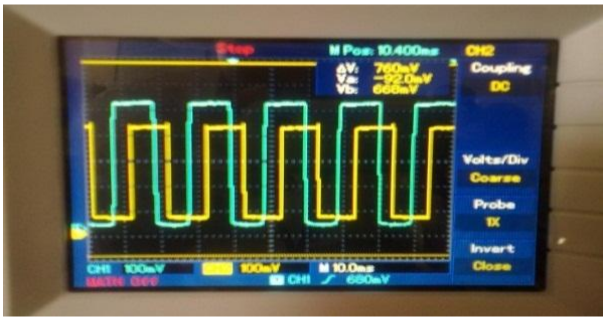

Figure 22. Zero crossing detection before correction with 1hp inductive load.

The load monitoring of 1hp inductive load is shown in Figure 23.

Figure 23. Load monitoring for 1hp inductive load.

According to the phase delay in signals, microcontroller takes the intelligent decision and adds the desired value of capacitor (58.148µF) as shown in Figure 24.

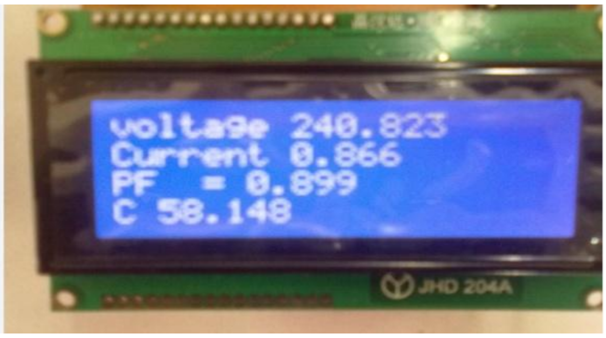

Figure 24. LCD showing selected value of ‘C’ for desired PFC.

When the desired value of the capacitors added the required reactive power to the system, the current and voltage waveforms are in phase in accordance with the set referenced value of power factor (0.9 lagging), as shown in Figure 25.

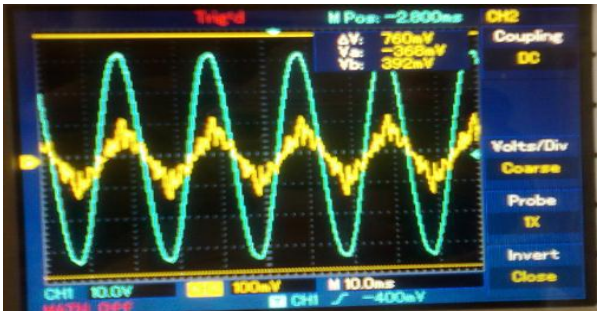

Figure 25. V and I behavior after correction with 1hp inductive load.

After the insertion of in demand value of capacitor, the V and I zero cross detector signals are also in phase as per set referenced value of power factor (0.9 lagging).

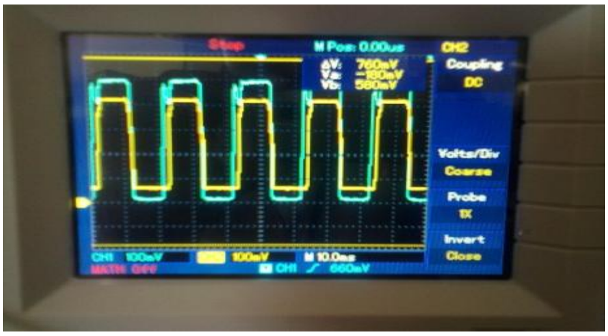

Figure 26. Zero crossing detection after correction with 1hp inductive load.

Case 4: When both 0.5hp and 1hp motors are ON

When an inductive load of 1hp and 0.5hp motors are ON, there is phase delay in between current and voltage signals, as shown in Figure 27. Microcontroller senses the delay produced by the load, and according to the delay, it inserts the desired value of capacitor to improve the power factor of the system.

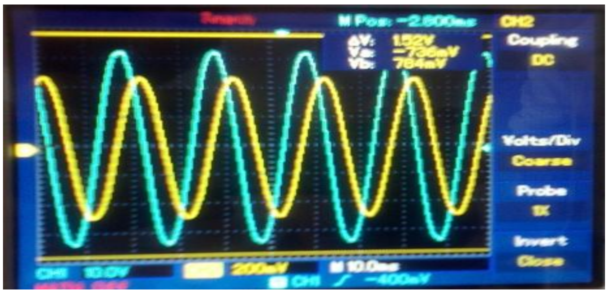

Figure 27. V and I behavior before correction with 1.5hp inductive load.

The load monitoring of 1.5hp inductive loadis shown in Figure 28.

Figure 28. Load monitoring for 1.5hp inductive load.

According to the phase delay in signals, microcontroller takes the intelligent decision and adds the desired value of capacitor (92.982 μF) as shown in Figure 29.

Figure 29. LCD showing value of ‘C’.

When the desired value of the capacitors added the required reactive power to the system, the current and voltage waveforms are somehow in phase as per set referenced value of power factor (0.9 lagging), as shown in Figure 30.

Figure 30. V and I behavior after correction with 1.5hp inductive load.

After the insertion of in demand value of capacitor, the V and I zero cross detector signals are also in phase as per already set referenced value of power factor (0.9 lagging).

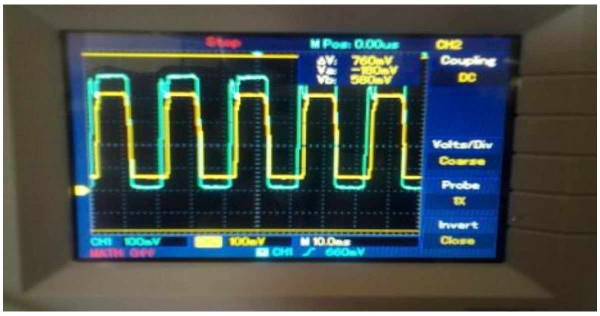

Figure 31. Zero crossing detection after correction with 1.5hp inductive load.

Case 5: When both resistive and inductive load are ON:

When both inductive and resistive loads is ON, there is phase delay in between current and voltage signals,as shown in Figure 32. Microcontroller senses the delay produced by the load, and according to the delay, it inserts the desired value of capacitor to improve the power factor of the system.

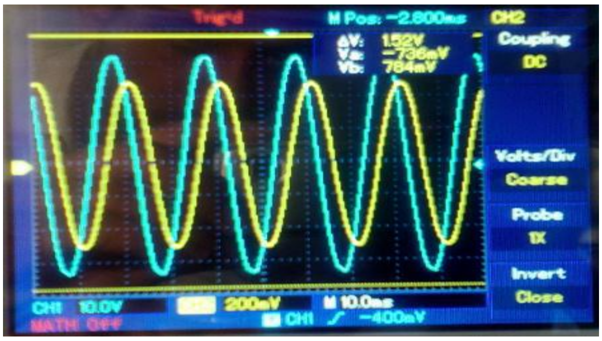

Figure 32. V and I behavior before correction with resistive and inductive load.

The load monitoring of resistive and inductive loads are shown in Figure 33.

Figure 33. Load monitoring for resistive and inductive load.

When the desired value of the capacitors added the required reactive power to the system, the current and voltage waveforms are somehow in phase as per set referenced value of power factor (0.9 lagging), as shown in Figure 34.

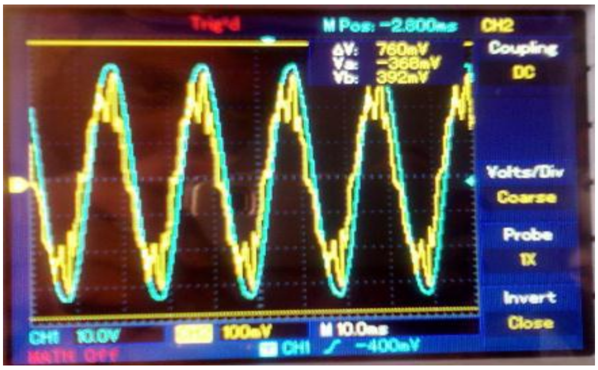

Figure 34. V and I behavior after correction with resistive and inductive load.

According to the phase delay in signals, microcontroller takes the intelligent decision and adds the desired value of capacitor (92.982 µF) as shown in Figure 35.

Figure 35. LCD showing selected value of ‘C’ for desired PFC.

6. Conclusions

This project work is carried out to design and implement the automatic power factor controlling system using PIC Microcontroller (18F452). PIC Microcontroller senses the power factor by continuously monitoring the load of the system, and then according to the lagging behavior of power factor due to load it performs the control action through a proper algorithm by switching capacitor bank through different relays and improves the power factor of the load. This project gives more reliable and user friendly power factor controlling system by continuously monitoring the load of the system. Measuring of power factor from load is achieved by using developed algorithm for PIC Microcontroller. It determines and trigger sufficient switching of capacitors in order to compensate demand of excessive reactive power locally, thus bringing power factor near to desired level.

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