Microcontroller Based Power Factor Controller Using Static VAR Compensator

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Abstract- **Power factor correction (PFC) is a technique of counteracting the undesirable effects of electric loads that create a power factor that is less than one. Power factor correction may be applied either by an electrical power transmission utility to improve the stability and efficiency of the transmission network or correction may be installed by individual electrical customers to reduce the costs charged to them by their electricity supplier. In order to improve transmission efficiency, power factor correction research has become a hot topic. Many control methods for PFC have been proposed. This paper proposes the design and development of a power factor corrector using PIC (programmable interface controller) microcontroller chip. This involves measuring the power factor value from the load using PIC and proper algorithm to determine the sufficient firing angle to trigger the TRIAC in order to compensate excessive reactive components, thus bringing power factor near to unity.**

Index Terms- **Static VAR compensator (SVC), power factor controller, thyristor controlled reactor (TCR), energy saving, microcontroller PIC 16F877A.**

I. INTRODUCTION

The deterioration in power system quality is caused mainly by the use of constant growth of nonlinear loads, which essentially contain loads such as induction motor, arc furnaces, transformers, etc., Electric power quality is an area of study that includes methods or devices designed to maintain a near sinusoidal voltage waveform, at the rated voltage magnitude and frequency for power systems. Also an adequate reactive-power support is important to improve the electrical grid stability. Loads such as induction motor, arc furnaces, etc., are inductive in nature and hence have low lagging power factor. There are different methods of power factor correction implemented with large lagging or leading nonlinear loads [l]. The most conventional methods used to improve power factor is group of capacitors connected in parallel and synchronous condenser (i.e. synchronous motor when operated in over-excited mode). The capacitor bank allows a step by step control of the reactive power delivered by group of capacitors though Synchronous condensers in comparison provides smooth control of reactive power but it requires substantial amount of foundation, starting and protective equipment. Synchronous condensers cannot be controlled fast enough to compensate for rapid load changes due to large time constant of their field circuit and they have much higher losses. One of the new approaches is to use a variable inductor in parallel with a fixed capacitor as a reactive power compensating circuit [5-6]. In this method the reactive power taken from the supply can be regulated continuously by appropriately controlling the firing angle of TCR from π/2 to π or in other words the source power factor gets improved from lagging to leading as the firing angle is progressively adjusted from π/2 to π. The SVC is characterized by continuous control, low losses, redundancy, and flexibility. The main concept behind controlling TCR is the control of the firing instant of the thyristor to control the current in the reactor, thus controlling the reactive power absorbed by the TCR.

The adjustment of the thyristors' firing angle involve measuring the power factor value from the load using microcontroller and developing proper algorithm to determine the desired firing angle to control the current flowing through TCR in order to compensate excessive reactive components, thus bringing power factor near to unity. The system can adjust the supplied system power factor to almost any required reference value. The proposed power factor correction scheme will be designed to operate with most of the possible lagging or leading values of the load power factor. This shows the adaptability of this power factor corrector.

This paper proposes a real-time microcontroller (PIC 16F877A) based power factor correction scheme for low power factor loads. The hardware and software required to implement the suggested adaptive power factor correction scheme are explained, and its operation is described in the following sections.

II. BLOCK DIAGRAM AND DESCRIPTION

The block diagram of the microcontroller based power factor corrector is shown in Figure 1. Microcontroller 16F877A with a crystal frequency of 4 MHz is used in the proposed scheme. The static compensator employed in the system is a parallel combination of fixed capacitor and a TRIAC controlled reactor. The TRIAC is used to control the current flow through the inductor. The Load voltage and current signals, taken through a potential transformer and a current transformer, respectively, is applied to zero crossing detectors. Subsequently, the two sinusoidal waveforms are modified to square waves through two zero-crossing detectors as the microcontroller can only detect the digital input signal, or known as pulse. The output pulses obtained from the zero crossing detectors are used to measure the phase displacement between voltage and current (I_L). The detail of zero crossing detectors is depicted in Figure 2. LM339 is a comparator IC which compares the inputs with a reference value and provides the output as pulse.

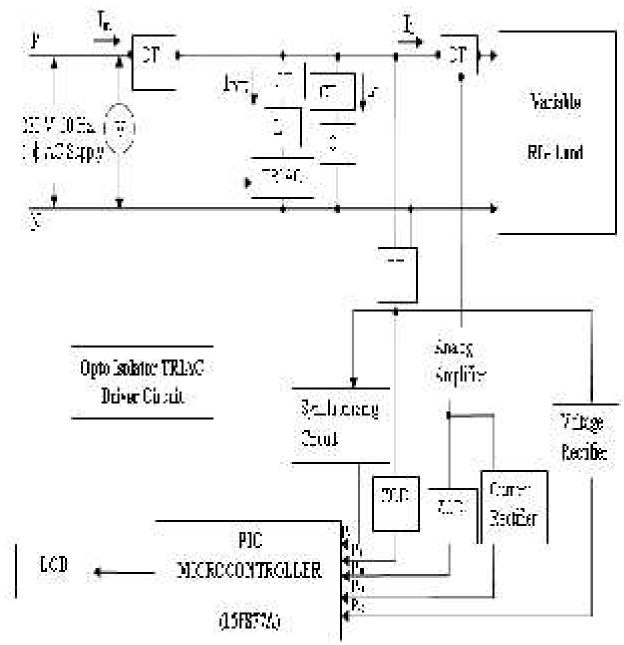


Fig. 1 Overview of the block diagram for the microcontroller-based power factor controller using Static VAR compensator

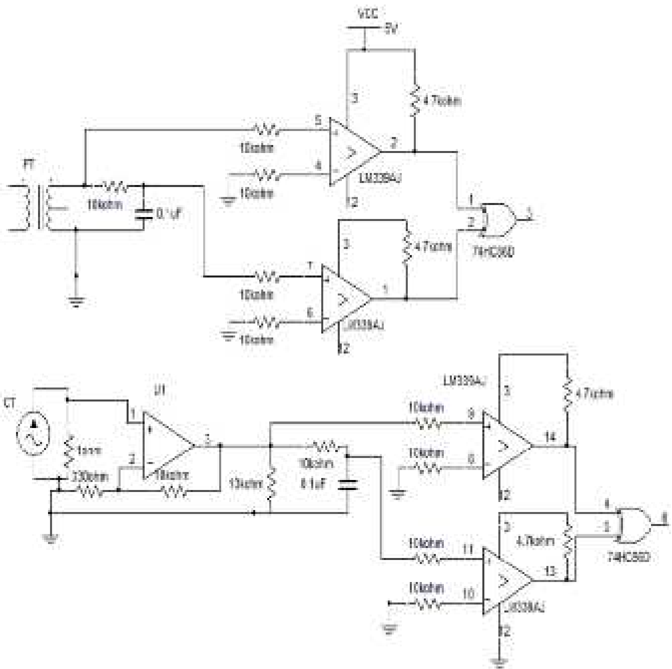


Fig. 2 Zero Crossing Detector

The synchronizing unit produces a pulse at each zero-crossing of the supplied sine wave voltage. The output pulses obtained from the synchronizing unit are applied to the input of microcontroller as a reference in order to achieve a required firing pulse to control the TRIAC firing angle. The pulse signal from the microcontroller drives the gate of the TRIAC so as to control the reactor current. The load phase angle, ϕ_L between the fundamental components of the load voltage and current (V and I_L respectively) is measured by the microcontroller. The measured reactive power is then compared with look up table and that determines the number that is loaded into the programmable interval timer in order to change the firing angle of the TRIAC in the static compensator circuit. These changes should be in the direction that reduces the phase angle ϕ_m between supply voltage and current (V and I_m respectively) to a certain acceptable tolerance value.

III. Control Design Considerations

The Figure 3 shows the circuit diagram for the power factor controller technique using SVC which consists of a variable RL-Load, whose power factor is to be improved and Static VAR Compensator branch, a fixed capacitor in parallel with TCR. The Figure 4 shows the equivalent circuit of SVC. The TCR is used to support the variable-load reactive-power demand by changing the reflected inductance. The main concept behind controlling TCR is the control of the firing instant of the thyristor to control the current in the reactor, thus controlling the reactive power absorbed by the TCR.

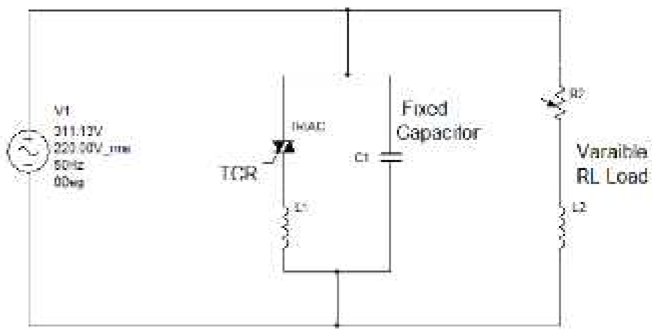


Fig. 3 Circuit diagram for the power factor controller using SVC

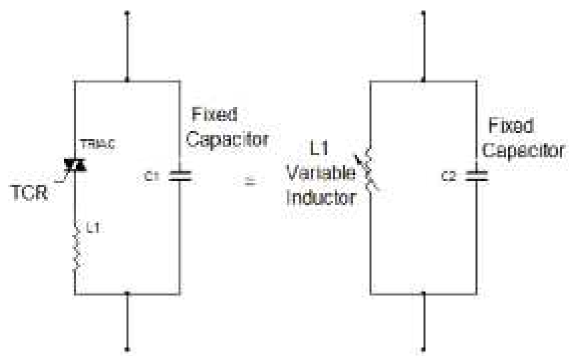


Fig. 4 Equivalent Circuit of SVC

A. Extraction of Firing Angle α

The current flowing through the reactor can be controlled by varying the firing angle of the TRIAC and is given by:

$$I_L = \frac{V}{\omega L} \times \frac{2\pi - 2\alpha + \sin 2\alpha}{\pi} \quad (1)$$

The reflected reactance can be varied and its value as a function of firing angle is given by:

$$L(\alpha) = L\frac{\pi}{2\pi - 2\alpha + \sin 2\alpha} \quad (2)$$

Where the firing angle (α) is bounded as (π/2) < α < π

The Figure 5 shows the variation of reflected reactance with respect to firing angle (α) for L=10 mH, it can be seen from the plot that the reflected reactance is 4 Ω for α = 90^0 and the reflected reactance increases with increase in firing angle, the reflected reactance is ∞ for α = 180^0.

B. Variation of Reactive Power of Static VAR compensator W.R.T Firing Angle

The reactive power (Q) taken from the supply can be regulated continuously by appropriately controlling the firing angle of TCR from π/2 to π or in other words the source power factor gets improved from lagging to leading as the firing angle is progressively altered from π/2 to π.

The reactive power of Static VAR compensator is given by:

$$Q(\alpha) = V^2(B_c - B_L(\alpha)) \quad (3)$$

$$B_c = \omega_0 C \quad (4)$$

The susceptance of TCR as a function of firing angle is given by:

$$B_L(\alpha) = B_L\frac{2\pi - 2\alpha + \sin 2\alpha}{\pi} \quad (5)$$

$$B_L = \frac{1}{\omega_0 L} \quad (6)$$

Where the firing angle (α) is bounded as (π/2) < α < π

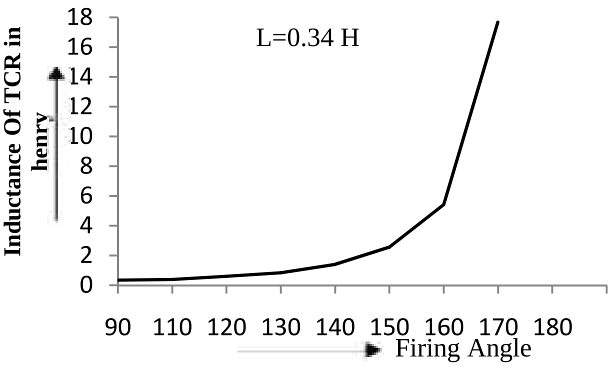


Fig. 5 Curve between TCR reactance vs firing angle

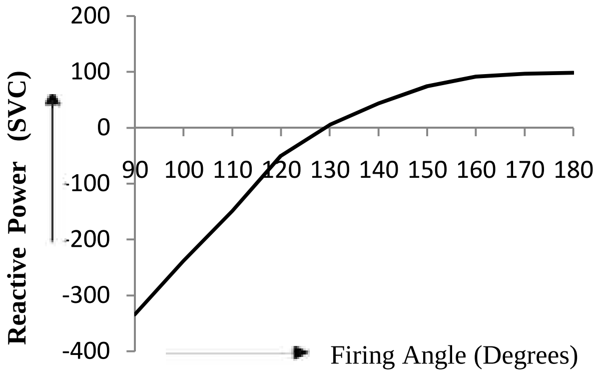


Fig. 6 Curve between reactive power of SVC vs firing angle

The reactive power of the SVC is either positive or negative, as from equation (3) the sign of the reactive power depends on the firing angle of the TCR. If $B_c < B_L(\alpha)$, the sign of the reactive power is negative thus the SVC provides lagging reactive power i.e. the SVC acts as inductive reactance where as if $B_c > B_L(\alpha)$, the sign of the reactive power is positive thus the SVC provides leading reactive power i.e. the SVC acts as capacitive reactance. The figure 6 shows the variation of reactive power of SVC w.r.t firing angle (α).

IV. MICROCONTROLLER ROUTINES

The microcontroller PIC16F877A has five I/O ports, namely PORTA, PORTB, PORTC, PORTD and PORTE. PORTD has eight pins. RD0, RD1 are programmed to operate as input pins, in which the RD0 representing voltage zero crossing detector pin and RD1 representing current zero crossing detector pin, the synchronizing pulse is applied to RB0, which is an external interrupt pin. Meanwhile, the pin RC0 operates as output pin. The microcontroller PIC16F877A has three timers namely TIMER0, TIMER1 and TIMER2. TIMER1 is a 16-bit timer having two 8-bit registers TMR1L and TMR1H.

The flow chart of the program has been developed and is given in Figure 7. Initially the TIMER0 is initialized with TRIAC firing angle of 6ms.

First step is to step down the voltage from higher level to 4V to 5V level which is suitable for PIC. Outcome of input voltage after passing through the diode before enters into pin port (A1 & A2), the diode clipped the negative portion of the sine waveform so that to prevent PIC take in excessive negative voltage. The outcomes of rectified voltage and current are shown in the Fig. 5.2 respectively. At the same time, it drains some voltage hence channels waveform is slightly lower. A series resistor of 10KΩ is connected to analogue channel which acts as a buffer. We take the analog channel 1(RA1) for current measurement and analog channel 2(RA2) for voltage measurement. These analog channels are connected to the inbuilt analog to digital conversion (ADC) module of microcontroller. ADC module converts the analog signals to the 10 bit digital value using successive approximation method.

Second step is to calculate the phase angle between load voltage (V) and load current (I_L). The 16- bit TIMER1 is used to calculate the phase angle. When input RD0 goes high at the end of the low input test, the microcontroller TIMER1 is turned ON and starts testing input RD1. If the input is high, this denotes that the load current (I_L) lags the main supplied voltage and that can be referred as lagging power factor. As long as input RD0 is high, the microcontroller keeps looping and testing the input. As the input at RD1 changes its state from high to low the TIMER1stops and thus the time gap between voltage and current is calculated. If the contents of TIMER1 are found to be zero, this means that load phase angle equals to 0, which in turn means that the fundamental supplied voltage and load current are in phase and if the contents of TIMER1 are found to be in between 0 to 625_d, this means that load phase angle is lagging and it lies between 0^0 to 90^0.

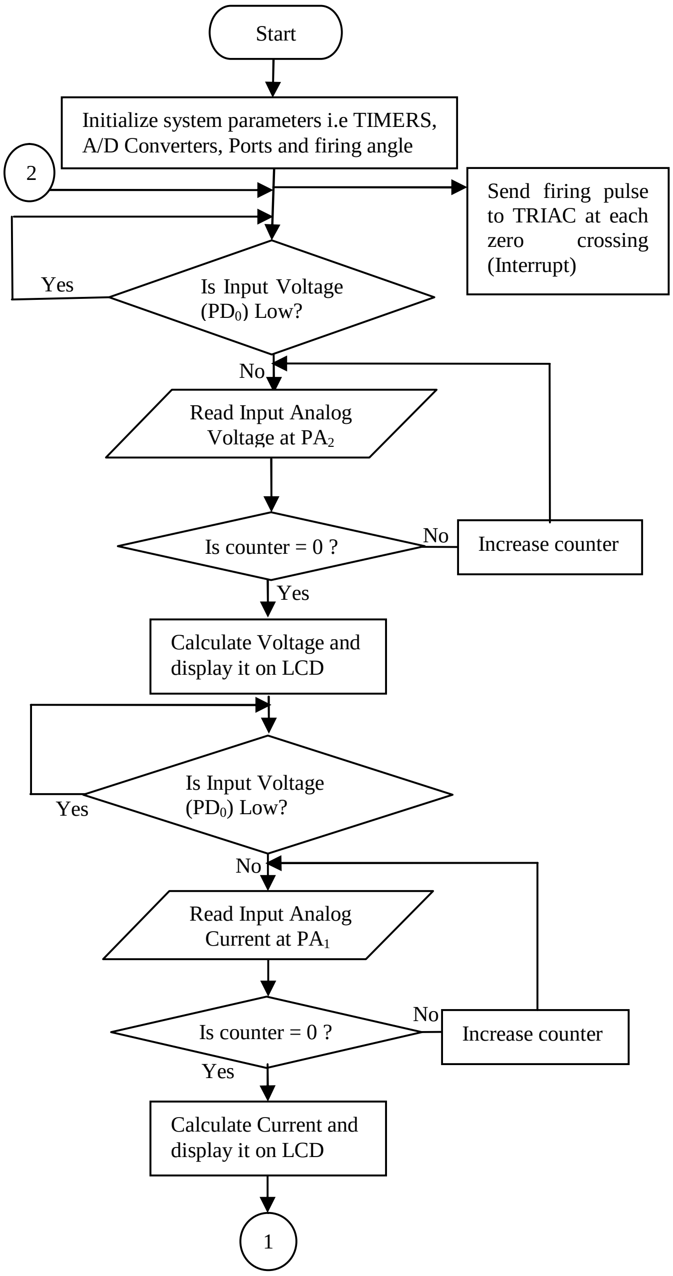
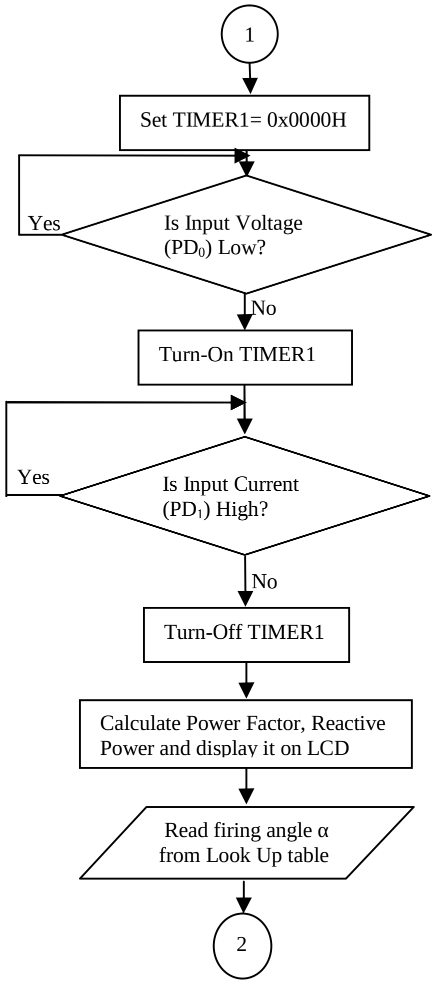


Fig. 7 Flow Chart of the Proposed PFC Circuit (Cont.)



(Cont.) Fig. 7 Flow Chart of the Proposed PFC Circuit

The delay in ms, the phase angle, power factor and reactive power of load at supply frequency 50HZ, and at rated voltage of 220V are calculated by the following relations.

$$Delay\ (in\ ms) = 4*(Prescale*Timer1/F_{OSC.}) \quad (7)$$

Here; Prescale=8, $F_{Oscillator}$ = 4 MHZ

$$Phase\ Angle = 1.8*(Delay\ (in\ ms)\ /20msec)*360 \quad (8)$$

$$Power\ factor = \cos\ (Phase\ Angle) \quad (9)$$

$$Reactive\ Power\ (Q) = V*I*\sin\phi \quad (10)$$

After that, the microcontroller reloads the value of α from the look up table and the above sequence is repeated.

V. Experimental Results

The proposed microcontroller based power factor controller using SVC is implemented and tested, with the load specifications given in Table I, static VAR compensator branch specifications given in Table II and TRIAC firing angle (α) specification to correct the power factor in Table III.

TABLE I
LOAD PARAMETERS FOR SIMULATION

Parameter	Value
line voltage and frequency	Vs (rms) =220 V, fs = 50Hz
fixed load impedance (choke)	Rc = 136 Ω, Lc = 1.61 H
variable load resistance	R = 0-550 Ω
load phase angle	$\Phi=33.0^0$ - 74.8^0
load reactive power	Q = 27-90 VARs

TABLE III
SVC BRANCH PARAMETERS

Parameter	Value
fixed capacitor	C = 6.5μF
thyristor controlled reactor impedance	R_{TCR} = 11.08 Ω, L_{TCR} =0.34H
reactive power of svc	Q_{SVC} = -334.0 to +98 VARs
firing angle (α) of tcr	$\alpha = 90^0 - 180^0$

TABLE IIII
LOOK UP TABLE

$Q_{RL - Load}$ In VARs	Load Phase Angle	Firing angle Time Period in msecs	Firing angle α In degree	TIMER1 Values in HEX
33	35.0^0	7.37 ms	132^0	FC65
45	40.7^0	7.77 ms	139^0	FC33
59	51.8^0	8.00 ms	144^0	FC17
75	61.4^0	8.32 ms	149^0	FBEE
90	74.5^0	8.74 ms	157^0	FBBA

The proposed control strategy is implemented with a PIC 16F877A microcontroller, PIC16F877A is based on the core technology of microchip MPLAB IDE which is compatible with the assembly language as well as higher level language such as most common language C with suitable software and hardware support. An evaluation version of microchip MPLAB IDE along with Hi-Tech ANSI C compiler was down loaded from the website: to convert a C program to machine language, it takes several steps however, and the main idea is to produce a HEX file at the end. This HEX file was then used by the 'burner' EC804_Flash_Programmer, is Serial Universal Device Programmer to write every byte of data at the appropriate place in the Flash memory of the PIC16F877A. The Code memory array of the PIC16F877A can be programmed using the serial In System Programming (ISP) interface. The serial interface consists of pins SCK, MOSI (input) and MISO (output) of the microcontroller IC PIC16F877A. Before a reprogramming sequence can occur, a Chip Erase operation is required.

The load reactive power in proposed work is varied in steps from 29-90 VARs by varying the variable load resistance in steps. During the change of load condition, the system maintains a unity-power-factor operation and the main current is also decreased from its load current. The results confirm the good performance of the power factor controller for different load conditions. The observation of the results has been proposed into 2 study cases depending on the load conditions. i.e. for a phase angle of 33.3^0 and 74.5^0.

A. Study Case (1)

In this case, the system voltage lags the load current by a phase angle of 33.3^0. The microcontroller then determines the reactive power of the load i.e. 26 VARs and accordingly picks up the TRIAC firing angle from the look-up table, which is 7.37ms or 132^0 and thus can be observed in the Figure 8 that the system voltage and main current (I_m) maintains a unity-power factor operation and the main current (I_m) is also decreased to that of load current (I_L).

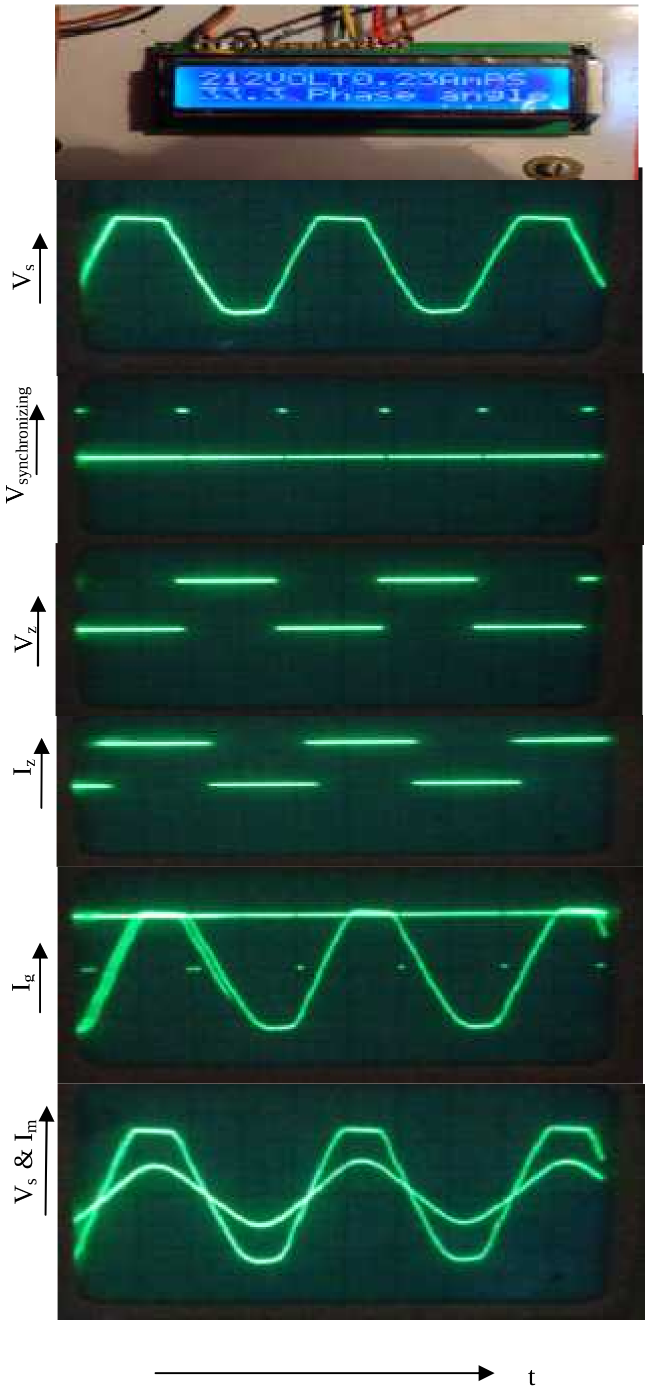


Fig. 8 Waveforms for study case 1

B. Study Case (2)

In this case, the system voltage lags the load current by a phase angle of 74.5^0. The microcontroller then determines the reactive power of the load i.e. 90 VARs and accordingly picks up the TRIAC firing angle from the look-up table, which is 8.74 ms or 157^0 and thus can be observed in the Figure 9 that the system voltage and main current (I_m) maintains a unity-power factor operation and the main current (I_m) is also decreased to that of load current (I_L).

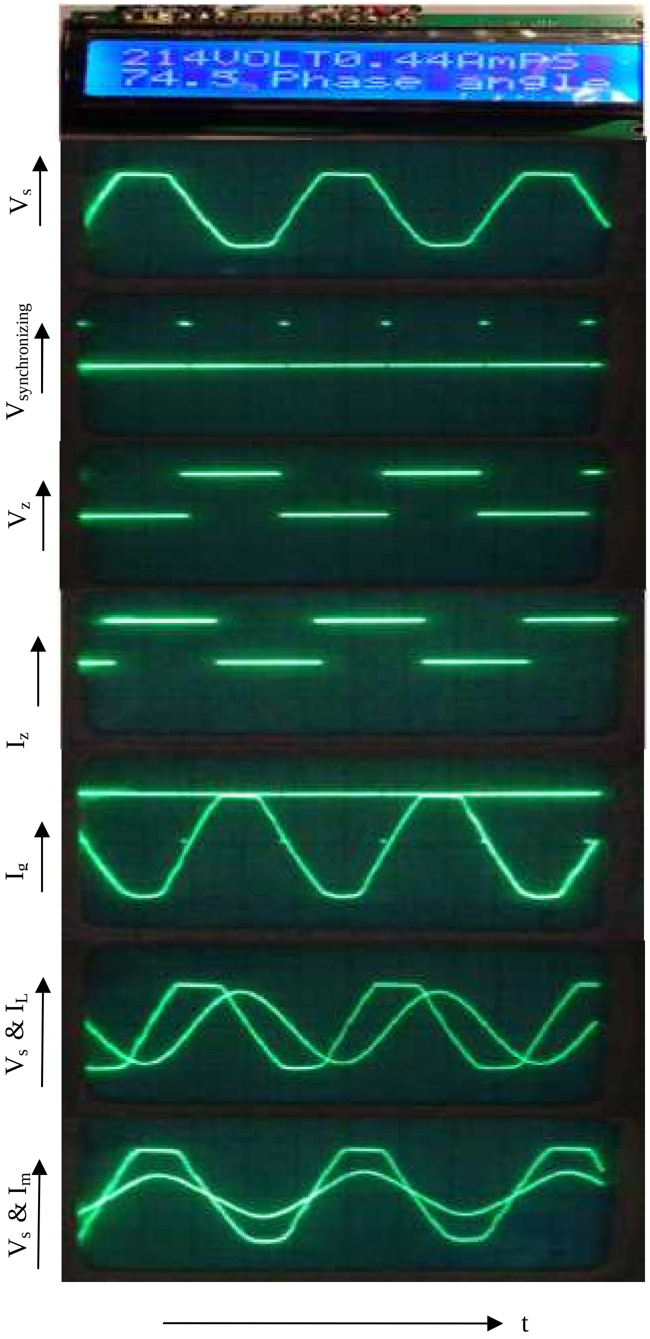


Fig. 9 Waveforms for study case 2

VI. CONCLUSION

This thesis work is an attempt to design and implement the power factor controller using PIC micro controller. PIC monitors continuously the load power factor and takes the control action. This thesis gives more reliable and user friendly power factor controller. This thesis also facilitates to monitor the power factor changes on LCD in real time.

A microcontroller-based power factor corrector for single phase low power factor loads has been presented in terms of the software algorithm development. The system can adjust the supplied system power factor to almost any required reference value. The proposed power factor correction scheme is designed to operate with most of the possible lagging or leading values of the load power factor. This shows the adaptability of this power factor corrector. This is because its operation principles' is based on the measurement of the displacement angle between the fundamental components of the supplied voltage and current, rather than measuring the system voltage signal. The principle of operation adopted in this paper may be applied further in designing the power factor correction schemes for loads driven by 3-phase voltage supplies.

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