Development of Power Factor Controller using PIC Microcontroller

A thesis

submitted towards the partial fulfillment of
the requirements of the degree of

Master of Engineering
in
Electronic Instrumentation and Control Engineering

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CERTIFICATE

This is to certify that my work presented in this thesis entitled **"Development of Power Factor Controller using PIC Microcontroller"** *submitted in partial fulfillment of the requirement for the award of the degree of* **Master of Engineering in Electronic Instrumentation and Control Engineering** *at* **Thapar University, Patiala**, *is an original record under supervision and guidance of* **Mr. Mandeep Singh.** *The matter embodied in this report has not been submitted anywhere for the award of any degree.*

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It is certified that the above statement made by the student is correct to the best of our knowledge and belief.

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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 the Power Factor Correction (PFC) have been proposed. This thesis describes 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 and trigger sufficient switching capacitors in order to compensate excessive reactive components, thus bringing power factor near to unity.

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List of abbreviation

Sr. no.	Short form	Abbreviation
1	ADC	Analog to Digital Convertor
2	APFC	Adaptive Power Factor Controller
3	BOR	Programmable Brown-Out Reset
4	BSM	Binary Search Method
5	CISC	Complex Instruction Set Computer
6	COA	Centre of Area
7	CPFC	Capacitive Power Factor Controller
8	ICD	In Circuit Debug
9	LCD	Liquid Crystal Display
10	LPF	Lower Power Factor
11	LUTM	Look-Up Table Method
12	MOM	Mean of Maxima
13	MSB	Most Significant Bit
14	MSSP	Master Synchronous Serial Port
15	PFC	Power Factor Controller
16	PIC	Peripheral Interface Controller
17	PLVD	Programmable Low Voltage Detection
18	PWM	Pulse Width Modulation
19	PSP	Parallel Slave Port
20	RMS	Root-Mean-Square
21	RISC	Reduced Instruction Set Computer
22	SAM	Successive Approximation Method
23	SCR	Silicon Controlled Rectifier
24	SMPS	Switched-Mode Power Supplies
25	SCPFC	Single Controller Power Factor
26	USCM	Unity Step Control Method
27	UPF	Upper Power Factor

Though correction of power factor is very old practice, we have considered the work done in last 25 years in our survey, starting from 1983.

Jones and Blackwell proposed a technique for maintaining 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 the Energy Saver Power Factor Controller for induction motors developed and patented by NASA Marshall Space Flight Center. The method constantly and automatically adjusted the DC field current of a 3-phase synchronous machine such that the AC line current would always operate at the minimal point of the well-known "V" curves [Jones and Blackwell 1983].

Sharkawi et al. proposed an adaptive power factor controller for three-phase induction generators. The controller sensed the reactive current drawn by the machine and accordingly provided the needed reactive power to improve the power factor to as close to unity as possible. The controller was a modular, low-cost, harmonic free device. It did not create any transients in line current. It was designed to eliminate the self-excitation problems associated with induction generators. The controller was tested on an induction generator [Sharkawi et al. 1985].

Sharkawi et al. proposed a continuing effort to develop an effective, reliable, and inexpensive adaptive power factor controller (APFC). The APFC was able to compensate adaptively the reactive power of rapidly varying loads without adding harmonics or transients to the power system. Based on thousands of hours of field operation, the APFC had substantially modified to improve its reliability and effectiveness [Sharkawi et al. 1988].

Nalbant proposed the calculations and measurements of power factor correction and distortion reduction using the peak current programmed boost topology. The topology and a regulator used a dedicated power factor controller were introduced. The input current wave shape was modeled mathematically and analytical expressions for the calculation of the power factor and total harmonic distortion were derived. Various measurement methods were described and actual data related to the high-power regulator were presented, including pictures of the low-frequency spectrum of the input current [Nalbant 1990].

Ioannides and Papadopoulos proposed the speed and power factor of an adjustable speed slip power recovery drive were controlled in order to optimize the operation. This was accomplished by means of a variable-voltage-variable-frequencies power converter. The function of the digital controller of the power converter was to provide the online speed and power factor regulation [Ioannides and Papadopoulos 1991].

Fuld et al. proposed a combined buck and boost power-factor-controller for three-phase input which was the combination of a buck and a boost stage, which gave important advantages at high input voltage, favorable output voltage, e.g. 400 V, wide input voltage range and no additional inrush limiter necessary. For three-phase input, it was possible to use three single phase units connected each to two phases (line-to-line) [Fuld et al. 1991].

Malesani et al. proposed a single-switch fully-controlled three-phase rectifier, which provided high AC power factor and wide DC voltage regulation while allowed high-frequency insulation. Owed to one-cycle control, output voltage ripple was also eliminated and switch voltage stress was limited by a lossless clamper circuit [Malesani et al. 1993].

Miller et al. proposed a family of rectifiers with power outputs from 1.5 kW to 7 kW, based on high frequency (200 kHz) converters using power MOSFETs. The circuit used full-bridge converters in the quasi-resonant mode (zero-voltage switching), which resulted in very low switching losses. Both single-phase and three-phase designs were available. The single-phase 230 V versions were equipped with a power factor controller to comply with IEC 555-2. Two bridges were mounted in series for operation from a three-phase 400 V supply [Miller et al. 1993].

Mandal et al. proposed a laboratory model of a microcomputer-based power factor controller (PFC) for compensating the reactive power of rapidly varying loads by switching capacitors sized in a binary ratio, with the help of zero voltage static switches [Mandal et al. 1994].

Kurachi et al. proposed a detailed analysis of the ripple current of an electrolytic capacitor in a boost-type power factor control circuit. The ripple current was divided into two components, namely the low-frequency and the high-frequency components. The root-mean-square value of the capacitor current was derived for both components [Kurachi et al. 1995].

Ayres and Barbi proposed the continuous current mode (CCM) operation of the family of power converters for power recycling during the burn-in test of synchronized uninterrupted power supply (UPS) with sinusoidal output voltage. The CCM operation reduced the current peak in the semiconductors and the filters volume. The circuit operates at constant frequency, the control was based on the average current value and performed by a power factor controller IC [Ayres and Babri 1996 a].

Masserant and Stuart proposed study compares calculated losses with measured losses obtained from the temperature rise of the heat sink of the IGBT. Measurements of insulated gate bipolar transistor (IGBT) losses in modulated converters presented a difficult challenge because of the wide variations in the waveform [Masserant and Stuart 1996].

Ayres and Barbi proposed conventional integrated circuits for PWM and power factor controllers. Conventionally, the burn-in test of DC power supplies used resistors as load. Consequently, all the energy involved was lost by heating, provoking still an additional energy waste with the air conditioning system. The power recycler was a power converter that replaces the resistors load banks in the burn-in test of DC power supplies with the advantage that most of the energy was sent back to the utility grid with low THD and quasi-unitary power factor [Ayres and Barbi 1996 b].

Rao et al. proposed the solid state AC voltage stabilizer was novel due to the unity power factor at the input side, low current harmonics injected into the input side, excellent output voltage regulation for line voltage and load current variations, good dynamic response for line voltage and load current variations, low total harmonic distortion in the output voltage wave shape, low weight to power ratio and low volume to power ratio. The suggested static voltage stabilizer operated similar to a servo controlled stabilizer, but the servo stabilizer was replaced with an electronic AC voltage generator [Rao et al. 1998].

Dallago et al. proposed about the Monolithic ICs that allowed the simple and cheap single-phase power factor correction (PFC) systems to be implemented. They contained an analog multiplier, the transfer characteristic of which may be nonlinear. In this delta-sigma (ΔΣ) modulation technique was applied to fully implement the algebraic operations of a PFC system's multiplier block. A ΔΣ multiplier prototype was bread boarded and inserted in a PFC control loop based on a commercial IC [Dallago et al. 1998].

Tinggren proposed a new integrated power quality device-power factor controller (PFC) for power distribution system and industrial power circuit applications. A PFC integrated breaker-switched capacitor banks into a compact design with low cost sensing elements and an intelligent control unit. The device provided more accurate voltage control and power factor correction than traditional shunt capacitor bank installations [Tinggren 1999].

Jee and Bong proposed a novel power-factor controller for single-phase pulse width modulated rectifiers. The unity power-factor controller for a sinusoidal input current was derived using the feedback linearization concept. Two active switches and two diodes were utilized for AC-to-DC power conversion [Jee and Bong 1999].

Hurley et al. proposed a functional description of voltage, VAr, and power factor (PF) controllers and regulators, along with an example demonstrated the superior steady-state voltage support performance on a transmission system by regulating voltage, rather than VArs or PF. They concluded that VAr/PF controllers or regulators should not generally specified or utilized on excitation controls for voltage supporting generator applications [Hurley et al. 1999].

Cereda et al. proposed a better understanding of power quality (PQ) problems and their mutual impact on the power system and on the end-users facilities can lead to building and operating a safer, more reliable and more profitable energy supply system. The privatization of utilities and deregulation of the electrical energy market was boosting the interest for the energy supply PQ, focusing on its economic value [Cereda et al. 2000].

Ali et al. proposed a power factor controller (PFC) for a three-phase induction motor (IM), utilized the programmable logic controller (PLC). It focused on the implementation of a laboratory model for a PLC based PFC to improve the power factor of a three-phase induction motor. During the online process a set of capacitors sized in a binary ratio would be switched on or off with the help of zero voltage static switches according to a control strategy to obtain a pre-specified power factor. This control strategy relied on a look-up table and an expert system [Ali et al. 2000].

Consoli et al. proposed an innovative converter topology that improved the performance of a switched reluctance motor drive, aimed to equip home appliances. It was based on a modified C-dump converter configuration, where the energy recovery stage acted as an active power factor controller for off-line operation [Consoli et al. 2001].

Borlotti et al. proposed a general description of new functions integrated in the medium voltage switchboard to meet the power quality challenge. They described circuit breakers with magnetic actuators that were easy to justify economically and gave low cost power quality solutions [Borlotti et al. 2001].

Andersen et al. proposed a grid connected inverter for fuel cells. The fuel cell operated with a low voltage in a wide voltage range (25 V-45 V) this voltage transformed to around 350-400 V in order to invert this DC power into AC power to the grid. Converter consisted of an isolated DC-DC converter cascaded with a single phase H-bridge inverter. The DC-DC converter was a current-fed push-pull converter [Andersen et al. 2002].

Machmoum et al. proposed a three-phase switching converter, acted as a PWM rectifier (PWMR) and/or as an active power filter (APF). A resonant current controller (RCC) for a sinusoidal input current was involved. Pulse modulation allowed an efficiently control of the converter maximum switching frequency which slightly dependent on the electrical load, input passive filter or mains parameters. The converter provided controllable DC link voltage and a high power factor [Machmoum et al. 2002].

Marent and Zudrell proposed the business of no dimming electronic ballasts for fluorescent lamps was dominated by strong requirements for cost reduction. Sub micron mixed signal ASIC technology in the lighting business was already state-of-the-art. This technology offered many advantages like high complexity on small silicon area [Marent and Zudrell 2003].

Kim et al. proposed a high-performance line conditioner with excellent efficiency and power factor. The line conditioner consisted of a three-leg rectifier-inverter, which operated as a boost converter and a buck converter. This boost-buck topology enabled constant output voltage regulation, irrespective of input voltage disturbances. In addition the three-leg bridge reduced the number of switching devices and system loss, while maintained the capabilities of power factor correction and good output voltage regulation. The power factor controller for the single-phase pulse-width modulated (PWM) rectifier was derived using the feedback linearization concept [Kim et al. 2004].

Kiprakis and Wallace proposed the implications of the increasing capacity of synchronous generators at the remote ends of rural distribution networks where the line resistances were high and the X/R ratios were low. Local voltage variation was specifically examined and two methods of compensation were described. The first of them was a deterministic system that used a set of rules to switch intelligently between voltage and power factor control modes, while the second was based on a fuzzy inference system that adjusts the reference setting of the automatic power factor controller in response to the terminal voltage [Kiprakis and Wallace 2004].

Consoli et al. proposed an innovative converter topology was presented that improved the performance of electronically commutated motor drives, aimed to equip home appliances. The proposed topology was based on a modified C-dump converter configuration, where the energy recovery stage acted as an active power factor controller (PFC) for offline operation [Consoli et al. 2004].

Freitas et al. proposed a dynamic study about the influences of ac generators (induction and synchronous machines) and distribution static synchronous compensator (DSTATCOM) devices on the dynamic behavior of distribution networks. The performance of a DSTATCOM as a voltage controller or a power factor controller was analyzed. The impacts of these controllers on the stability and protection system of distribution networks with distributed generators were determined [Freitas et al. 2005].

Meza et al. proposed the analysis, modeling and design of a power conditioning system for grid-connected photovoltaic (PV) systems. The designed power stage consisted of a transformer less boost-buck converter. The power conditioning system's control scheme included a variable structure controller to assure output unity power factor. To maximize the steady-state input-output energy transfer ratio a linear controller was designed out of a large-signal sampled data model of the system [Meza et al. 2005].

Cacciato et al. proposed a new approach that aimed at improving the power factor of pulse width-modulation inverters that equip low-power electric motor drives for household appliances. The key feature of the proposed approach consists of exploiting the dc-bus current as a suitable dither generator by means of a high-frequency transformer [Cacciato et al. 2005].

Molina and Mercado proposed the dynamic performance of a distribution static compensator (DSTATCOM) coupled with an energy storage system (ESS) for improving the power quality of distribution systems. The integrated DSTATCOM/ESS compensator was analyzed as a voltage controller, a power factor controller and an active power controller. Modeling and control approaches were proposed, including a detailed modeling of the DSTATCOM/ESS [Molina and Mercado 2006].

Barsoum proposed the programming of PIC micro-controller for power factor correction that described the design and development of a three-phase power factor corrector using PIC (Programmable Interface Microcontroller) chip. This involved sensing and measuring the power factor value from the load using PIC and sensors, then using proper algorithm to determine and trigger sufficient switching capacitors in order to compensate excessive reactive components, thus withdraw PF near to unity [Barsoum 2007].

Organization of thesis

This thesis contains six chapters each having its own importance. First chapter contains the all detailed information about the power factor and its correction methods especially the capacitor correction methods. Second chapter described the hardware and its configuration. Third chapter embodies software development module, which is the base of this thesis. Next chapter is related with the control scheme. Result and discussion along the conclusion and future scope are given in the last two chapters. Many references are taken in consideration before summarizing the thesis. These references along with the appendix having details of software is given at the end of this thesis.

Chapter 1

Introduction

Power factor is the ratio of true power or watts to apparent power or volt amps. They are identical only when current and voltage are in phase then the power factor is 1.0. The power in an ac circuit is very seldom equal to the direct product of the volts and amperes. In order to find the power of a single phase ac circuit the product of volts and amperes must be multiplied by the power factor. Ammeters and voltmeters indicate the effective value of amps and volts. True power or watts can be measured with a wattmeter. If the true power is 1870 watts and the volt amp reading is 2200. Than the power factor is 0.85 or 85 percent. True power divided by apparent power. The power factor is expressed in decimal or percentage. Thus power factors of 0.8 are the same as 80 percent. Low power factor is usually associated with motors and transformers. An incandescent bulb would have a power factor of close to 1.0. A one hp motor has power factor about 0.80. With low power factor loads, the current flowing through electrical system components is higher than necessary to do the required work. These results in excess heating, which can damage or shorten the life of equipment, a low power factor can also cause low-voltage conditions, resulting in dimming of lights and sluggish motor operation.

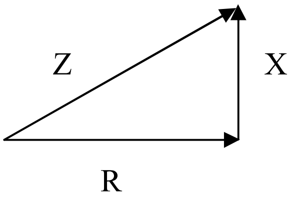
Low power factor is usually not that much of a problem in residential homes. It does however become a problem in industry where multiple large motors are used. So there is a requirement to correct the power factor in industries. Generally the power factor correction capacitors are used to try to correct this problem.

1.1 Introduction to power factor

For a DC circuit the power is P=VI and this relationship also holds for the instantaneous power in an AC circuit. However, the average power in an AC circuit expressed in terms of the rms voltage and current is

$$P_{avg} = VI \cos\varphi \qquad \text{eq. 1}$$

Where, φ is the phase angle between the voltage and current. The additional term is called the power factor. Power factor triangle is shown in figure 1.1.



$$\text{Power factor} = \frac{R}{Z}$$

Figure 1.1: power factor triangle

From the phasor diagram for AC impedance, it can be seen that the power factor is R/Z. For a purely resistive AC circuit, R=Z and the power factor = 1.

1.1.1 Instantaneous power

As in DC circuits, the instantaneous electric power in an AC circuit is given by P=VI where V and I are the instantaneous voltage and current. Instantaneous voltage and current is shown in figure 1.2.

Since

$$V = V_m \sin\omega t \quad \& \quad I = I_m \sin(\omega t - \varphi) \qquad \text{eq. 2}$$

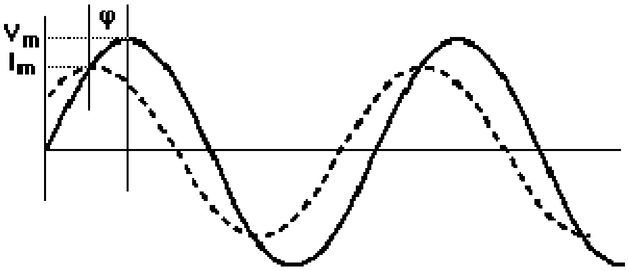


Figure 1.2: Instantaneous voltage and current

Then the instantaneous power at any time t can be expressed as

$$P_{instanteneous} = V_m I_m \sin\omega t \sin(\omega t - \varphi) \qquad \text{eq. 3}$$

After using trigonometric identity:

$$\sin(t-\varphi) = \sin\omega t \cos\varphi - \cos\omega t \sin\varphi \qquad \text{eq.4}$$

The power becomes:

$$P_{instantaneous} = V_m I_m \sin^2\omega t \cos\varphi - V_m I_m \sin\omega t \sin\varphi \cos \omega t \qquad \text{eq.5}$$

Averaging this power over a complete cycle gives the average power.

1.1.2 Average Power

Normally the average power is the power of interest in AC circuits. Since the expression for the instantaneous power

$$P_{instanteneous} = V_m I_m \sin^2\omega t \cos\varphi - V_m I_m \sin\omega t \sin\varphi \cos \omega t$$

is a continuously varying one with time, the average must be obtained by integration. Averaging over one period T of the sinusoidal function will give the average power. The second term in the power expression above averages to zero since it is an odd function of t. The average of the first term is given by

$$Pavg = Vm \operatorname{Im} \cos\varphi \frac{\int_0^T \sin^2 \omega t dt}{T} = \frac{Vm \operatorname{Im}}{2} \cos\varphi \qquad \text{eq. 6}$$

Since the rms voltage and current are given by

$$V = V_m / \sqrt{2} \qquad \text{eq. 7}$$

$$I = I_m / \sqrt{2} \qquad \text{eq. 8}$$

The average power can be expressed as

$$P_{avg} = VI \cos\varphi$$

Average Power Integral

Finding the value of the average power for sinusoidal voltages involves the integral

$$Pavg = Vm \operatorname{Im} \cos\varphi \frac{\int_0^T \sin^2 \omega t dt}{T} = \frac{Vm \operatorname{Im}}{2} \cos\varphi$$

The period T of the sinusoid is related to the angular frequency ω and angle θ by

$$T = \frac{2\pi}{\omega}$$

or $$\omega T = 2\pi$$

or $$\theta = \omega T \qquad \text{eq. 9}$$

Using these relationships, the integral above can be recast in the form:

$$\frac{\int_0^{2\pi} \sin^2\theta d\theta}{2\pi} = \frac{1}{2} \qquad \text{eq. 10}$$

The average of $\sin^2\theta$ or $\cos^2\theta$ is equal to ½. This can be shown using the trig identity:

$$\sin^2\alpha = \frac{1}{2}(1 - \cos 2\alpha) \qquad \text{eq. 11}$$

Which reduces the integral to the value 1/2 since the second term on the right has an integral of zero over the full period?

1.1.3 Phase and phasor diagram

When capacitors or inductors are involved in an AC circuit, the current and voltage do not peak at the same time. The fraction of a period difference between the peaks expressed in degrees is said to be the phase difference. The phase difference is <= 90 degrees. It is customary to use the angle by which the voltage leads the current. This leads to a positive phase for inductive circuits since current lags the voltage in an inductive circuit. The phase is negative for a capacitive circuit since the current leads the voltage. The useful mnemonic ELI the ICE man helps to remember the sign of the phase. The phase relation is often depicted graphically in a phasor diagram [hyp phys b].

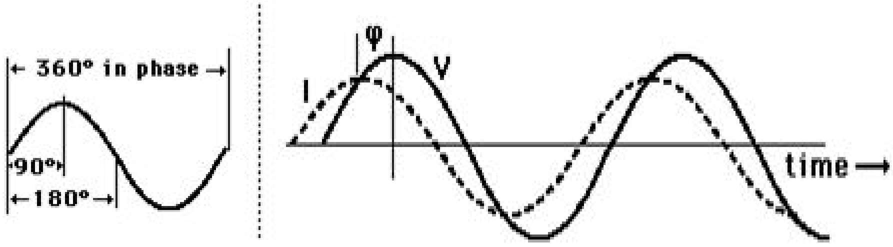


Figure 1.3: Phase diagram

Phasor Diagrams

The reference for zero phase is taken to be the positive x-axis and is associated with the resistor since voltage and current are in phase. The length of the phasor is proportional to the magnitude of the quantity represented, and its angle represents its phase relative to that of the current through the resistor. The phasor diagram for the RLC series circuit shows in figure 1.4 [hyp phys b].

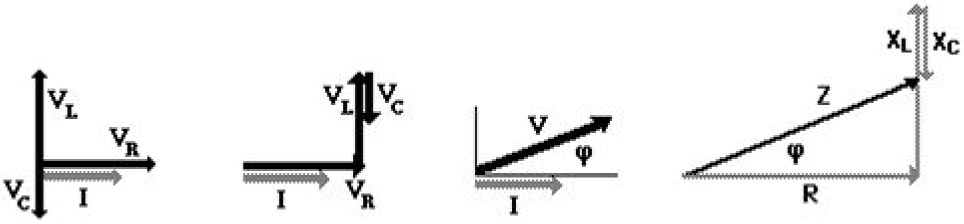


Figure 1.4: Phasor diagram

Equivalent voltage and phase angle is given as:

$$V = \sqrt{(V_R)^2 + (V_L - V_C)^2} \qquad \varphi = \tan^{-1}\frac{V_L - V_C}{V_R} \qquad \text{eq. 12}$$

Equivalent impedance and phase angle is given as:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \qquad \varphi = \tan^{-1}\frac{X_L - X_C}{R} \qquad \text{eq. 13}$$

1.1.4 AC response of inductor capacitor and resistor

Inductor

An inductor with AC supply is shown in figure 1.5 and phasor diagram is shown in figure 1.6 which shows the phase angle between current and voltage. In case of inductor voltage lead current by 90^0. The voltage across an inductor leads the current because the Lenz' law behavior resists the buildup of the current, and it takes a finite time for an imposed voltage to force the buildup of current to its maximum.

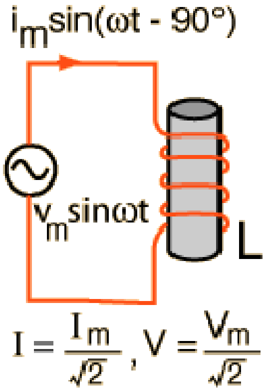


Figure 1.5: Inductor

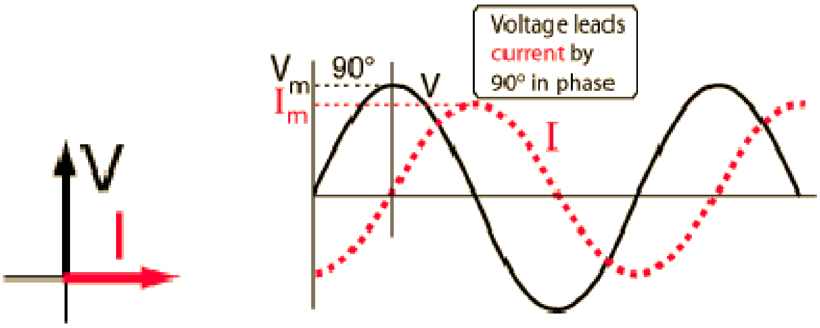


Figure 1.6: Phasor diagram of inductor

Capacitor

A capacitor with AC supply is shown in figure 1.7 and phasor diagram is shown in figure 1.8 which shows the phase angle between current and voltage. In case of capacitor voltage lag current by 90^0. The voltage across a capacitor lags the current because the current must flow to build up charge, and the voltage is proportional to that charge which is built up on the capacitor plates.

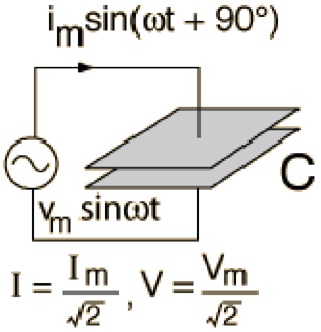


Figure 1.7: Capacitor

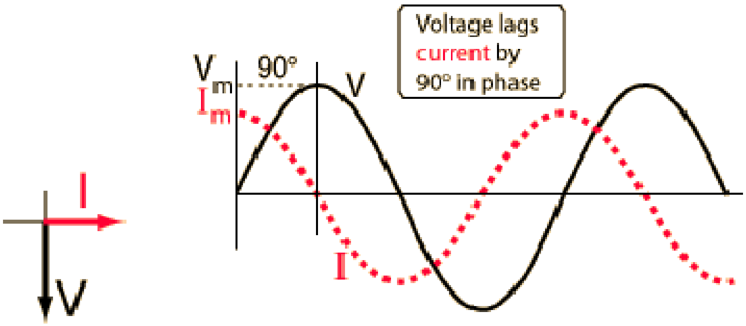


Figure 1.8: phasor diagram of capacitor

Resistor

A resistor with AC supply is shown in figure 1.9 and phasor diagram is shown in figure 1.10 which shows the phase angle between voltage and current is 0^0. For ordinary currents and frequencies, the behavior of a resistor is that of a dissipative element which converts electrical energy into heat. It is independent of the direction of current flow and independent of the frequency. So we say that the AC impedance of a resistor is the same as its DC resistance.

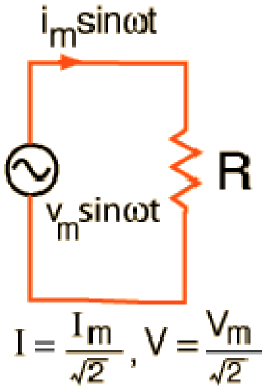


Figure 1.9: Resistance

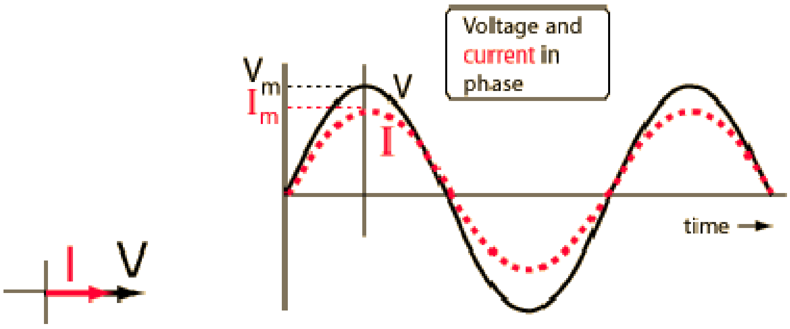


Figure 1.10: Phasor diagram of resistance

1.2 Needs of power factor controller

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.

1.2.1 Explanation

An electrical load that operates on alternating current requires apparent power, which consists of real power plus reactive power. Real power is the power actually consumed by the load. Reactive power is repeatedly demanded by the load and returned to the power source, and it is the cyclical effect that occurs when alternating current passes through a load that contains a reactive component. The presence of reactive power causes the real power to be less than the apparent power, and so, the electric load has a power factor of less than 1.

The reactive power increases the current flowing between the power source and the load, which increases the power losses through transmission and distribution lines. This results in operational and financial losses for power companies. Therefore, power companies require their customers, especially those with large loads, to maintain their power factors above a specified amount (usually 0.90 or higher) or be subject to additional charges. Electrical engineers involved with the generation, transmission, distribution and consumption of electrical power have an interest in the power factor of loads because power factors affect efficiencies and costs for both the electrical power industry and the consumers. In addition to the increased operating costs, reactive power can require the use of wiring, switches, circuit breakers, transformers and transmission lines with higher current capacities.

Power factor correction attempts to adjust the power factor of an AC load or an AC power transmission system to unity (1.00) through various methods. Simple methods include switching in or out banks of capacitors or inductors which act to cancel the inductive or capacitive effects of the load, respectively. For example, the inductive effect of motor loads may be offset by locally connected capacitors. It is also possible to effect power factor correction with an unloaded synchronous motor connected across the supply. The power factor of the motor is varied by adjusting the field excitation and can be made to behave like a capacitor when over excited.

Non-linear loads create harmonic currents in addition to the original AC current. The simple correction techniques described above do not cancel out the reactive power at harmonic frequencies, so more sophisticated techniques must be used to correct for non-linear loads.

1.2.2 Electricity industry aspects

PFC is desirable because the source of electrical energy must be capable of supplying real power as well as any reactive power demanded by the load. This can require larger, more expensive power plant equipment, transmission lines, transformers, switches, etc. than would be necessary for only real power delivered. Also, resistive losses in the transmission lines mean that some of the generated power is wasted because the extra current needed to supply reactive power only serves to heat up the power lines.

The electric utilities therefore put a limit on the power factor of the loads that they will supply. The ideal figure for load power factor is 1, (that is, a purely resistive load), because it requires the smallest current to transmit a given amount of real power. Real loads deviate from this ideal. Electric motor loads are phase lagging (inductive), therefore requiring capacitor banks to counter this inductance. Sometimes, when the power factor is leading due to capacitive loading, inductors (also known as reactors in this context) are used to correct the power factor. In the electricity industry, inductors are said to consume reactive power and capacitors are said to supply it, even though the reactive power is actually just moving back and forth between each AC cycle.

Electricity utilities measure reactive power used by high demand customers and charge higher rates accordingly. Some consumers install power factor correction schemes at their factories to cut down on these higher costs.

1.3 Types of power factor controller

Generally there are two types of technique are used to control the power factor these are:

1.3.1 Passive PFC

This is a simple way of correcting the nonlinearity of a load by using capacitor banks. It is not as effective as active PFC, switching the capacitors into or out of the circuit causes harmonics, which is why active PFC or a synchronous motor is preferred [Wiki].

1.3.2 Active PFC

An active power factor corrector (active PFC) is a power electronic system that controls the amount of power drawn by a load in order to obtain a Power factor as close as possible to unity. In most applications, the active PFC controls the input current of the load so that the current waveform is proportional to the mains voltage waveform (a sine wave).Some types of active PFC are: Boost, Buck and Buck-boost. Active power factor correctors can be single-stage or multi-stage. Active PFC is the most effective and can produce a PFC of 0.99 (99%) [Wiki].

1.3.3 Synchronous

Synchronous motors can also be used for PFC. Shaft less motors is used, so that no load can be connected and run freely on the line at capacitive (leading) power factor for the purposes of PFC.

1.4 Capacitive power factor correction (CPFC)

Capacitive Power Factor correction is applied to circuits, which include induction motors as a means of reducing the inductive component of the current and thereby reduce the losses in the supply. There should be no effect on the operation of the motor itself. An induction motor draws current from the supply, which is made up of resistive components and inductive components. The resistive components are: Load current and Loss current; and the inductive components are: Leakage reactance and Magnetizing current. Figure 1.11 is showing relations between magnetizing current motor current and work current

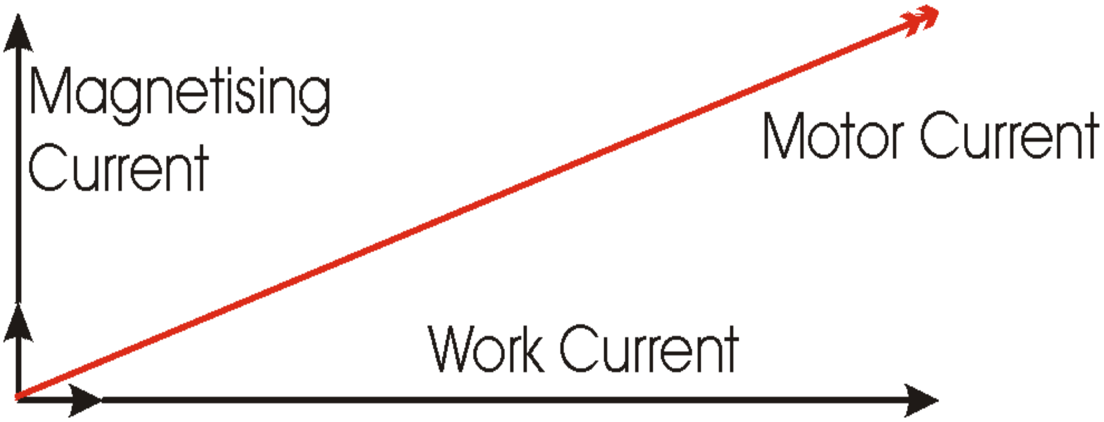


Figure 1.11: Showing relations between magnetizing current motor current and work current

The current due to the leakage reactance is dependent on the total current drawn by the motor, but the magnetizing current is independent of the load on the motor. The magnetizing current will typically be between 20% and 60% of the rated full load current of the motor. The magnetizing current is the current that establishes the flux in the iron and is very necessary if the motor is going to operate. The magnetizing current does not actually contribute to the actual work output of the motor. It is catalyst that allows the motor to work properly. The magnetizing current and the leakage reactance can be considered passenger components of current that will not affect the power drawn by the motor, but will contribute to the power dissipated in the supply and distribution system. Take for example a motor with a current draw of 100 Amps and a power factor of 0.75. The resistive component of the current is 75 Amps and this is what the KWh meter measures. The higher current will result in an increase in the distribution losses of (100 x 100) / (75 x 75) = 1.777 or a 78% increase in the supply losses. In the interest of reducing the losses in the distribution system, power factor correction is added to neutralize a portion of the magnetizing current of the motor. Typically, the corrected power factor will be 0.92 - 0.95. Some power retailers offer incentives for operating with a power factor of better than 0.9, while others penalize consumers with a poor power factor. There are many ways that this is metered, but the net result is that in order to reduce wasted energy in the distribution system, the consumer will be encouraged to apply power factor correction.

Power factor correction is achieved by the addition of capacitors in parallel with the connected motor circuits and can be applied at the starter, or applied at the switchboard or distribution panel. The resulting capacitive current is leading current and is used to cancel the lagging inductive current flowing from the supply.

1.4.1 Different types of capacitive power factor correction

Different types of capacitive power factor correction are

- **1.4.1.1** Bulk correction
- **1.4.1.2** Static correction
- **1.4.1.3** Inverter
- **1.4.1.4** Solid-state soft starter

1.4.1.1 Bulk correction

The Power factor of the total current supplied to the distribution board is monitored by a controller which then switches capacitor banks. In a fashion to maintain a power factor better than a preset limit. (Typically 0.95) Ideally, the power factor should be as close to unity as possible. There is no problem with bulk correction operating at unity; however correction should not be applied to an unloaded or lightly loaded transformer. If correction is applied to an unloaded transformer, we create a high Q resonant circuit between the leakage reactance of the transformer and the capacitors and high voltages can result. In figure 1.12 bulk correction using capacitor bank is shown.

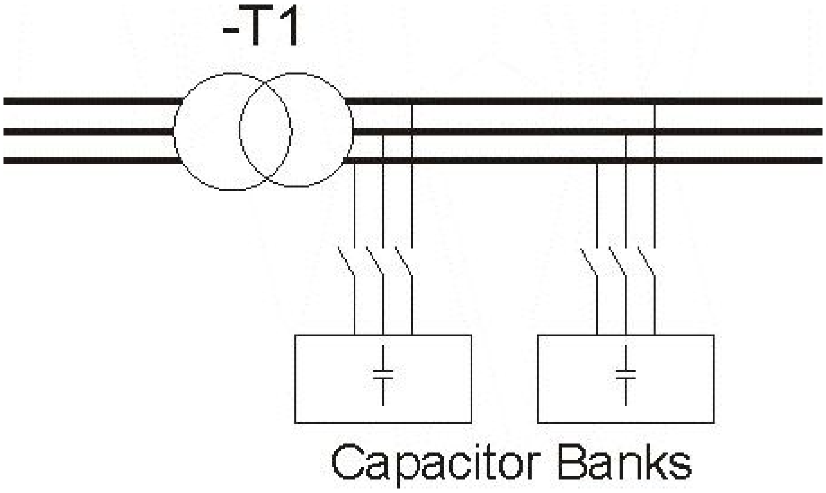


Figure 1.12: Bulk correction using capacitor bank

1.4.1.2 Static correction

As a large proportion of the inductive or lagging current on the supply is due to the magnetizing current of induction motors, it is easy to correct each individual motor by connecting the correction capacitors to the motor starters. With static correction, it is important that the capacitive current is less than the inductive magnetizing current of the induction motor. In many installations employing static power factor correction, the correction capacitors are connected directly in parallel with the motor windings. When the motor is Off Line, the capacitors are also Off Line. When the motor is connected to the supply, the capacitors are also connected providing correction at all times that the motor is connected to the supply. This removes the requirement for any expensive power factor monitoring and control equipment. In this situation, the capacitors remain connected to the motor terminals as the motor slows down. An induction motor, while connected to the supply, is driven by a rotating magnetic field in the stator that induces current into the rotor. When the motor is disconnected from the supply, there is for a period of time, a magnetic field associated with the rotor. As the motor decelerates, it generates voltage out its terminals at a frequency which is related to it's speed. The capacitors connected across the motor terminals, form a resonant circuit with the motor inductance. If the motor is critically corrected, (corrected to a power factor of 1.0) the inductive reactance equals the capacitive reactance at the line frequency and therefore the resonant frequency is equal to the line frequency. If the motor is over corrected, the resonant frequency will be below the line frequency. If the frequency of the voltage generated by the decelerating motor passes through the resonant frequency of the corrected motor, there will be high currents and voltages around the motor/capacitor circuit. This can result in severe damage to the capacitors and motor. It is imperative that motors are never over corrected or critically corrected when static correction is employed. Static power factor correction should provide capacitive current equal to 80% of the magnetizing current, which is essentially the open shaft current of the motor.

The magnetizing current for induction motors can vary considerably. Typically, magnetizing currents for large two pole machines can be as low as 20% of the rated current of the motor while smaller low speed motors can have a magnetizing current as high as 60% of the rated full load current of the motor. It is not practical to use a "Standard table" for the correction of induction motors giving optimum correction on all motors. Tables result in under correction on most motors but can result in over correction in some cases. Where the open shaft current cannot be measured, and the magnetizing current is not quoted, an approximate level for the maximum correction that can be applied can be calculated from the half load characteristics of the motor. It is dangerous to base correction on the full load characteristics of the motor as in some cases, motors can exhibit a high leakage reactance and correction to 0.95 at full load will result in over correction under no load, or disconnected conditions.

Static correction is commonly applied by using one contactor to control both the motor and the capacitors. It is better practice to use two contactors, one for the motor and one for the capacitors. Where one contactor is employed, it should be up sized for the capacitive load. The use of a second contactor eliminates the problems of resonance between the motor and the capacitors. Static correction is shown in figure 1.13.

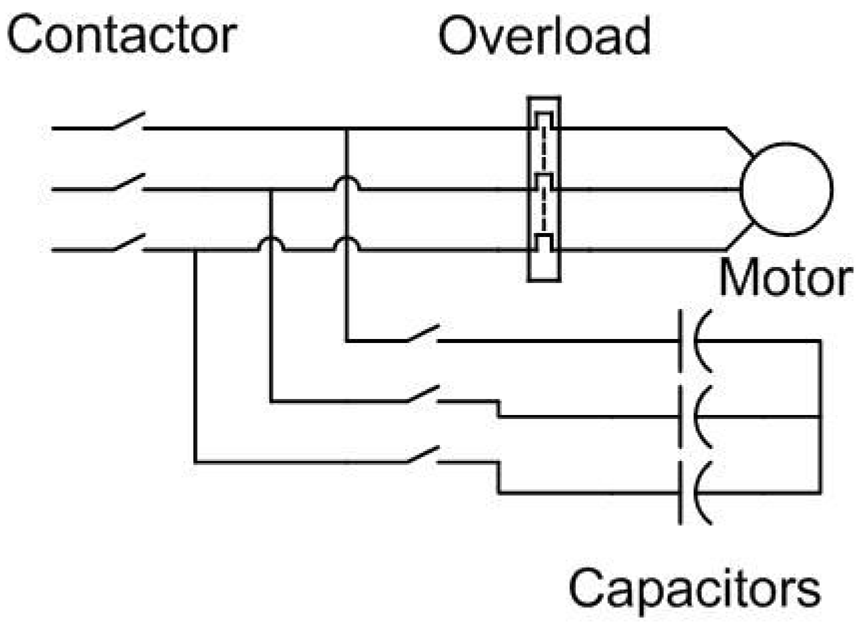


Figure 1.13: Static correction using capacitor

1.4.1.3 Inverter

Static Power factor correction must not be used when a variable speed drive or inverter controls the motor. The connection of capacitors to the output of an inverter can cause serious damage to the inverter and the capacitors due to the high frequency switched voltage on the output of the inverters. The current drawn from the inverter has a poor power factor, particularly at low load, but the motor current is isolated from the supply by the inverter. The phase angle of the current drawn by the inverter from the supply is close to zero resulting in very low inductive current irrespective of what the motor is doing. The inverter does not however, operate with a good power factor. Many inverter manufacturers quote a cos Ø of better than 0.95 and this is generally true, however the current is non sinusoidal and the resultant harmonics cause a power factor (KW/KVA) of closer to 0.7 depending on the input design of the inverter. Inverters with input reactors and DC bus reactors will exhibit a higher true power factor than those without. The connection of capacitors close to the input of the inverter can also result in damage to the inverter. The capacitors tend to cause transients to be amplified, resulting in higher voltage impulses applied to the input circuits of the inverter, and the energy behind the impulses is much greater due to the energy storage of the capacitors. It is recommended that capacitors should be at least 75 Meters away from inverter inputs to elevate the impedance between the inverter and capacitors and reduce the potential damage caused. Switching capacitors, Automatic bank correction etc, causes voltage transients and these transients can damage the input circuits of inverters. The energy is proportional to the amount of capacitance being switched. It is better to switch lots of small amounts of capacitance than few large amounts.

1.4.1.4 Solid state soft starter.

Static Power Factor correction capacitors must not be connected to the output of a solid-state soft starter. When a solid-state soft starter is used, a separate contactor must control the capacitors. The capacitor contactor is only switched on when the soft starter output voltage has reached line voltage. Many soft starters provide a "top of ramp" or "bypass contactor control" which can be used to control the PFC capacitor contactor. If the soft starter is used without an isolation contactor, the connection of capacitors close to the input of the soft starter can also cause damage if they are switched while the soft starter is not drawing current. The capacitors tend to cause transients to be amplified resulting in higher voltage impulses applied to the SCR’s of the soft starter, and due to the energy storage of capacitors, the energy behind the impulses is much greater. In such installations, it is recommended that the capacitors be mounted at least 50 meters from the soft starter. The elevated the impedance between the soft starter and the capacitors reduces the potential for damage to the SCR’s. Switching capacitors, Automatic bank correction etc, will cause voltage transients and these transients can damage the SCR’s of Soft Starters if they are in the off state without an input contactor. The energy is proportional to the amount of capacitance being switched. It is better to switch lots of small amounts of capacitance than few large amounts. Power factor controller solid-state soft starter is shown in figure 1.14.

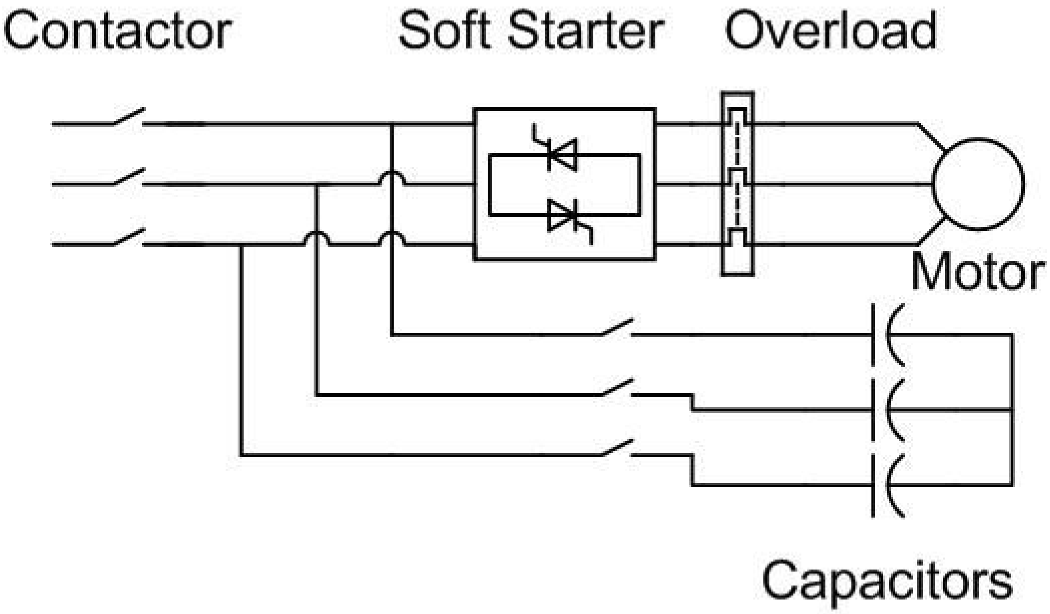


Figure 1.14: Power factor controller solid-state soft starter

1.4.2 Demerits of CPFC and its solution

1.4.2.1 Capacitor selection.

Static Power factor correction must neutralize no more than 80% of the magnetizing current of the motor. If the correction is too high, there is a high probability of over correction which can result in equipment failure with severe damage to the motor and capacitors. Unfortunately, the magnetizing current of induction motors varies considerably between different motor designs. The magnetizing current is almost always higher than 20% of the rated full load current of the motor, but can be as high as 60% of the rated current of the motor. Most power factor correction is too light due to the selection based on tables which have been published by a number of sources. These tables assume the lowest magnetizing current and quote capacitors for this current. In practice, this can mean that the correction is often less than half the value that it should be and the consumer is unnecessarily penalized. Power factor correction must be correctly selected based on the actual motor being corrected. The electrical calculations software provides two methods of calculating the correct value of KVAR correction to apply to a motor. The first method requires the magnetizing current of the motor. Where this figure is available, then this is the preferred method. Where the magnetizing current is not available, the second method is employed and is based on the half load power factor and efficiency of that motor.

1.4.2.2 Supply harmonics

Harmonics on the supply cause a higher current to flow in the capacitors. This is because the impedance of the capacitors goes down as the frequency goes up. This increase in current flow through the capacitor will result in additional heating of the capacitor and reduce its life. The harmonics are caused but many non linear loads, the most common in the industrial market today, are the variable speed controllers and switch mode power supplies. Harmonic voltages can be reduced by the use of a harmonic compensator, which is essentially a large inverter that chancels out the harmonics. This is an expensive option. Passive harmonic filters comprising resistors, inductors and capacitors can also be used to reduce harmonic voltages. This is also an expensive exercise.

In order to reduce the damage caused to the capacitors by the harmonic currents, it is becoming common today to install detuning reactors in series with the power factor correction capacitors. These reactors are designed to make the correction circuit inductive to the higher frequency harmonics. Typically, a reactor would be designed to create a resonant circuit with the capacitors above the third harmonic, but sometimes it is below. (Never tuned to a harmonic frequency) Adding the inductance in series with the capacitors will reduce their effective capacitance at the supply frequency. Reducing the resonant or tuned frequency will reduce the effective capacitance further. The object is to make the circuit look as inductive as possible at the 5th harmonic and higher, but as capacitive as possible at the fundamental frequency. Detuning reactors will also reduce the chance of the tuned circuit formed by the capacitors and the inductive supply being resonant on a supply harmonic frequency, thereby reducing damage due to supply resonances amplifying harmonic voltages caused by non linear loads.

1.4.2.3 Detuning reactors

Detuning reactors are connected in series with power factor correction capacitors to reduce harmonic currents and to ensure that the series resonant frequency does not occur at a harmonic of the supply frequency. The reactors are usually chosen and rated as either 5% or 7% reactors. This means that at the line frequency, the capacitive reactance is reduced by 5% or 7%. Using detuning reactors results a lower KVAR, so the capacitance needs to be increased for the same level of correction. When detuning reactors are used in installations with high harmonic voltages, there can be a high resultant voltage across the capacitors. This necessitates the use of capacitors that are designed to operate at a high sustained voltage. Capacitors designed for use at line voltage only, should not be used with detuning reactors. Check the suitability of the capacitors for use with line reactors before installation. The detuning reactors can dissipate a lot of heat. The enclosure must be well ventilated, typically forced air cooled. The detuning reactor must be specified to match the KVAR of the capacitance selected. The reactor would typically be rated as 12.5KVAR 5% meaning that it is a 5% reactor to connect to a 12.5KVAR capacitor. Supply resonance is shown in figure1.15.

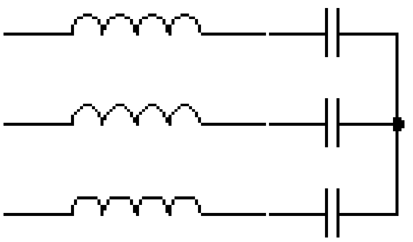


Figure 1.15: Supply Resonance.

Capacitive Power factor correction connected to a supply causes resonance between the supply and the capacitors. If the fault current of the supply is very high, the effect of the resonance will be minimal, however in a rural installation where the supply is very inductive and can be high impedance, the resonances can be very severe resulting in major damage to plant and equipment. Voltage surges and transients of several times the supply voltage are not uncommon in rural areas with weak supplies, especially when the load on the supply is low. As with any resonant system, a transient or sudden change in current results in the resonant circuit ringing, generating a high voltage. The magnitude of the voltage is dependent on the 'Q' of the circuit which in turn is a function of the circuit loading. One of the problems with supply resonance is that the 'reaction' is often well removed from the 'stimulus' unlike a pure voltage drop problem due to an overloaded supply. This makes fault finding very difficult and often damaging surges and transients on the supply are treated as 'just one of those things'.

To minimize supply resonance problems, there are a few steps that can be taken, but they do need to be taken by all on the particular supply. These are:

Minimize the amount of power factor correction, particularly when the load is light. The power factor correction minimizes losses in the supply. When the supply is lightly loaded, this is not such a problem; Minimize switching transients. Eliminate open transition switching - usually associated with generator plants and alternative supply switching, and with some electromechanical starters such as the star/delta starter; Switch capacitors on to the supply in lots of small steps rather than a few large steps. Switch capacitors on to the supply after the load has been applied and switch off the supply before or with the load removal; Harmonic Power Factor correction is not applied to circuits that draw either discontinuous or distorted current waveforms.

Most electronic equipment includes a means of creating a DC supply. This involves rectifying the AC voltage, causing harmonic currents. In some cases, these harmonic currents are insignificant relative to the total load current drawn, but in many installations, a large proportion of the current drawn is rich in harmonics. If the total harmonic current is large enough, there will be a resultant distortion of the supply waveform, which can interfere with the correct operation of other equipment. The addition of harmonic currents results in increased losses in the supply.

Power factor correction for distorted supplies cannot be achieved by the addition of capacitors. The harmonics can be reduced by designing the equipment using active rectifiers, by the addition of passive filters (LCR) or by the addition of electronic power factor correction inverters which restore the waveform back to its undistorted state. This is a specialist area requiring either major design changes, or specialized equipment to be used.

Reactive power

In a direct current (DC) circuit, or in an alternating current (AC) circuit whose impedance is a pure resistance, the voltage and current are in phase, and the following equation holds:

$$P = E_{\mathrm{rms}} I_{\mathrm{rms}} \qquad \text{eq. 14}$$

Where P is the power in watts, E_{rms} is the root-mean-square (rms) voltage in volts, and I_{rms} is the rms current in amperes. But in an AC circuit whose impedance consists of reactance as well as resistance, the voltage and current are not in phase. This complicates the determination of power. In the absence of reactance, the product $E_{\mathrm{rms}} I_{\mathrm{rms}}$ represents true power because it is manifested in tangible form (radiation, dissipation, and/or mechanical motion). But when there is reactance in an AC circuit, the product $E_{\mathrm{rms}} I_{\mathrm{rms}}$ is greater than the true power. The excess is called reactive power, and represents energy alternately stored and released by inductors and/or capacitors. The vector sum of the true and reactive power is known as apparent power.

1.5 Objective of work

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. This thesis defines the PIC (programmable interface controller) based power factor controller and various aspect of PIC (programmable interface controller) based power factor controller. The main core of this work is to design a PIC (programmable interface controller) based power factorcontroller. This system will be able to control the power factor of both linear and nonlinear load system.

1.6 Application

1.6.1 Electricity industry: power factor correction of linear loads

Power factor correction is achieved by complementing an inductive or a capacitive circuit with a (locally connected) reactance of opposite phase. For a typical phase lagging power factor load, such as a large induction motor, this would consist of a capacitor bank in the form of several parallel capacitors at the power input to the device.

Instead of using a capacitor, it is possible to use an unloaded synchronous motor. This is referred to as a synchronous condenser. It is started and connected to the electrical network. It operates at full leading power factor and puts VARs onto the network as required to support a system's voltage or to maintain the system power factor at a specified level. The condenser's installation and operation are identical to large electric motors.

The reactive power drawn by the synchronous motor is a function of its field excitation. Its principal advantage is the ease with which the amount of correction can be adjusted. It behaves like an electrically variable capacitor.

1.6.2 Switched-mode power supplies: power factor correction of non-linear loads

A typical switched-mode power supply first makes a DC bus, using a bridge rectifier or similar circuit. The output voltage is then derived from this DC bus. The problem with this is that the rectifier is a non-linear device, so the input current is highly non-linear. That means that the input current has energy at harmonics of the frequency of the voltage.

This presents a particular problem for the power companies, because they cannot compensate for the harmonic current by adding capacitors or inductors, as they could for the reactive power drawn by a linear load. Many jurisdictions are beginning to legally require PFC for all power supplies above a certain power level.

The simplest way to control the harmonic current is to use a filter: it is possible to design a filter that passes current only at line frequency (e.g. 50 or 60 Hz). This filter kills the harmonic current, which means that the non-linear device now looks like a linear load. At this point the power factor can be brought to near unity, using capacitors or inductors as required. This filter requires large-value high-current inductors, however, which are bulky and expensive.

It is also possible to perform active PFC. In this case, a boost converter is inserted between the bridge rectifier and the main input capacitors. The boost converter attempts to maintain a constant DC bus voltage on its output while drawing a current that is always in phase with and at the same frequency as the line voltage. Another switch mode converter inside the power supply produces the desired output voltage from the DC bus. This approach requires additional semiconductor switches and control electronics, but permits cheaper and smaller passive components. It is frequently used in practice. Due to their very wide input voltage range, many power supplies with active PFC can automatically adjust to operate on AC power from about 100 V (Japan) to 240 V (UK). That feature is particularly welcome in power supplies for laptops and cell phones.

Chapter 2

Hardware and its configuration

2.1 Methodology

The design aims to monitor phase angle continuously and in the event of phase angle deviation, a correction action is initialized to compensate for this difference by continuous changing variable capacitors value via switching process. The overall system requires only one PIC chip, a few power electronic components and a bank of capacitors.

2.2 Description of complete system

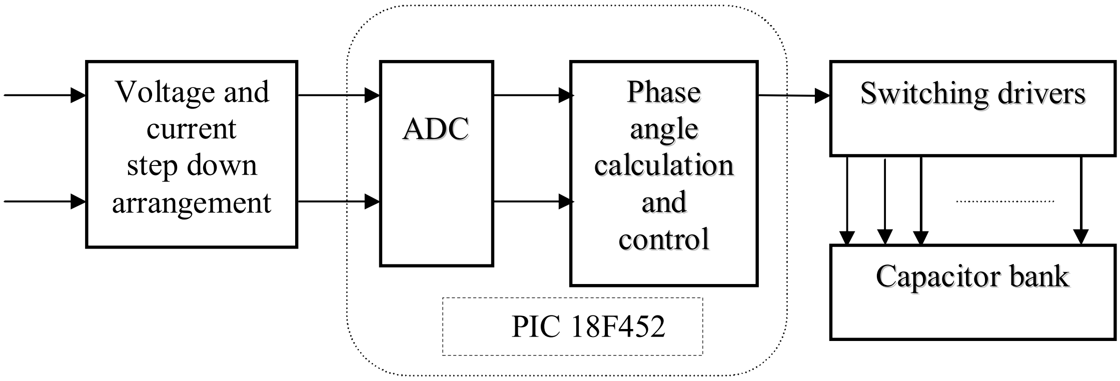


Figure 2.1: Block diagram of PIC based PFC

Block diagram of PIC based PFC is shown in figure 2.1 and PIC based PFC is shown in figure 2.2. Whole system may be divided into four stages. First stage is concern with the conversion of incoming voltage and current into the PIC level voltage (e.g. 5V). Here we have to use the step down arrangement like step down transformer; it is shown in figure 2.2.

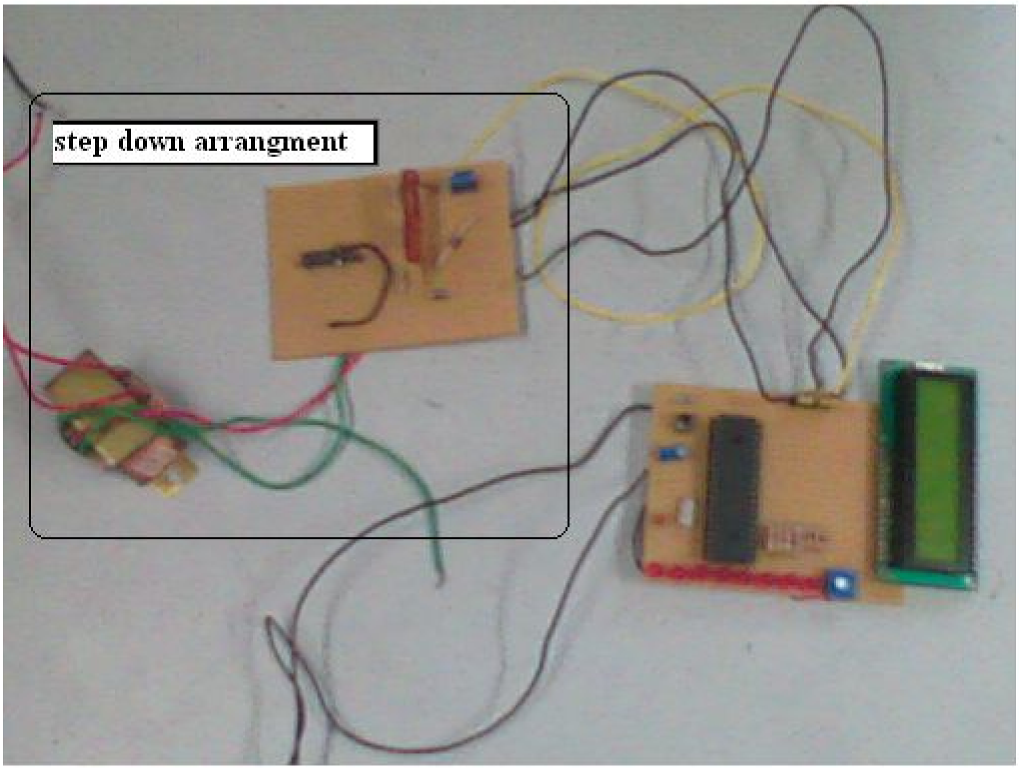


Figure 2.2: Picture showing PIC based PFC

Second stage is concerned with conversion of analog to digital signal. This is done by use of PIC. In this stage we calculate the phase angle between current and voltage that is continuously displayed on LCD as shown in figure 2.3. The digital voltage and current signal so acquired are processed in the PIC with the help of appropriate algorithm realized in its software. On the basis of phase angle PIC controls the switching drivers for on/off action of capacitor bank.

PIC 18F452 suits well to perform these tasks because of its following feature:

It has built in 10-bit Analog-to-Digital Converter module (A/D) with fast sampling rate approximately 0.632 MHz and good linearity (≤ 1 LSb). It has high current sink/ source (25 mA) for digital input/output. It has 3 external interrupt pins and four timer module, namely: Timer0 module: 8-bit/16-bit timer/counter with 8-bit programmable prescale; Timer1 module: 16-bit timer/counter; Timer2 module: 8-bit timer/counter with 8-bit period registers (time-base for PWM); Timer3 module: 16-bit timer/counter. One major reason for selecting 18F452 is its library support for interfacing multimedia card (MMC) drivers. A single command is required to write or read any data from MMC.

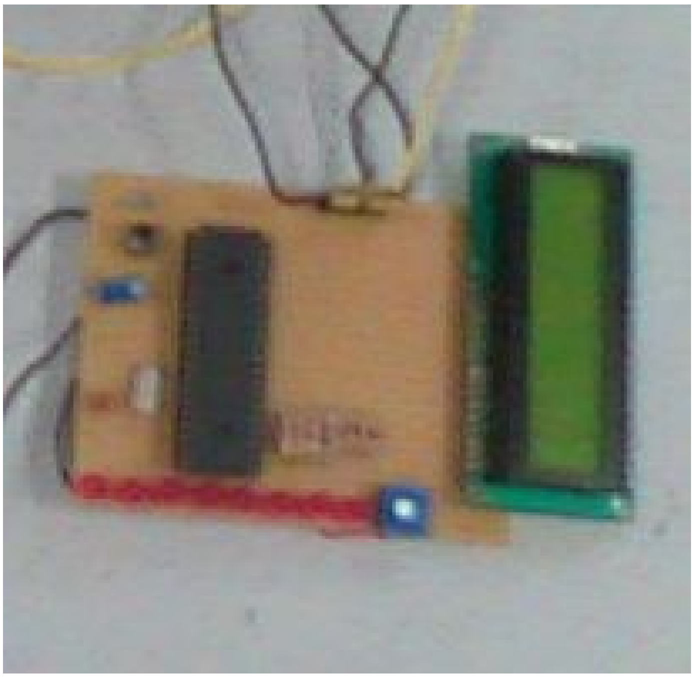
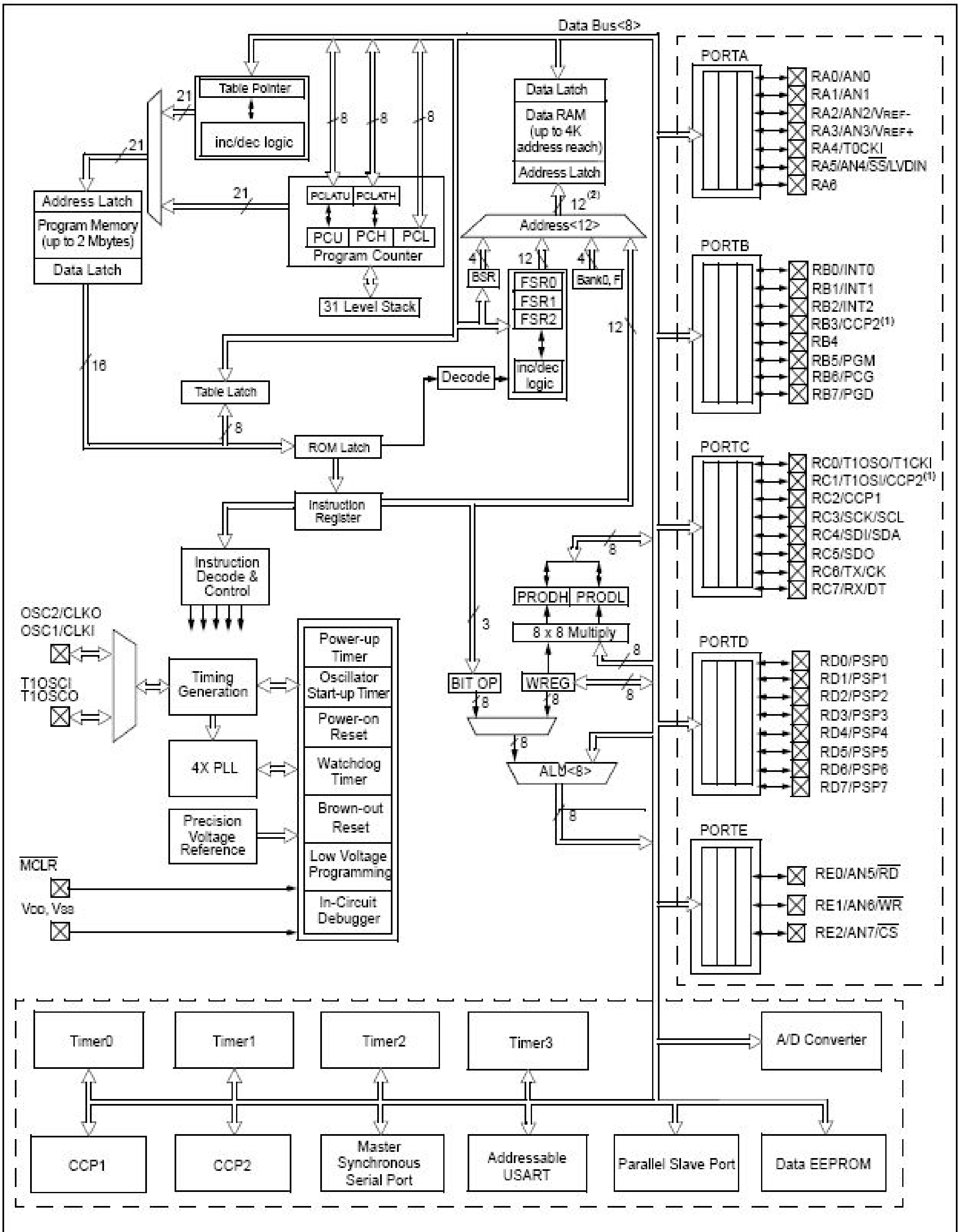


Figure 2.3: Continuously monitor on LCD

2.3 PIC18f452

PIC 18F452 is a16 bit microcontroller having high performance RISC CPU optimized architecture/instruction set, source code compatible with the PIC16 and PIC17 instruction sets. Linear program memory can address up to 32 Kbytes and linear data memory can address up to 1.5 Kbytes. Block diagram of 18F452 is shown in figure 2.5 [PIC 18F452 manual].



Note 1: Optional multiplexing of CCP2 input/output with RB3 is enabled by selection of configuration bit.

2: The high order bits of the Direct Address for the RAM are from the BSR register (except for the `MOVFF` instruction).

3: Many of the general purpose I/O pins are multiplexed with one or more peripheral module functions. The multiplexing combinations are device dependent.

Figure 2.4: Block diagram of 18F452

2.3.1 PIC microcontroller architecture

PIC18f452 has RISC Harvard architecture. Harvard architecture is a newer concept than von-Neumann. It rose out of the need to speed up the work of a microcontroller. In Harvard architecture data bus and address bus are separate. Thus a greater flow of data is possible through the central processing unit and of course a greater speed of work. Separating a program from data memory makes it further possible for instructions not to have to be 8-bit words. PIC18F452 uses 16 bits for instructions which allows for all instructions to be one word instructions. It is also typical for Harvard architecture to have fewer instructions than von-Neumann's, and to have instructions usually executed in one cycle.

Microcontrollers with Harvard architecture are also called "RISC microcontrollers". RISC stands for Reduced Instruction Set Computer. Microcontrollers with von-Neumann's architecture are called 'CISC microcontrollers', which stands for Complex Instruction Set Computer.

Since PIC18F452 is a RISC microcontroller, that means that it has a reduced set of instructions, more precisely 35 instructions. On the other hand CISC based Intel's and Motorola's microcontrollers have over hundred instructions.

PIC18F452 perfectly fits many uses, from automotive industries and controlling home appliances to industrial instruments, remote sensors, electrical door locks and safety devices. It is also ideal for smart cards as well as for battery-supplied devices because of its low power consumption. Block diagram of PIC 18F452 core feature is shown in figure 2.5.

2.3.2 Pin diagram

Pin diagram of PIC 18F452 is shown in figure 2.6. 18F 452 has 5 ports named as RA, RB, RC, RD and RE. Each pin of PIC 18F452 has more than one functions. Pin 11 and 32 are used as V_{DD}, pin 12 and 31 are used as V_{SS}. Pin 13 and 14 are used for oscillator. Pin 1 is used for reset and it is used in case of programming.

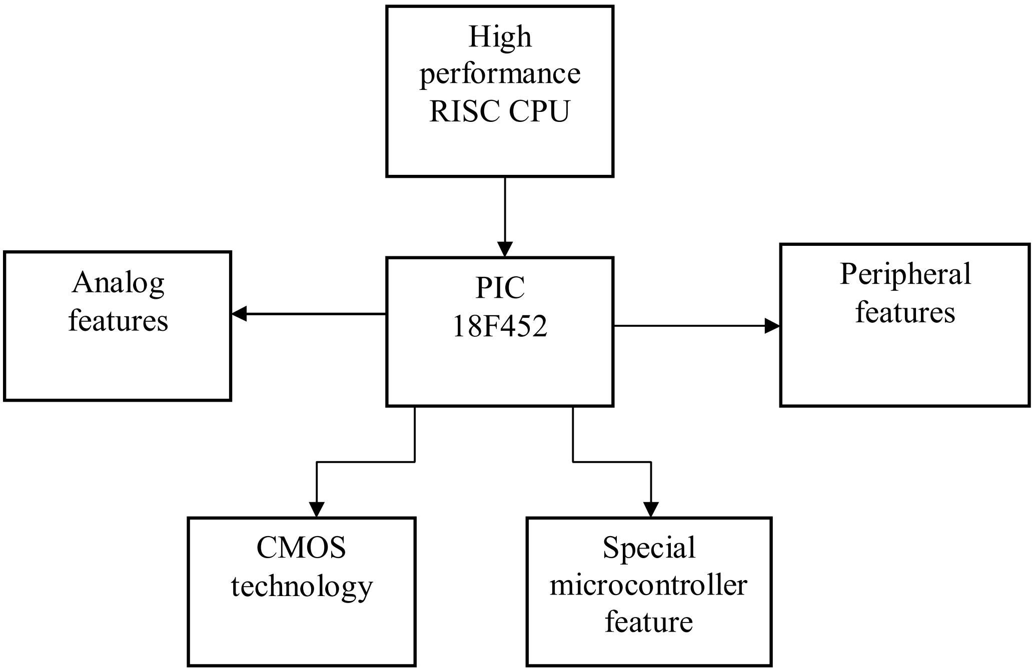


Figure 2.5: Block diagram of core features

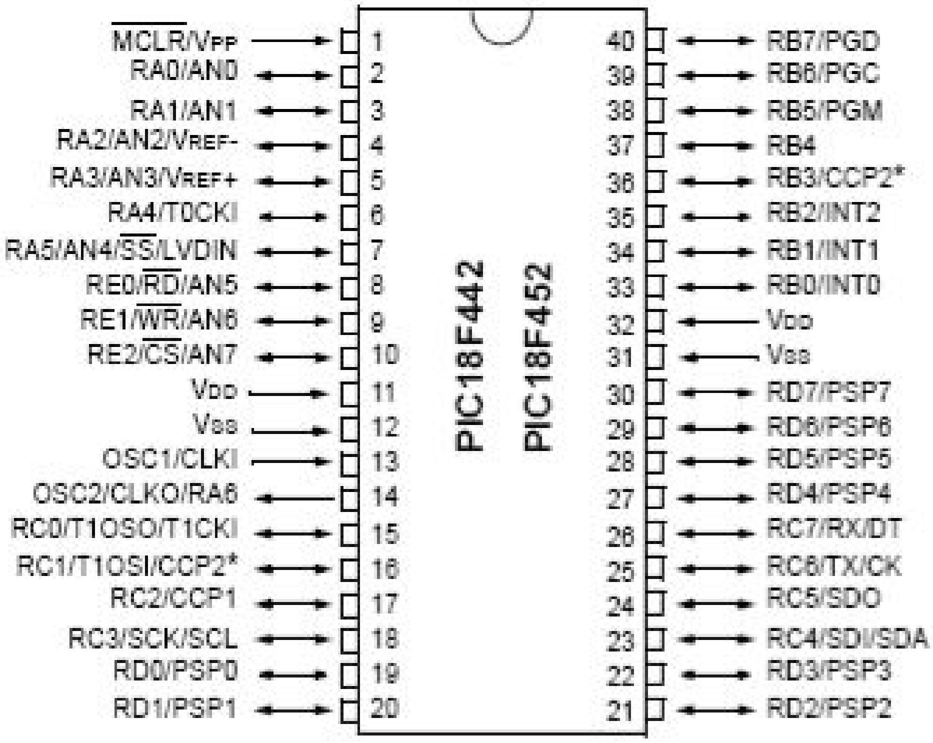


Figure 2.6: Pin diagram of PIC 18F452

2.3.3 Wiring the PIC

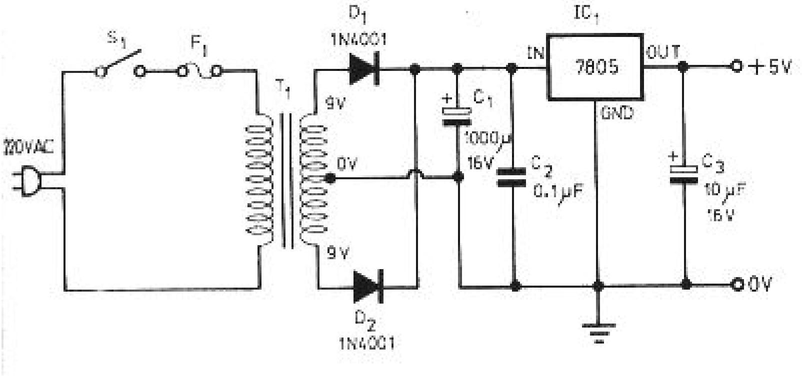


Figure 2.7: Power supply circuit

Power supply circuit diagram is shown in figure 2.7, which is used by the programming voltage (V_{PP}) pin and V_{DD} pin. V_{PP} pin is use only for providing V_{PP} voltage which is used by the PIC during programming.

2.3.4 Clock generator oscillator

Even though the microcontroller has built in oscillator, it cannot operate without external components which stabilize its operation and determine its frequency (operating speed of the microcontroller). Owing to the fact that it is almost impossible to make oscillator which operates sterilely over a wide frequency range, the microcontroller must know which crystal is connected in order that it can adjust the operation of its internal electronics to it. That is why all programs used for chip loading contain an option for oscillator mode selection. Depending on which elements are in use as well as their frequencies, the oscillator can be run in four different modes: LP - Low Power Crystal; XT - Crystal / Resonator; HS - High speed Crystal / Resonator; RC - Resistor / Capacitor. Deferent types of oscillator are:

2.3.5.1 Quartz resonator
2.3.5.2 Ceramic resonator
2.3.5.3 RC oscillator
2.3.5.4 External oscillator

2.3.4.1 Quartz resonator

In case a quartz crystal is used for frequency stabilization, the built in oscillator operates at very precise frequency which is independent from changes in temperature and voltage power supply as well. This frequency is normally labeled on the microcontroller package.

Apart from the crystal, in this case the capacitors C1 and C2 must be also connected as per scheme below. Their capacitance is not of great importance, therefore, the values provided in the table 2.1 should be considered as a recommendation rather than a strict rule.

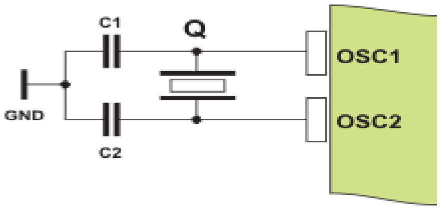
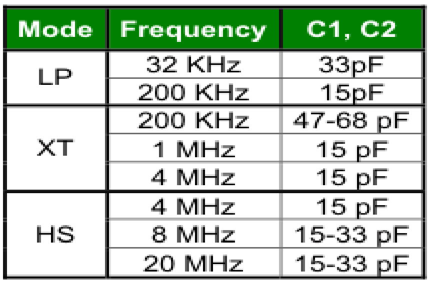


Figure 2.8: Quartz resonator circuit



Mode	Frequency	C1, C2
LP	32 KHz	33pF
	200 KHz	15pF
XT	200 KHz	47-68 pF
	1 MHz	15 pF
	4 MHz	15 pF
HS	4 MHz	15 pF
	8 MHz	15-33 pF
	20 MHz	15-33 pF

Table 2.1: capacitor with frequency

2.3.4.2 Ceramic resonator

Ceramic resonator is cheaper, but very similar to quartz by its function and the way of operating. That is why the schemes illustrating their connection to the microcontroller are identical. However, the capacitor value is a bit different in this case due to different electric features. Refer to the table 2.2.

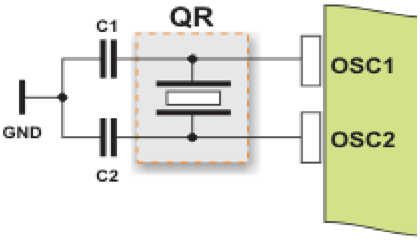
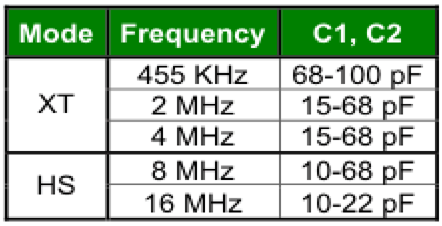


Figure 2.9: Ceramic resonator circuit



Mode	Frequency	C1, C2
XT	455 KHz	68-100 pF
	2 MHz	15-68 pF
	4 MHz	15-68 pF
HS	8 MHz	10-68 pF
	16 MHz	10-22 pF

Table 2.2: capacitor with frequency

These oscillators are used when it is not necessary to have extremely precise frequency.

2.3.4.3 RC oscillator

If the operating frequency is not of importance then there is no need to build in expensive components for stabilization. Instead of that, a simple RC network, as shown in figure 2.11 below, will be enough. Since only the input of the local oscillator input is in use here, clock signal with frequency Fosc/4 will appear on the OSC2 pin. Furthermore, that frequency represents at the same time a precise operating frequency of the microcontroller, i.e. the speed of instruction execution.

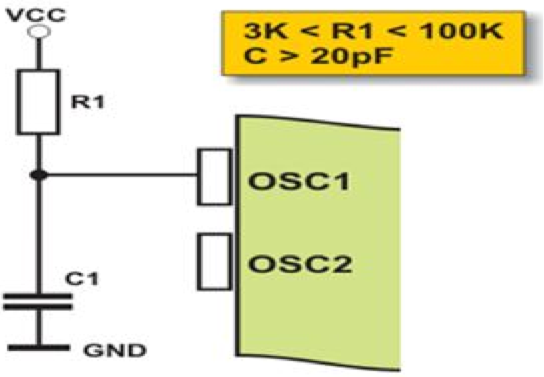


Figure 2.10: RC oscillator circuit

2.3.4.4 External oscillator

If it is needed to synchronize the operation of several microcontrollers or if for some reason it is not possible to use any of the previous schemes, a clock signal may be generated by an external oscillator. Refer to figure 2.12.

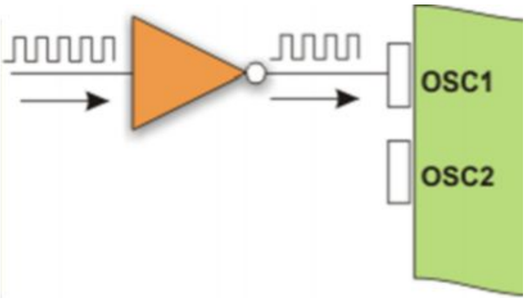


Figure 2.11: External oscillator circuit

In our work, we have used quartz crystal oscillator in XT mode because quartz crystal is used for frequency stabilization, the built in oscillator operates at very precise frequency, which is independent from changes in temperature and voltage power supply as well. This frequency is normally labeled on the microcontroller package.

2.3.5 Reset

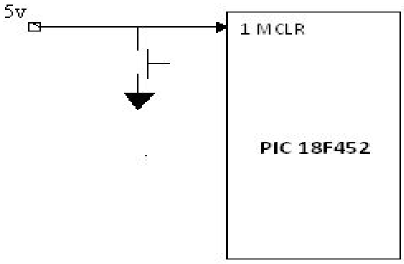


Figure 2.12: Reset circuit

Reset circuit is shown in figure 2.12. 5 V supply is given at pin 1 and one switch is attached with it so that when we press it, the pin 1 is reset. It is used to reset the program. It is also an interrupt having highest priority.

2.3.6 System programming

In order to program a program memory, microcontroller must be set to special working mode by bringing up V_{pp} pin to 13.5V, and supply voltage V_{DD} has to be stabilized between 4.5 to 5.5. Program memory can be programmed serially using two data/ clock pins which must previously be separated from device lines, so that errors wouldn't come up during programming.

2.4 MMC card and its connection with PIC

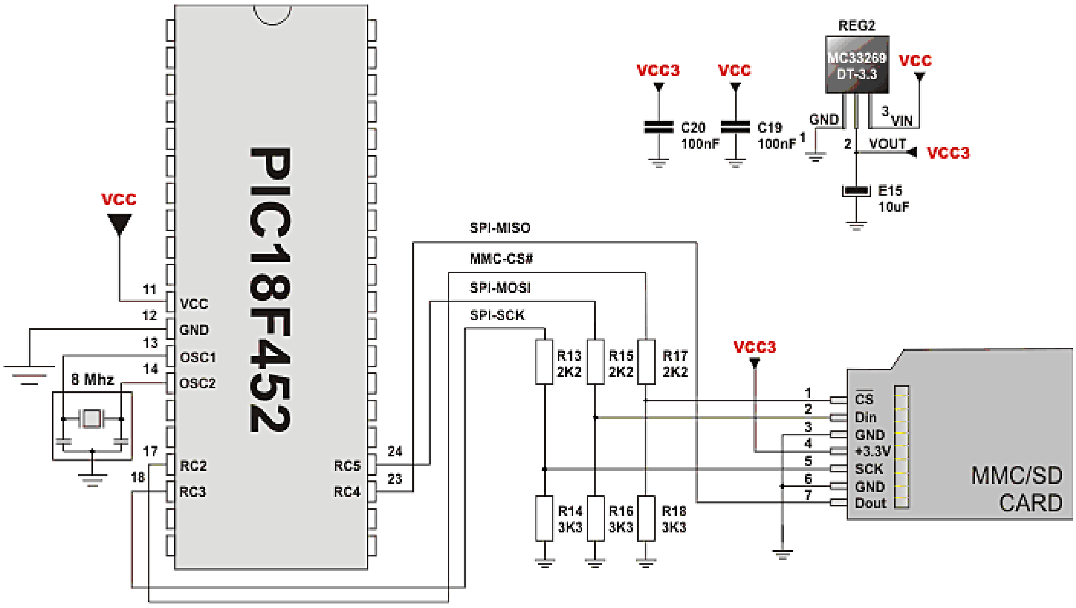


Figure 2.13: MMC card connection diagram

The Multi Media Card (MMC) is a flash memory card standard. MMC cards are currently available in sizes up to and including 1 GB, and are used in cell phones, mp3 players, digital cameras, and PDA's.

Secure Digital (SD) is a flash memory card standard, based on the older Multi Media Card (MMC) format. SD cards are currently available in sizes of up to and including 2 GB, and are used in cell phones, mp3 players, digital cameras, and PDAs. These two only works with PIC18 family.

2.5 LCD and its connection with PIC

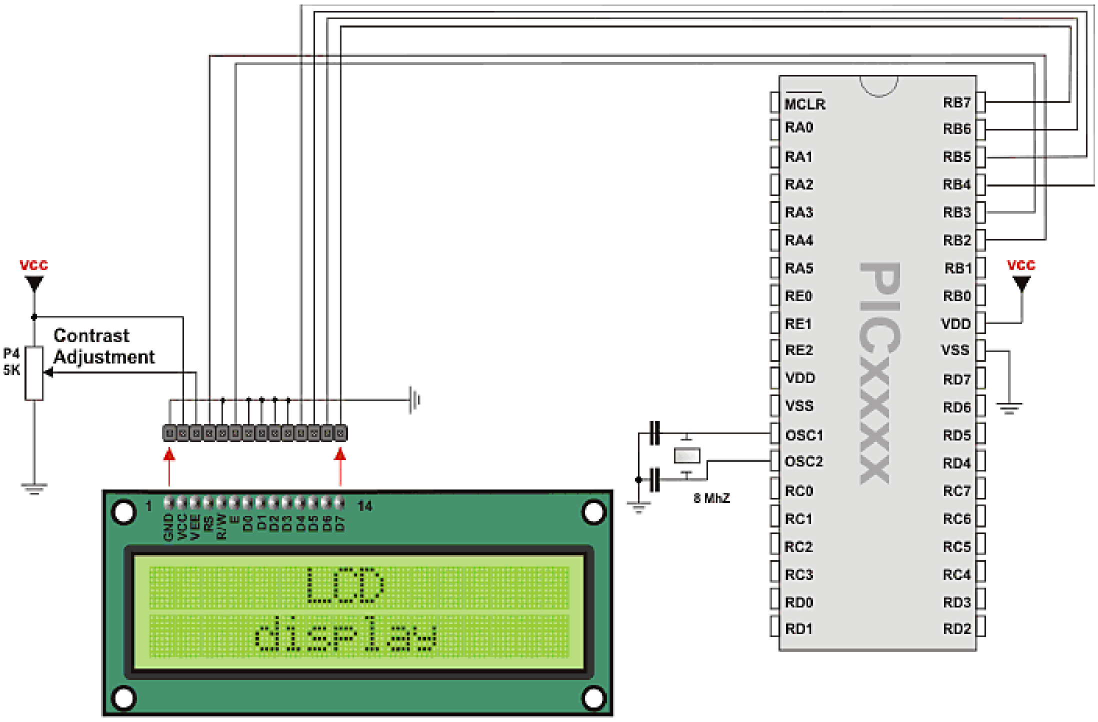


Figure 2.14: LCD connection diagram

A liquid crystal display (LCD) is a thin, flat display device made up of any number of color or monochrome pixels arrayed in front of a light source or reflector. It is often utilized in battery-powered electronic devices because it uses very small amounts of electric power.

LCDs with a small number of segments, such as those used in digital watches and pocket calculators, have individual electrical contacts for each segment. An external dedicated circuit supplies an electric charge to control each segment. This display structure is unwieldy for more than a few display elements.

Small monochrome displays such as those found in personal organizers, or older laptop screens have a passive-matrix structure employing super-twisted nematic (STN) or double-layer STN (DSTN) technology—the latter of which addresses a color-shifting problem with the former—and color-STN (CSTN)—wherein color is added by using an internal filter. Each row or column of the display has a single electrical circuit. The pixels are addressed one at a time by row and column addresses. This type of display is called *passive-matrix addressed* because the pixel must retain its state between refreshes without the benefit of a steady electrical charge. As the number of pixels (and, correspondingly, columns and rows) increases, this type of display becomes less feasible. Very slow response times and poor contrast are typical of passive-matrix addressed LCDs.

2.6 Capacitor banks used for power factor correction

Generally used capacitors for power factor controller are: LKT type power factor correction capacitors; C and CB Type capacitor modules; SBA Type - Automatically Controlled Capacitor Modules; SBC Type - Statically Controlled Capacitor Modules

2.6.1 LKT type power factor correction capacitors

These capacitors feature an all metallic construction within a cylindrical aluminum case. Advanced safety features include; self healing qualities, an integral overpressure disconnect device and non toxic impregnated polypropylene capacitor elements. The unique construction of this product prevents leakage even if the casing is punctured.

Safety features

The dielectric is self-healing. In the case of a breakdown caused, for example, by voltage overload, the self healing effect takes place. If the self healing process does not operate (e.g. because of voltage, current or thermal overload) the cover plate, which is designed as an overload valve, is raised and ruptures the internal connecting wires to the coils, so that the capacitor is separated from the mains.

2.6.2 C and CB type capacitor modules

The C and CB Type capacitor modules are designed for local correction of individual loads, such as single motors, starters or control gear, where Power Factor Correction is more appropriately located at the source. The CB Series Incorporates an integral Circuit Breaker for independent isolation and overload protection.

2.6.3 SBA type - Automatically controlled capacitor modules

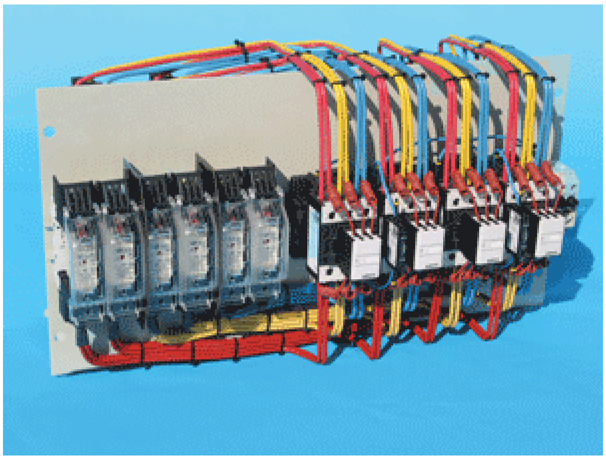


Figure 2.15: SBA type capacitor modules

These automatic modules are designed to fit into existing switchgear, control panels or pre-installed Power Factor Correction units. Control is provided automatically, via an independent or existing Power Factor control relay. The equipment incorporates a soft-switching contactor arrangement to minimize system disturbance caused by capacitor switching. A pre-connection resistor system is integrated within the contactors, which reduces the effect of current inrush to a minimum. Highly reliable, low loss capacitors with self healing properties. Safety protection system built into each capacitor element. SBA type capacitor modules is shown in figure 2.16

2.6.4 SBC type - Statically controlled capacitor modules

Static Power Factor Correction modules for placement within an existing control panel, switchgear cubicle or Power Factor Correction unit. These modules can be independently switched, if required, via customers own control gear. Highly reliable, low loss capacitors with self healing properties.

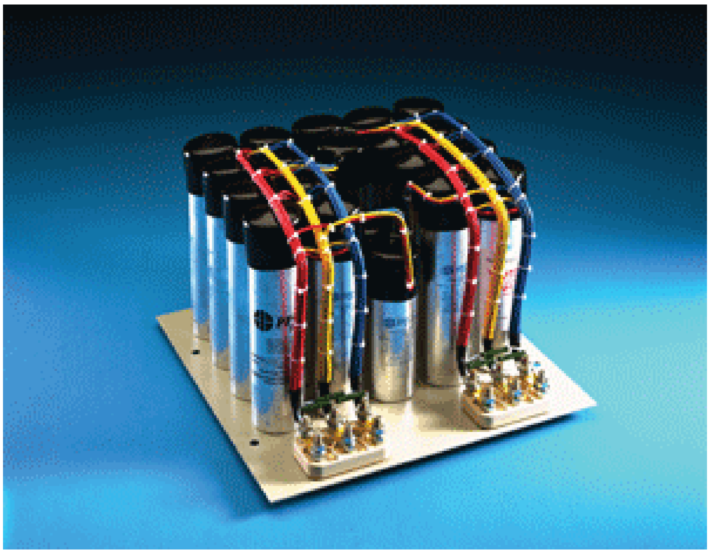


Figure 2.16: SBC type capacitor module

Safety protection system incorporated into each capacitor element. SBC type capacitor module is shown in figure 2.17.

Chapter 3

Software development environment

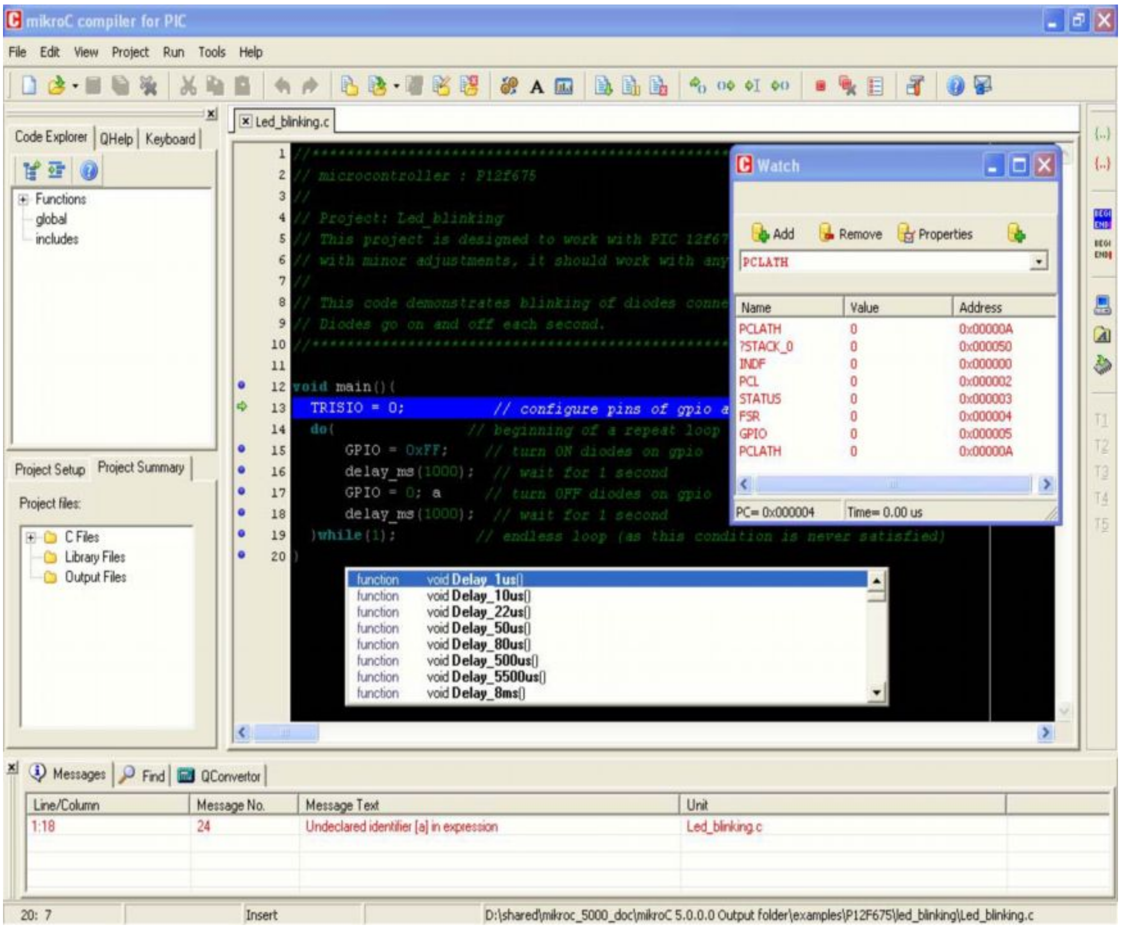
3.1 Introduction to mikroC

MikroC is a powerful, feature rich development tool for PIC controllers. It is designed to provide the user with the easiest possible solution for developing applications for embedded systems, without compromising performance or control. MikroC provides a successful match featuring highly advanced Integrated Development Environment, American National Standards Institute compliant compiler, broad set of hardware libraries, comprehensive documentation, and plenty of ready-to-run examples.

MikroC allows quickly develop and deploy complex applications. For programming PIC with mikroC C source code is first written using the highly advanced Code Editor, the included mikroC libraries are used to speed up the development: data acquisition, memory, displays and conversions function. Functions are used to monitor program structure, variables, and functions in the Code Explorer. MikroC generates commented, human-readable assembly, and standard HEX compatible with all programmers. The program is finely inspected with flow and debugs executable logic with the integrated Debugger. Figure 3.1 shows mikroC window.

3.2 MikroC integrated development environment

MikroC IDE has Seven different part through which we can make the projects. These are: Code editor, Code explorer, Debugger, Error window, Statistics, Integrated tools and Keyboard shortcuts [MikroC manual].



```
//**************************************************
// microcontroller : P12f675
//
// Project: Led_blinking
// This project is designed to work with PIC 12f67
// with minor adjustments, it should work with any
//
// This code demonstrates blinking of diodes conne
// Diodes go on and off each second.
//**************************************************

void main(){
  TRISIO = 0;              // configure pins of gpio a
  do{                   // beginning of a repeat loop
      GPIO = 0xFF;     // turn ON diodes on gpio
      delay_ms(1000);  // wait for 1 second
      GPIO = 0; a      // turn OFF diodes on gpio
      delay_ms(1000);  // wait for 1 second
  }while(1);           // endless loop (as this condition is never satisfied)
}
```

```
function    void Delay_1us()
function    void Delay_10us()
function    void Delay_22us()
function    void Delay_50us()
function    void Delay_80us()
function    void Delay_500us()
function    void Delay_5500us()
function    void Delay_8ms()
```

PCLATH

Name	Value	Address
PCLATH	0	0x00000A
?STACK_0	0	0x000050
INDF	0	0x000000
PCL	0	0x000002
STATUS	0	0x000003
FSR	0	0x000004
GPIO	0	0x000005
PCLATH	0	0x00000A

PC= 0x000004 Time= 0.00 us

Line/Column	Message No.	Message Text	Unit
1:18	24	Undeclared identifier [a] in expression	Led_blinking.c

20: 7 Insert D:\shared\mikroc_5000_doc\mikroC 5.0.0.0 Output folder\examples\P12F675\led_blinking\Led_blinking.c

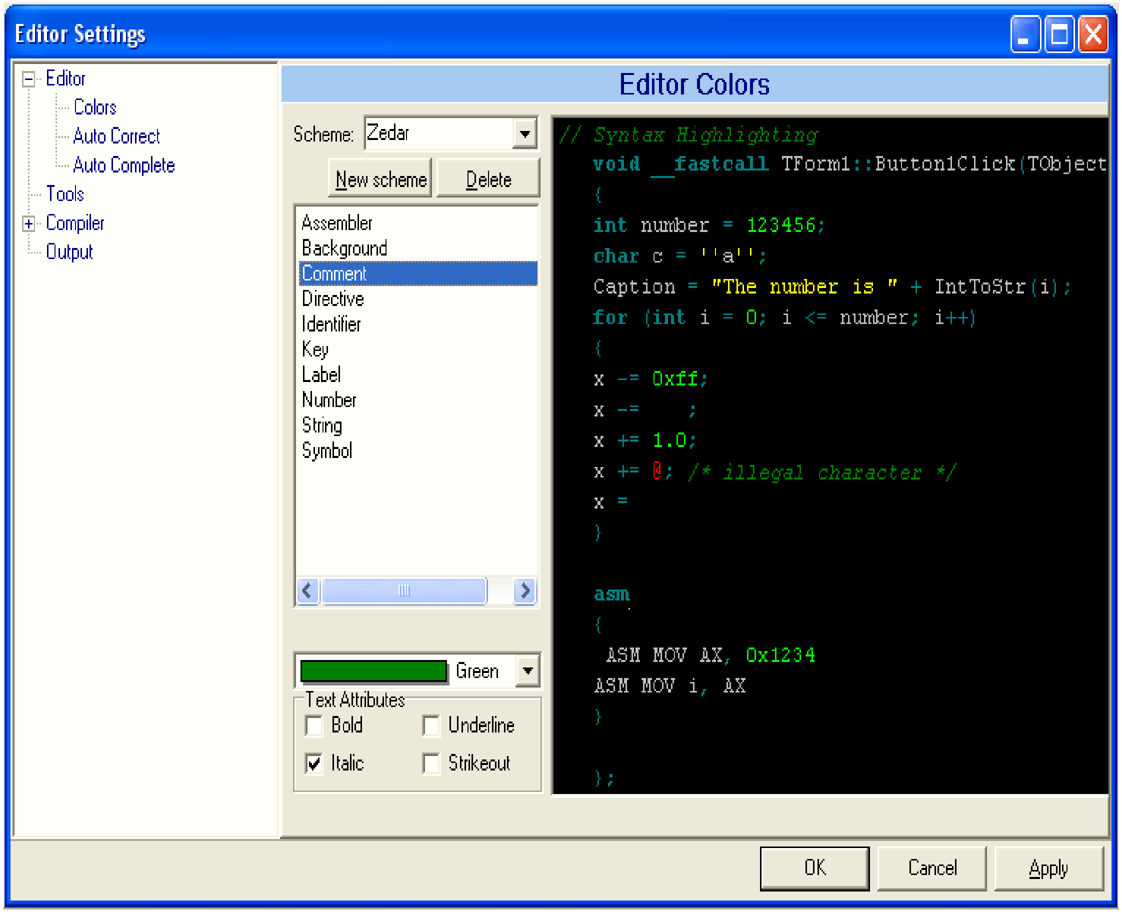
Figure 3.1: MikroC window

3.2.1 Code editor

The Code Editor is an advanced text editor fashioned to satisfy the needs of professionals. General code editing is same as working with any standard text-editor, including familiar Copy, Paste, and Undo actions, common for Windows environment. Advanced Editor Features include:

Adjustable Syntax Highlighting, Code Assistant, Parameter Assistant, Code Templates (Auto Complete), Auto Correct for common typos and Bookmarks and Goto Line.

We can customize these options from the Editor Settings dialog. To access the settings, choose Tools > Options from the drop-down menu, or click the Tools icon. Figure 3.2 shows code editor [MikroC manual].



Scheme: Zedar

Green

☐ Bold ☐ Underline

☑ Italic ☐ Strikeout

```
// Syntax Highlighting
   void __fastcall TForm1::Button1Click(TObject
   {
   int number = 123456;
   char c = ''a'';
   Caption = "The number is " + IntToStr(i);
   for (int i = 0; i <= number; i++)
   {
   x -= 0xff;
   x -=    ;
   x += 1.0;
   x += @; /* illegal character */
   x =
   }

   asm
   {
    ASM MOV AX, 0x1234
   ASM MOV i, AX
   }

   };
```

Figure 3.2: code editor

3.2.2 Code explorer

The Code Explorer is placed to the left of the main window by default, and gives a clear view of every declared item in the source code. We can jump to a declaration of any item by clicking it, or by clicking the Find Declaration icon. To expand or collapse tree view in Code Explorer, the Collapse/Expand All icon is used. Also, two more tabs are available in Code Explorer. Q Help Tab lists all the available built-in and library functions, for a quick reference. Double-clicking a routine in QHelp Tab opens the relevant Help topic. Keyboard Tab lists all the available Collapse/Expand keyboard shortcuts in mikroC. Figure 3.3 shows the code explorer[MikroC manual].

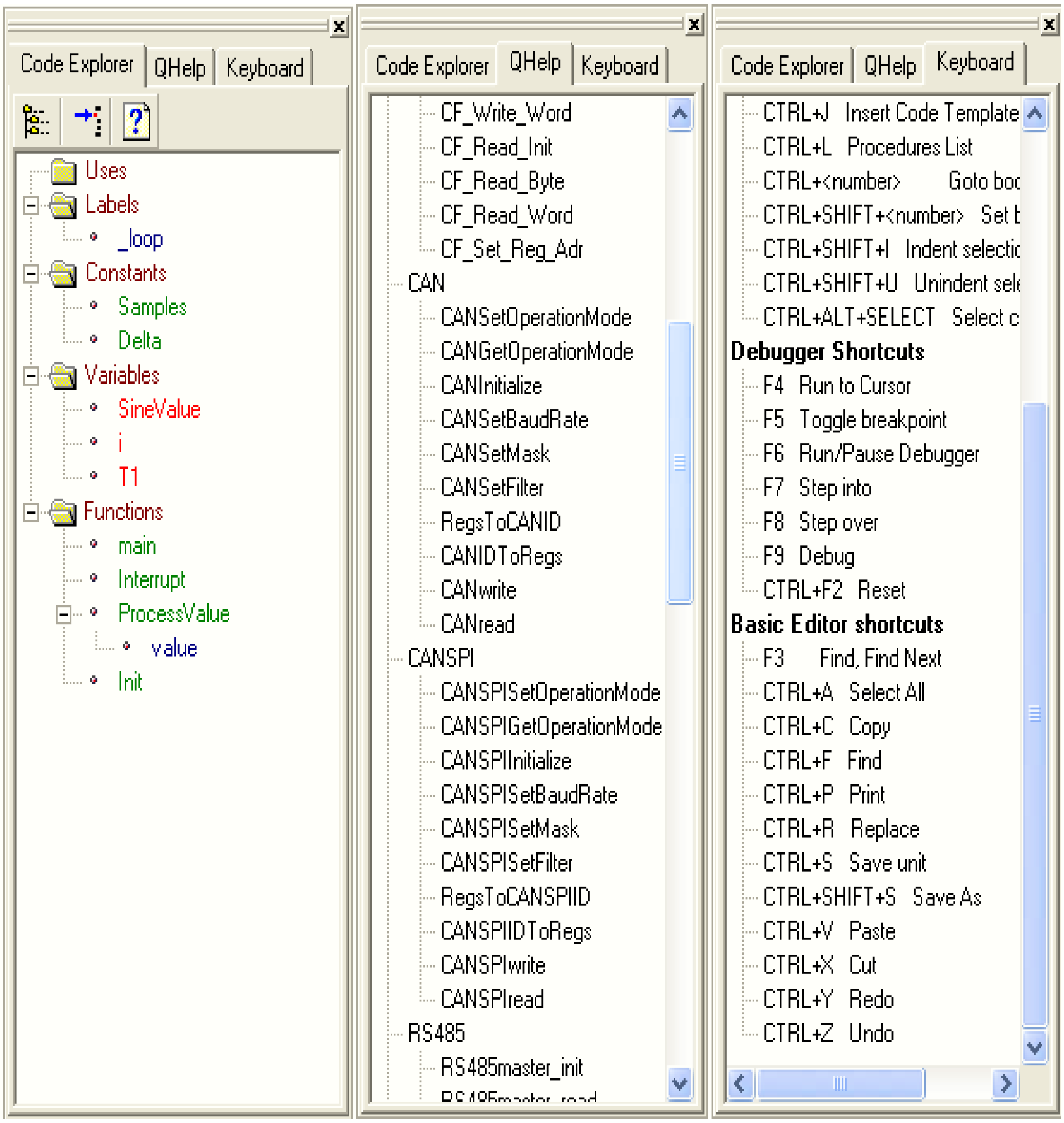


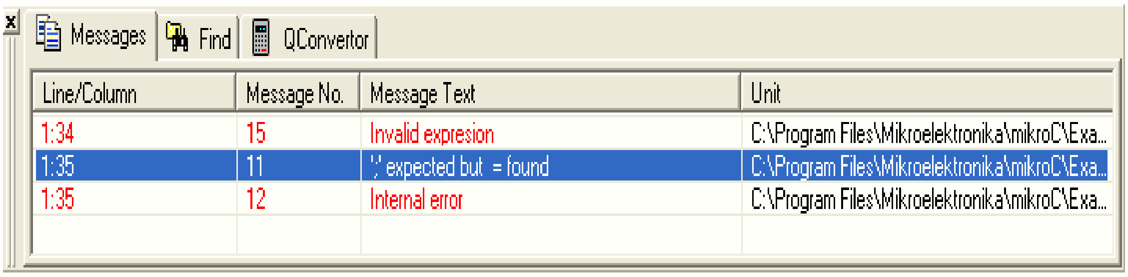
Figure 3.3: code explorer

3.2.3 Debugger

The source-level Debugger is an integral component of mikroC development environment. It is designed to simulate operations of Microchip Technology's PIC micros and to assist users in debugging software written for these devices. Start Debugger -The Debugger simulates program flow and execution of instruction lines, but does not fully emulate PIC device behavior: it does not update timers, interrupt flags, etc. After having successfully compiled the project, the Debugger is run by selecting Run > Debug from the drop-down menu, or by clicking the Debug Icon. Starting the Debugger makes more options available: Step Into, Step Over, Run to Cursor, etc. Line that is to be executed is color highlighted. Debug [F9] -Start the Debugger. Run/Pause Debugger [F6].

3.2.4 Error window

In case the errors were encountered during compiling, the compiler will report them and won't generate a hex file. The Error Window will be prompted at the bottom of the main window by default. The Error Window is located under the message tab, and displays location and type of errors compiler has encountered. The compiler also reports warnings, but these do not affect the output; only errors can interfere with generation of hex. Figure 3.4 shows error window.



Line/Column	Message No.	Message Text	Unit
1:34	15	Invalid expresion	C:\Program Files\Mikroelektronika\mikroC\Exa...
1:35	11	';' expected but = found	C:\Program Files\Mikroelektronika\mikroC\Exa...
1:35	12	Internal error	C:\Program Files\Mikroelektronika\mikroC\Exa...

Figure 3.4: Error window

3.2.5 Statistics

After successful compilation, we can review statistics of our code. Select Project > View Statistics from the drop-down menu, or click the Statistics icon. There are six tab windows: one of them is Memory Usage Window that Provides overview of RAM and ROM memory usage in form of histogram. Procedures (Graph) Window Displays functions in form of histogram, according to their memory allotment. Static window is shown in figure 3.5.

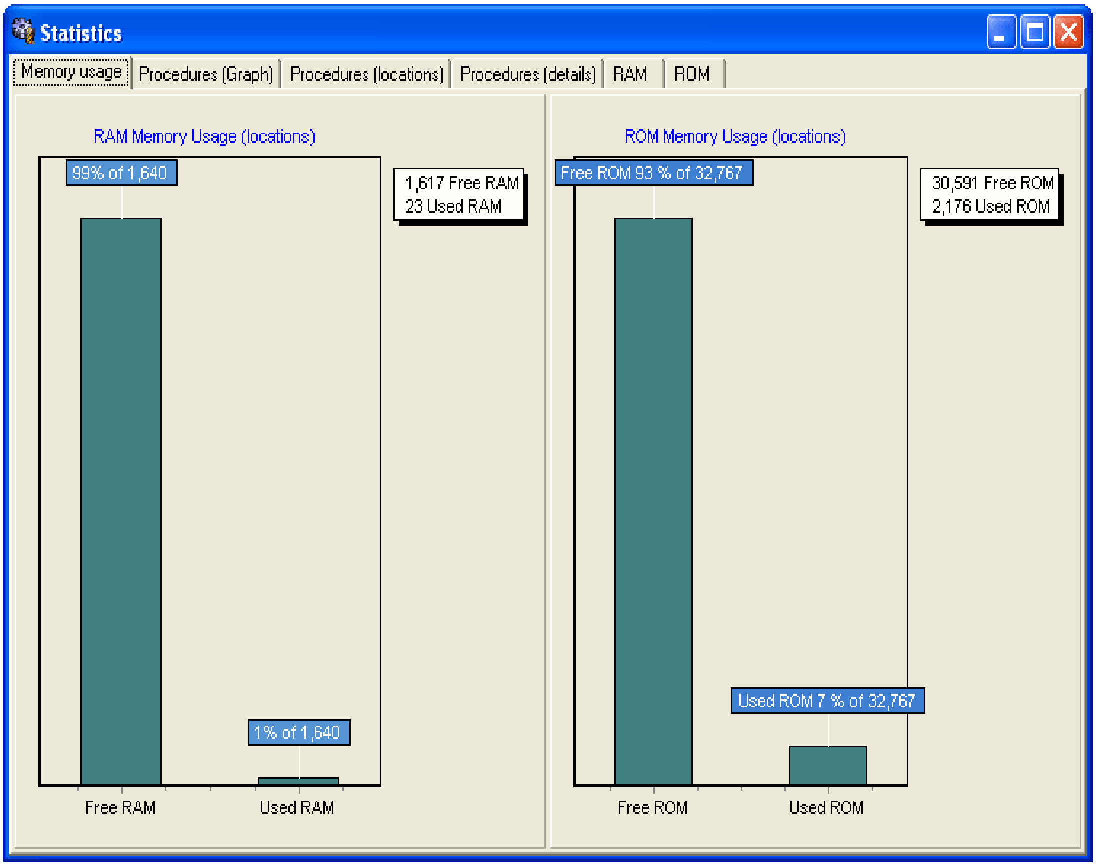


Figure 3.5: statistics window

3.2.6 Integrated tools

These contain four integrated tool namely: Universal synchronous asynchronous R/T terminal; ASCII chart; Seven segment display decoder; EEPROM editor.

3.2.6.1 Universal synchronous asynchronous R/T terminal

MikroC includes the USART (Universal Synchronous Asynchronous Receiver Transmitter) communication terminal for RS232 communication. It can be launched from the drop-down menu Tools > Terminal or by clicking the Terminal icon.

3.2.6.2 ASCII chart

The ASCII Chart is a handy tool, particularly useful when working with LCD display. You can launch it from the drop-down menu Tools > ASCII chart.

3.2.6.3 Seven segment display decoder

The 7seg Display Decoder is a convenient visual panel which returns decimal/hex value for any viable combination you would like to display on 7seg. It can be launched from the drop-down menu Tools > 7 Segment Display.

3.2.6.4 EEPROM editor

EEPROM Editor allows to easily managing EEPROM of PIC microcontroller.

3.2.7 Keyboard shortcuts

Below is the complete list of keyboard shortcuts available in mikroC IDE. It can be also viewed in Code Explorer window. IDE shortcuts are listed in table 3.1, Basic Editor Shortcuts are listed in table 3.2, Advance Editor Shortcuts are listed in table 3.3 and Debugger Shortcuts are listed in table 3.4..

IDE shortcuts

S.No.	Keyboard shortcuts	Explanation
1	F1	Help
2	CTRL + N	New unit
3	CTRL + O	Open
4	CTRL + F9	Compile
5	CTRL + F11	Code Explorer on/off
6	CTRL + SHIFT + F5	View breakpoints

Table 3.1: IDE shortcuts

Basic Editor Shortcuts

S.No.	Keyboard shortcuts	Explanation
1	F3	Find, Find Next
2	CTRL+A	Select All
3	CTRL+C	copy
4	CTRL+F	Find
5	CTRL+P	Print
6	CTRL+R	Replace
7	CTRL+S	Save Unit
8	CTRL+SHIFT+S	Save as
9	CTRL+V	Paste
10	CTRL+X	Cut
11	CTRL+Y	Redo
12	CTRL+Z	Undo

Table 3.2: Basic Editor Shortcuts

Advance Editor Shortcuts

S.No.	Keyboard shortcuts	Explanation
1	CTRL+SPACE	Code Assistant
2	CTRL+SHIFT+SPACE	Parameter Assistant
3	CTRL+D	Find declaration
4	CTRL+G	Goto Line
5	CTRL+J	Insert Code Template
6	CTRL+<number>	Goto Bookmark
7	CTRL+SHIFT+<number>	Set Bookmark
8	CTRL+SHIFT+I	Indent Selection
9	CTRL+SHIFT+U	UnIndent Selection
10	CTRL+ALT+SELECT	Select Columns

Table 3.3: Advance Editor Shortcuts

Debugger Shortcuts

S.No.	Keyboard shortcuts	Explanation
1	**F4**	Run to Cursor
2	**F5**	Toggle breakpoint
3	**F6**	Run/Pause Debugger
4	**F7**	Step into
5	**F8**	Step over
6	**F9**	Debug
7	**CTRL + F2**	Reset

Table 3.4: Debugger Shortcuts

3.3 Building application

Creating applications in mikroC is easy and intuitive. Project Wizard allows to set up the project in just few clicks: name the application, select chip and set flags. MikroC allows to distribute the projects in as many files as may be appropriate. MikroC compiled Libraries (.mcl files) can be showed with other .mcl developers without disclosing the source code [MikroC manual].

3.4 MikroC libraries

MikroC provides a number of built-in and library routines which help to develop the application faster and easier. Libraries for ADC, CAN, USART, SPI, I2C, 1-Wire, LCD, PWM, RS485, numeric formatting, bit manipulation, and many other are included along with practical, ready-to-use code examples, for detail go through the mikroC manual [MikroC manual].

Chapter 4

Control Scheme

4.1 Algorithm and programming

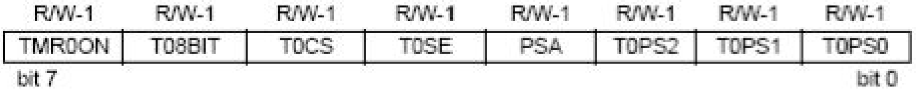
An algorithm is developed to make the PIC read the inputs and respond accordingly. There are two parts of programming one is related to counter, which is initialized through the timer 0 interrupt. Second is the main part of the program in which signal is taken by the PIC and gives the appropriate response to the controlling schemes.

Main program is divided into six parts-

1. Initialization of timer interrupt
2. Initialization of LCD
3. ADC module
4. Calculation of power factor
5. Comparison to the unity power factor
6. Generating the switching signal

4.2 Timer/Counter initialization

Timer register of timer 0 is shown in figure 4.1 [18F452 manual].



R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
TMR0ON	T08BIT	T0CS	T0SE	PSA	T0PS2	T0PS1	T0PS0
bit 7							bit 0

Figure 4.1: Timer register

The various bits of this register are programmed as per following scheme:

Bit 7 **TMR0ON:** Timer0 On/Off Control bit

1 = Enables Timer0

0 = Stops Timer0

bit 6 **T08BIT**: Timer0 8-bit/16-bit Control bit

1 = Timer0 is configured as an 8-bit timer/counter

0 = Timer0 is configured as a 16-bit timer/counter

bit 5 **T0CS**: Timer0 Clock Source Select bit

1 = Transition on T0CKI pin

0 = Internal instruction cycle clock (CLKO)

bit 4 **T0SE**: Timer0 Source Edge Select bit

1 = Increment on high-to-low transition on T0CKI pin

0 = Increment on low-to-high transition on T0CKI pin

bit 3 **PSA**: Timer0 Prescaler Assignment bit

1 = TImer0 prescaler is NOT assigned. Timer0 clock input bypasses prescaler.

0 = Timer0 prescaler is assigned. Timer0 clock input comes from prescaler output.

bit 2-0 **T0PS2:T0PS0**: Timer0 Prescaler Select bits

111 = 1:256 prescale value
110 = 1:128 prescale value
101 = 1:64 prescale value
100 = 1:32 prescale value
011 = 1:16 prescale value
010 = 1:8 prescale value
001 = 1:4 prescale value
000 = 1:2 prescale value

To program for the counter we have to initialize the counter by a initial value of 101, this value is calculated by using the formula:

Delay (in ms) = (# ticks) * 4*prescale*1000 /(clock frequency)

After initialization we enabled the timer interrupt with command INTCON = 0xA0, so that an interrupt is generated each time, when timer register overflows at this time the count will increase. For one second count value depends upon the prescale value as mentioned in Table 4.1. We have used prescale 1:4, count 3200 in our project.

Sr.no.	Prescale value	Count value
1	1:2	6400
2	1:4	3200
3	1:8	1600
4	1:16	800
5	1:32	400
6	1:64	200
7	1:128	100
8	1:256	50

Table 4.1: Count vale according to prescale value

4.3 LCD initialization

Figure 4.2 shows hardware interfacing of liquid crystal display (LCD) with PIC micro controller unit. MikroC provides a library for communicating with commonly used LCD (4-bit interface). We have to designate port with LCD as output, before using any of the following library functions. MikroC provides the user with seven library routines used for LCD. These are tabulated in Table 4.2 [mikroC manual].

Sr.No.	Commands	Work
1	Lcd_Config	For configuring the LCD
2	Lcd_Init	For initializing the LCD at any port
3	Lcd_Out	Print text to LCD at user define position
4	Lcd_Out_Cp	Print the text at next potion
5	Lcd_Chr	Print the character at user define position
6	Lcd_Chr_Cp	Print the character at next position
7	Lcd_Cmd	Use for giving any command to LCD

Table 4.2: LCD library routines

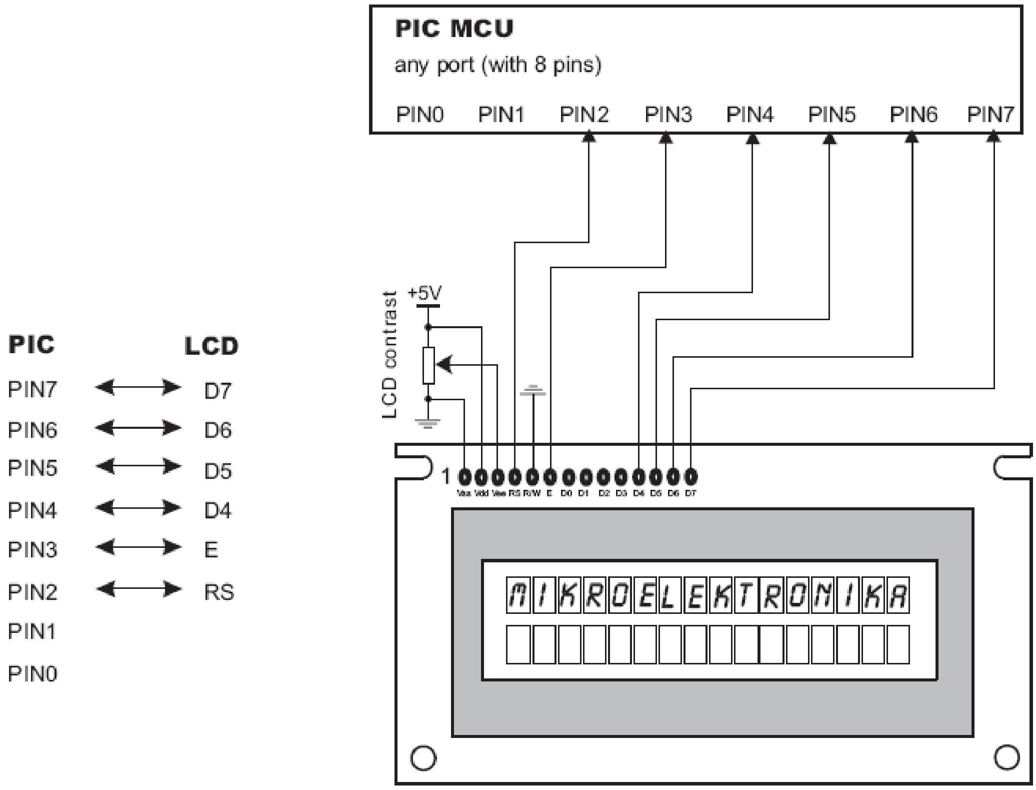


Figure 4.2: Connection diagram for LCD

After initialization we can display the output using some commands like, LCD_Out (row no. . column no., “text”) or LCD_char_cp (‘character’).

4.4 Analog to digital conversion

Apart from a large number of digital I/O lines, the PIC18F452 contains 8 analog inputs. They enable microcontroller to recognize not only whether some pin is driven to logic zero or one (0 or +5V), but to precisely measure its voltage and convert it into numerical value, i.e. digital format. The whole procedure takes place in A/D converter module which has the following features: the converter generates a 10-bit binary result using the method of successive approximation and stores the conversion results into the ADC registers (ADRESL and ADRESH); there are 8 separate analog inputs; the A/D converter allows conversion of an analog.

input signal to a 10-bit binary representation of that signal; by selecting voltage references Vref- and Vref+, the minimal resolution or quality of conversion may be adjusted to various needs.

4.4.1 ADC mode and registers

Even though the use of A/D converter seems to be very complicated, it is basically very simple, simpler than using timers and serial communication module [mikroe a].

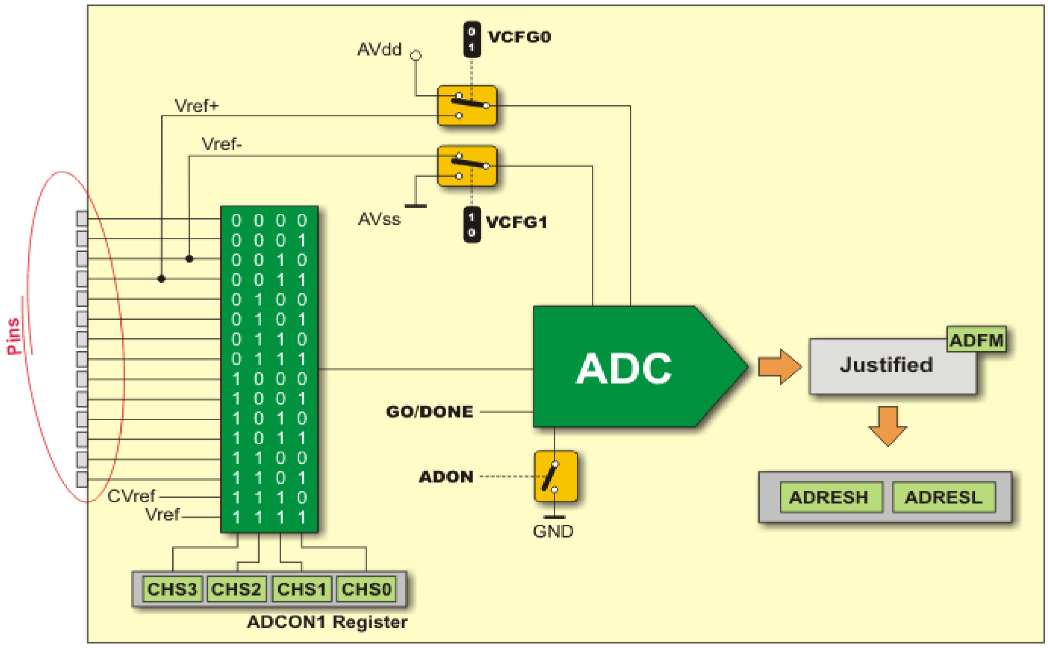


Figure 4.3: ADC Mode and Registers

The module is under control of the bits of four registers given in table 4.3.

Sr. No.	Register	Significant
1	ADRESH	Contains high byte of conversion result
2	ADRESL	Contains low byte of conversion result
3	ADCON0	Control register 0
4	ADCON1	Control register 1

Table 4.3: ADC mode registers

4.4.2 ADRESH and ADRESL registers

Upon converting an analog value into a digital one, the result of 10-bit A/D conversion will be stored in these two registers. In order to deal with this value easier, it can appear in two formats- left justified and right justified. The ADFM bit of the ADCON1 register determines the format of conversion result. In case the A/D converter is not used, these registers may be used as general-purpose registers.

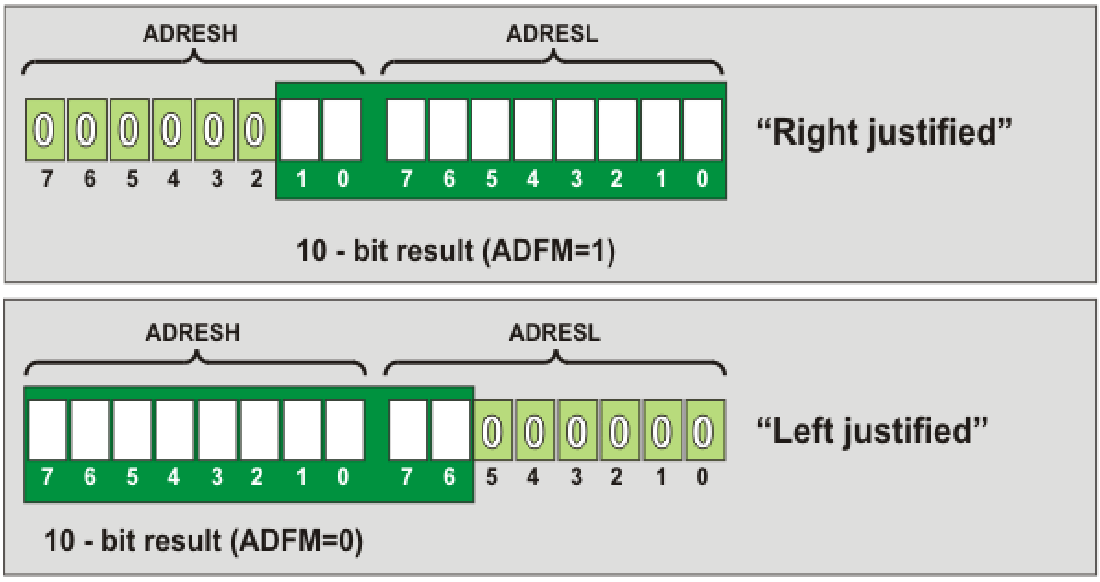


Figure 4.4: ADRESH and ADRESL Registers

4.4.3 A/D acquisition requirements

For the ADC to meet its specified accuracy, it is necessary to provide certain time delay between selecting specific analog input and measurement itself. That time is called "acquisition time" and mainly depends on the source impedance. In the worst case it amounts to approximately 20uS. Thus, after selecting (or changing) the analog input and before starting conversion it is necessary to provide at least 20uS time delay to enable the ADC maximal conversion accuracy.

4.4.4 ADC clock period

A time needed to complete one bit conversion is defined as time for analog to digital(TAD). The required TAD must be at least 1.6 uS. One full 10-bit A/D conversion is a bit longer than expected and amounts 11 TAD periods. However, since both the conversion clock frequency and source are determined by software, one of available combination of bits ADCS1 and ADCS0 should be selected before voltage measurement on some analog input starts. These bits are stored in the ADCON0 register [mikroe a].

ADC Clock Source	**ADCS1**	**ADCS0**	**Device Frequency (Fosc)**			
			20 Mhz	**8 Mhz**	**4 Mhz**	**1 Mhz**
Fosc/2	0	0	100 nS	250 nS	500 nS	2 uS
Fosc/8	0	1	400 nS	1 uS	2 uS	8 uS
Fosc/32	1	0	1.6 uS	4 uS	8 uS	32 uS
Frc	1	1	2 - 6 uS	2 - 6 uS	2 - 6 uS	2 - 6 uS

Table 4.4: ADC clock frequency with device clock frequency

Any change in the system clock frequency will affect the ADC clock frequency, which may adversely affect the ADC result. Device frequency characteristics are shown in the table 4.4. The values in the shaded cells are outside of recommended range.

4.4.5 Using A/D converter

In order to enable A/D converter to run without problems as well as to avoid unexpected results, it is necessary to consider the following: A/D converter does not differ between digital and analog voltages. In order to avoid errors in measurement or some chip damage to, the pins should be configured as analog inputs before conversion starts. The bits used for that purpose are stored in the TRIS and ANSELH registers; when the port with analog inputs marked as CH0-CH7 is read, the corresponding bits will be driven to logic zero (0); Roughly speaking, voltage measurement in converter is based on comparing input voltage with internal scale which has 1024 marks (210=1024). The lowest scale mark stands for the Vref- voltage, while the highest mark stands for the Vref+ voltage. Figure 4.5 shows selectable referent voltages and their minimum and maximum values as well.

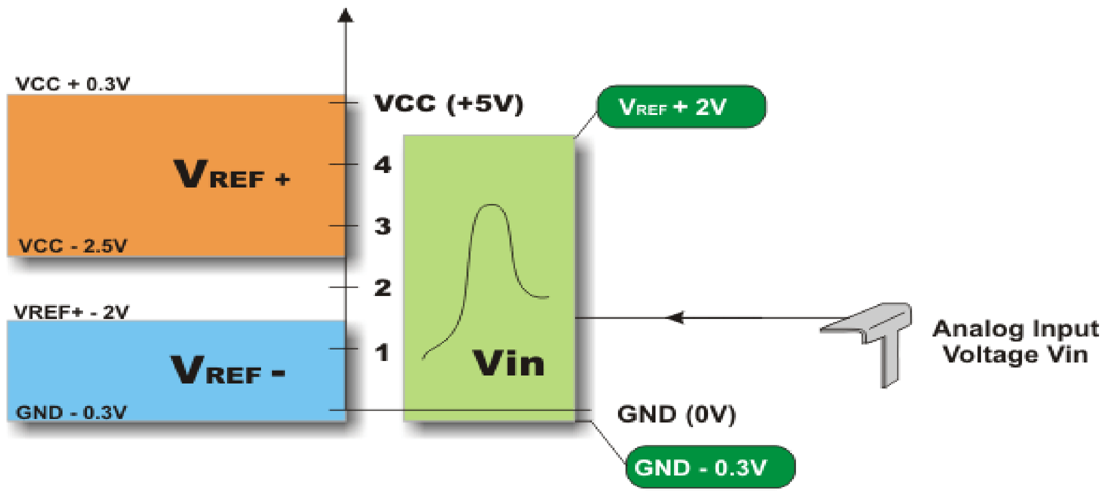
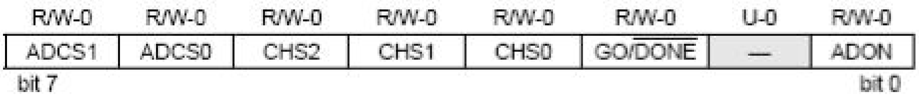


Figure 4.5: Voltage limits of A/D convertor

4.4.6 ADCON0 register

The ADCON0 register is used to control the operation of the A/D module. ADCON0 register is shown in figure 4.6 [18F452 manual].



R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	—	ADON
bit 7							bit 0

Figure 4.6: ADCON0 Register

ADCS1, ADCS0 - A/D Conversion Clock Select bits select clock frequency used internal synchronization of A/D converter. It also affects duration of conversion. Clock selection is depends upon the bit 6, 7 and ADCON1 register as shown in table 4.5.

Sr. No.	**ADCON1** **(ADCS2)**	**ADCON0** **(ADCS1:ADCS0)**	**Clock Conversion**
1	0	0 0	Fosc/2
2	0	0 1	Fosc/8
3	0	1 0	Fosc/32
4	0	1 1	Frc(clock derived from the internal A/D RC oscillator)
5	1	0 0	Fosc/4
6	1	0 1	Fosc/16
7	1	1 0	Fosc/64
8	1	1 1	Frc(clock derived from the internal A/D RC oscillator)

Table 4.5: Selection of clock

bit 5-3 **CHS2:CHS0:** Analog Channel Select bits

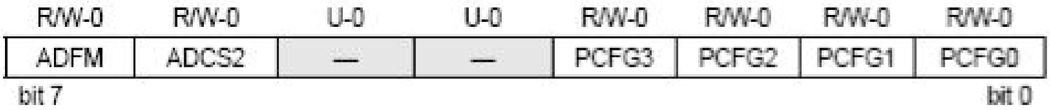
CHS2 :CHS1: CHS0	Analog Channel
0 0 0	channel 0, (AN0)
0 0 1	channel 1, (AN1)
0 1 0	channel 2, (AN2)
0 1 1	channel 2, (AN2)
1 0 0	channel 4, (AN4)
1 0 1	channel 5, (AN5)
1 1 0	channel 6, (AN6)
1 1 1	channel 7, (AN7)

Table 4.6: Analog channel selection

The PIC18F2X2 devices do not implement the full 8 A/D channels; the unimplemented selections are reserved. Do not select any unimplemented channel.

4.4.7 ADCON1 Register

The ADCON1 register, shown in figure 4.7, configures the functions of the port pins [18F452 manual].



R/W-0	R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	ADCS2	—	—	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

Figure 4.7: ADCON1register

Here only bit 3-0 **PCFG3:PCFG0** is used to configure the port pins as shown in table 4.7.

PCFG <3:0>	AN7	AN6	AN5	AN4	AN3	AN2	AN1	AN0	V_{REF+}	V_{REF-}	C/V
0000	A	A	A	A	A	A	A	A	V_{DD}	V_{SS}	8/0
0001	A	A	A	A	V_{REF+}	A	A	A	AN3	V_{SS}	7/1
0010	D	D	D	A	A	A	A	A	V_{DD}	V_{SS}	5/0
0010	D	D	D	A	V_{REF+}	A	A	A	AN3	V_{SS}	4/1
0100	D	D	D	D	A	D	A	A	V_{DD}	V_{SS}	3/0
0101	D	D	D	D	V_{REF+}	D	A	A	AN3	V_{SS}	2/1
011X	D	D	D	D	D	D	D	D	—	—	0/0
1000	A	A	A	A	V_{REF+}	V_{REF-}	A	A	AN3	AN2	6/2
1001	D	D	A	A	A	A	A	A	V_{DD}	V_{SS}	6/0
1010	D	D	A	A	V_{REF+}	A	A	A	AN3	V_{SS}	5/1
1011	D	D	A	A	V_{REF+}	V_{REF-}	A	A	AN3	AN2	4/2
1100	D	D	D	A	V_{REF+}	V_{REF-}	A	A	AN3	AN2	3/2
1101	D	D	D	D	V_{REF+}	V_{REF-}	A	A	AN3	AN2	2/2
1110	D	D	D	D	D	D	D	A	V_{DD}	V_{SS}	1/0
1111	D	D	D	D	V_{REF+}	V_{REF-}	D	A	AN3	AN2	1/2

Table 4.7: A/D Port Configuration

Here A = Analog input, D = Digital I/O, C/R = No. of analog input channels / No. of A/D voltage references, AN= Analog channel. Analog module is shown in figure 4.8.

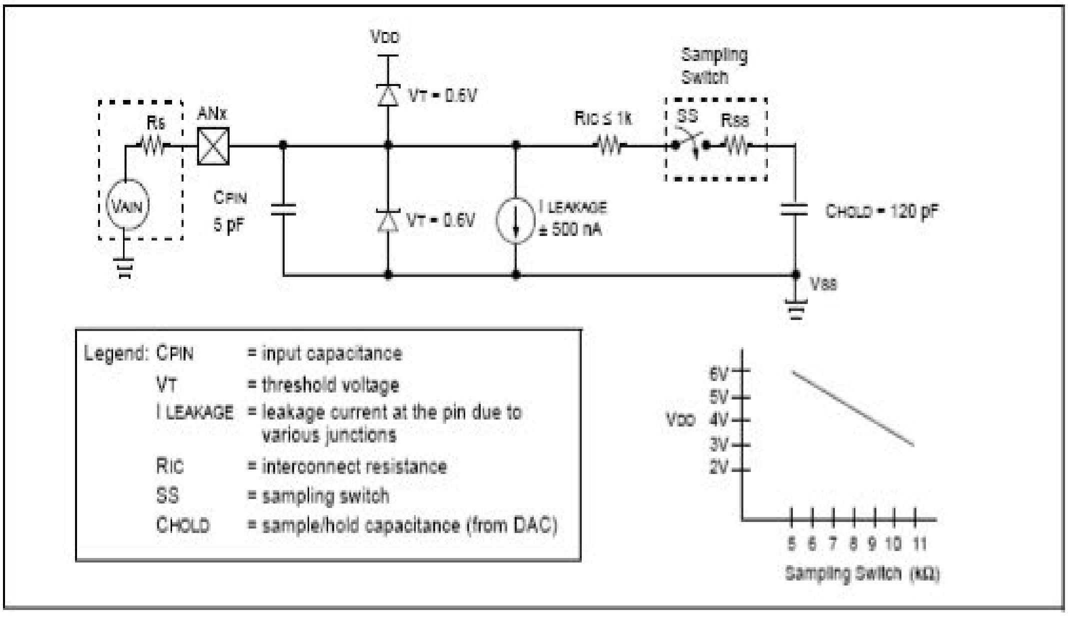


Figure 4.8: Analog module

In Short:

In order to measure voltage on an input pin by A/D converter the following are done:

Step 1- Configuring port: giving logic one (1) to the corresponding bit of the TRIS register to configure it as input; giving logic one (1) to the corresponding bit of the ADCON register to configure it as analog input.

Step 2- Configuring ADC module: configuring voltage reference in the ADCON1 register; selecting ADC conversion clock in the ADCON0 register; selecting one of input channels CH0-CH8 of the ADCON0 register; select data format using the ADFM bit of the ADCON1 register; enabling A/D converter by setting the ADON bit of the ADCON0 register.

Step 3- Configuring ADC interrupt (optionally): clearing the ADIF bit; set the ADIE, PEIE and GIE bits.

Step 4- Wait for the required acquisition time (approximately 20uS) to pass.

Step 5- Start conversion by setting the GO/DONE bit of the ADCON0 register.

Step 6- Wait for ADC conversion to complete. It is necessary to check in program loop whether the GO/DONE pin is cleared or wait for an A/D interrupt (must be previously enabled).

Step 7- Read ADC results: Read the ADRESH and ADRESL registers.

4.5 Algorithm for control scheme

Step 1- Set the user define lower and upper power factor (LPF & UPF).

Step 2- Set the user define threshold value of current (TUC).

Step 3- Determine power factor.

Step 4- determine value of current.

Step 5- if value of current is less than TUC, take no action and go to step 3.

Step 6- if the value of power factor is between LPF and UPF take no action and go to step 3.

Step 7- if the value of power factor is less than LPF switch on the next off capacitor and wait for 1.0 seconds. Go to step 3.

Step 8- If the value of power factor is more than UPF or as leading, switch off the first on capacitor and wait for 1.0 second. Go to step 3.

4.6 On/ off of capacitor

For the equally utilization of capacitors, we have chosen a method. In this method on/ off of capacitor is done in ascending order. 1st, 2nd … and so on. If it reaches to 8th then it rolls back to 1st.

Let initially one capacitor is on.

● ○ ○ ○ ○ ○ ○ ○

Then for lower power factor (lower than LPF)

● ● ○ ○ ○ ○ ○ ○

And it increases up to user limit.

● ● ● ○ ○ ○ ○ ○

● ● ● ● ○ ○ ○ ○

● ● ● ● ● ○ ○ ○

● ● ● ● ● ● ○ ○

As the power factor crosses the UPF limit then 1st capacitor is switched off.

○ ● ● ● ● ● ○ ○

And it continue up to the user limit

○ ○ ● ● ● ● ○ ○

○ ○ ○ ● ● ● ○ ○

○ ○ ○ ○ ● ● ○ ○

Again when it crosses the LPF limit then switching on process starts.

○ ○ ○ ○ ● ● ○ ○

○ ○ ○ ○ ● ● ● ○

○ ○ ○ ○ ● ● ● ●

As the 8th capacitor is switched on then next is 1st capacitor. Therefore 1st capacitor is switched on.

● ○ ○ ○ ● ● ● ●

And this way all capacitor is equally utilized.

4.7 Algorithm for determining power factor

Step 1- Check for voltage cross zero from negative to positive.

Step 2- Timer T starts (T).

Step 3- Timer ΔT starts (ΔT).

Step 4- Check for current cross zero from negative to positive.

Step 5- Timer ΔT stops.

Step 6- Check again for voltage cross zero from negative to positive.

Step 7- Timer T stops.

Step 8- Phase $\varphi = (\Delta T / T) * 360^0$.

Step 9- Get cos φ from look up table.

Step 10- If $\Delta T > T/4$ report power factor is leading.

Current and voltage waveform with time period (T) are shown in figure 4.9 and 4.10 and combined waveform with tme gap (∆T) is shown in figure 4.11.

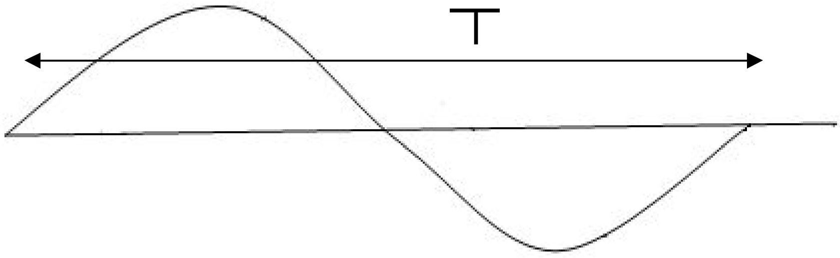


Figure 4.9: Voltage with time period

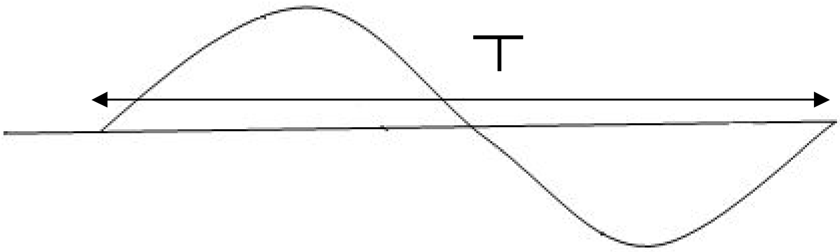


Figure 4.10: Current with time period

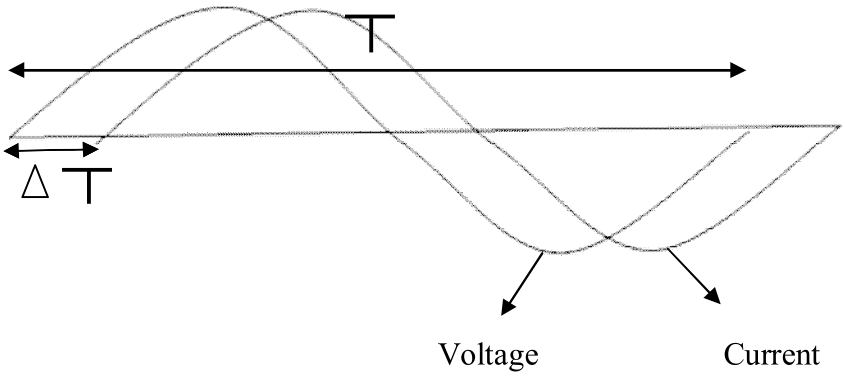
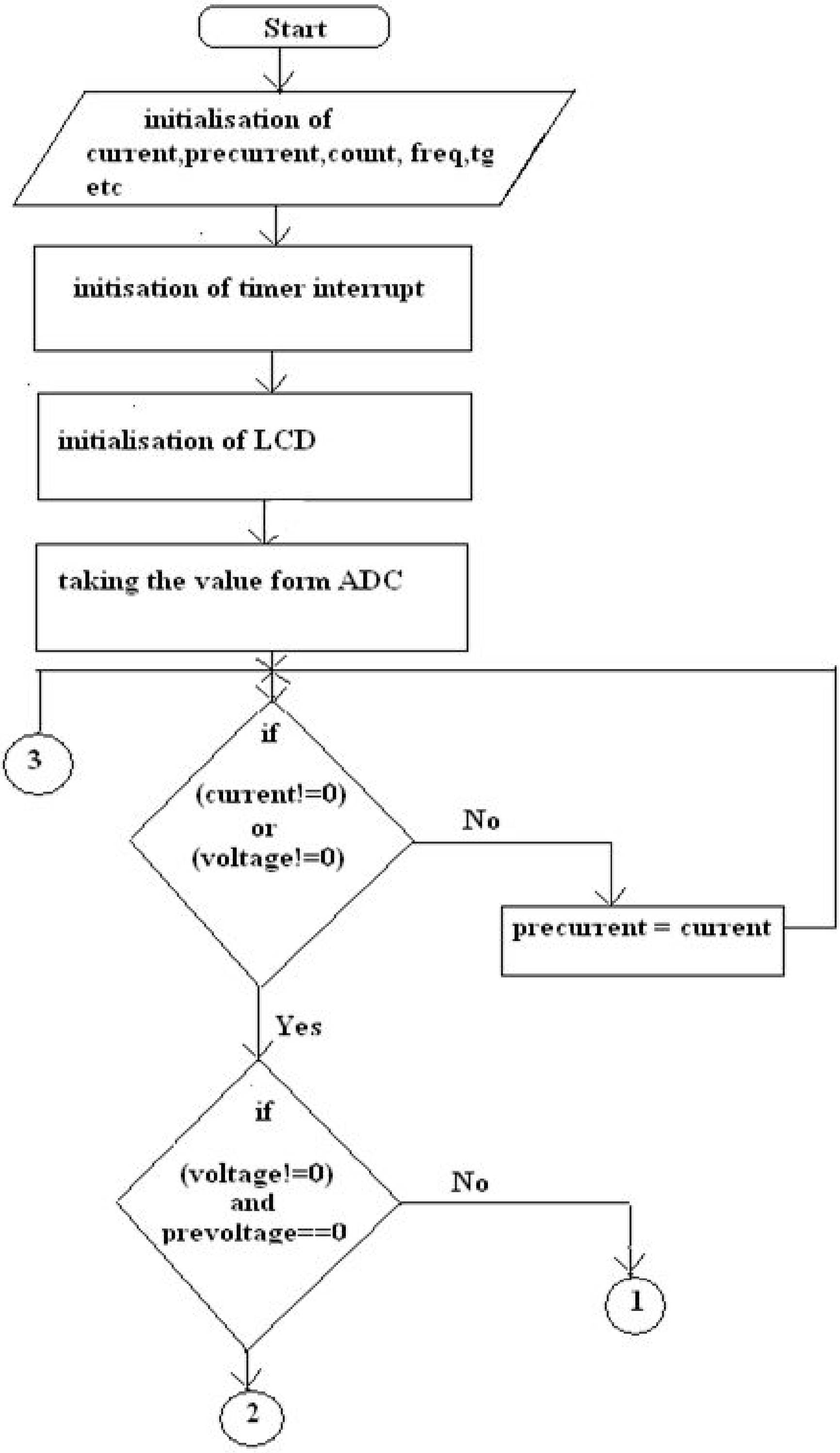
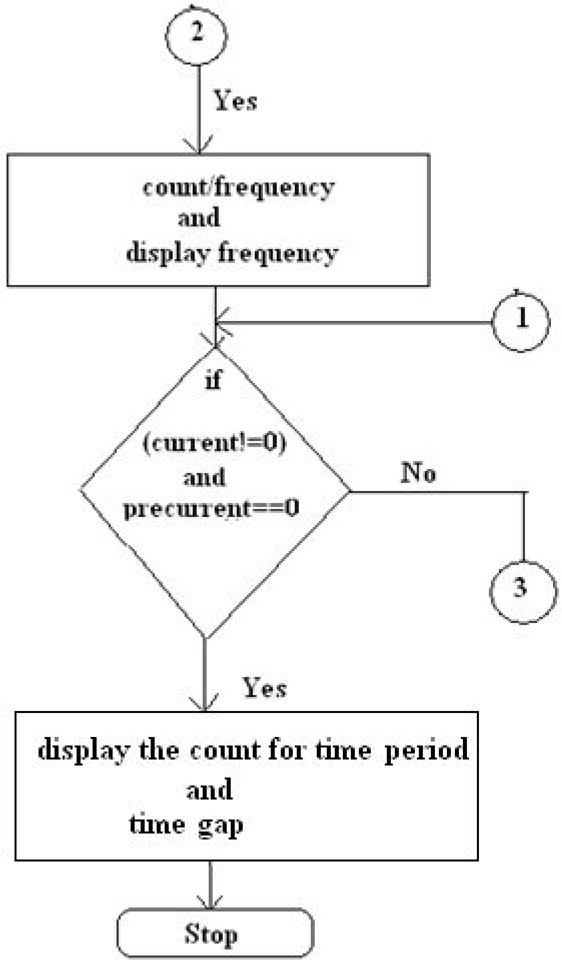


Figure 4.10: Current and voltage with time gap

4.8 Flow diagram for zero crossing




2
Yes
count/frequency
and
display frequency
1
if
(current!=0)
and
precurrent==0
No
3
Yes
display the count for time period
and
time gap
Stop

Chapter 5

Result and discussion

In this work, power factor is corrected using PIC 18F452. Here two facilities are mentioned; one is minimum current and second is power factor range both can be given by the user. System requires minimum current for the correction of power factor and it continuously monitors the power factor. If power factor is within the range then there is no action, otherwise it takes the action according to the lagging or leading power factor. The system design implementation and testing is divided into five major parts:

Test the voltage level and current level
Detecting zero crossing
Finding time gap between current and voltage
Power factor calculation
Physical testing of power factor controller

5.1 Test the voltage level and current level

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 are shown in the fig 5.1 and fig. 5.2.

At the same time, it drains some voltage hence channels waveform is slightly lower. A shunt resistor of any value must be connected after the diode and link to ground, this prevents harmonic appears.

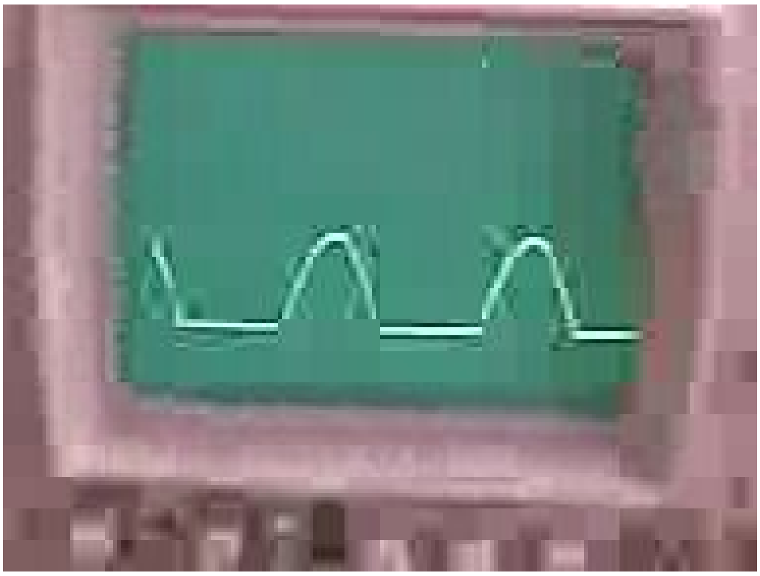


Figure 5.1: voltage waveform after diode

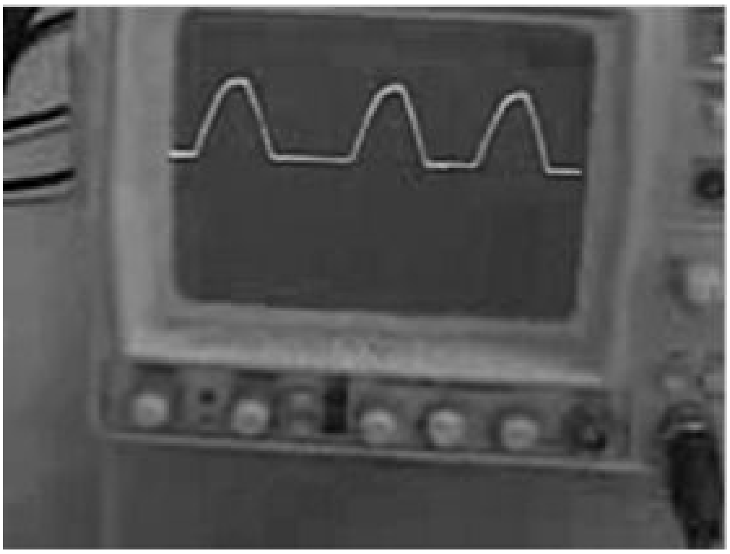


Figure 5.2: current waveform after diode

5.2 Detecting zero crossing

We take the analog channel 1(A1) for current and analog channel 2(A2) for voltage as shown in figure 5.4. These analog channels are connected to the analog to digital conversion (ADC) module. ADC module converts the analog signals to the 10 bit digital value using successive approximation method. For zero crossing, we write the program and take the current and voltage value from ADC module. We take the value of count which depends upon the prescale value. Table 5.1 shows the prescale values and respective count values.

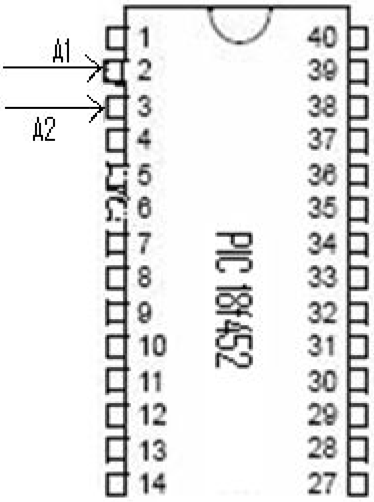


Figure 5.3: Connection with analog channel 1 and channel 2

We start timer when first zero crossing is detected and stop timer when second zero crossing is detected. In between first zero crossing and second zero crossing count is continuously increased then we find out the no. of count between both zero crossings. It gives the value of time period. Time period is shown in figure 5.4.

We set the timer0 at 101desimal value and we take the prescale value as 1:4. Due to the higher prescale the degree of accuracy increases. This prescale value and timer initial value defines the timer roll over time. As the timer rolls from FF to 00, the count increases by one.

At this prescale one count is equal to **3.125 x 10^{-4}** second.

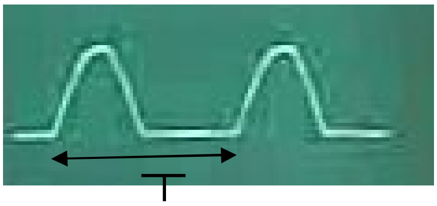


Figure 5.4: Time period as zero crossing

Prescale value	Count	Count for 1 sec	Frequency
1:2	128	6400	50Hz
1:4	**64**	**3200**	**50Hz**
1:8	32	1600	50Hz
1:16	16	800	50Hz
1:32	8	400	50Hz
1:64	4	200	50Hz
1:128	2	100	50Hz
1: 256	1	50	50Hz

Table 5.1: Comparing count with prescale

Bold row in table 5.1 is used during the calculation of power factor. We display the value of count at LCD. There is no need of any types of zero crossing circuit or comparator circuit. In 18 series PIC there is no comparator facility so we only use the timer and ADC mode to find out the time period and frequency.

5.3 Calculation of time gap between current and voltage

For the calculation of time gap between current and voltage we take the both signal and wait till the current crosses the zero. When current crosses the zero we start the timer and stop the timer when voltage crosses the zero. In between both zero crossing we find out the value of count. This count gives the time gap. Figure 5.5 shows the time gap between current and voltage waveform

The timer initial value and prescale value are 101 decimal vale and 1:4 respectively.

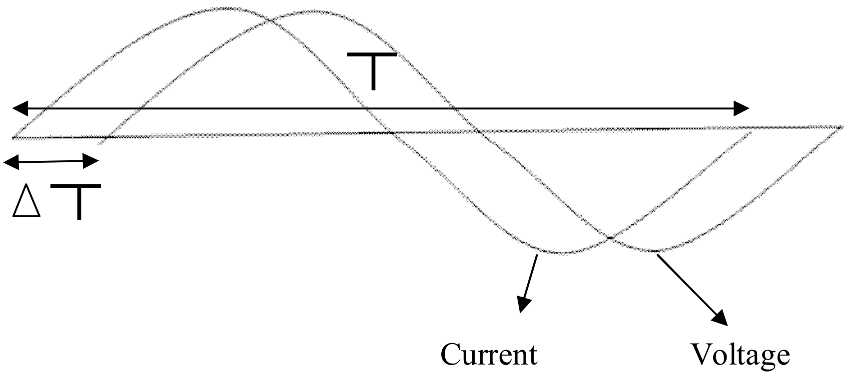


Figure 5.5: Time gap between current and voltage waveform

ΔT can be calculated with the help of count1 (here we have taken count 1 for time gap) and count for 1 sec, as-

$$\Delta T = \text{count1} / \text{count for 1 sec} \qquad \text{eq. 1}$$

For example: At prescale 1:32 count1 is 2 and count for 1 sec is 400 so the time gap will be-

$$\Delta T = 2/400 \text{ sec}$$

$$= 0.005\text{sec}$$

5.4 Power factor calculation

Here we take the value of count and value of count1 then take the ratio of count1 to count. This will give the ratio between time gap and time period. Now the angle is calculated as-

$$\text{Angle} = (\text{coun1} / \text{count}) * 360 \qquad \text{eq. 2}$$

And then

$$\text{Power factor} = \cos(\text{angle}) \qquad \text{eq. 3}$$

Power factor of the tested circuit at different prescale is show in table 5.2.

Sr.no.	Prescale value	Count1	Count	Power factor
1	1:2	24	128	0.382
2	1:4	12	64	0.382
3	1:8	6	32	0.382
4	1:16	3	16	0.382
5	1:32	2	8	0
6	1:64	1	4	0
7	1:128	1	2	-1
8	1: 256	1	1	0

Table 5.2: power factor of the circuit at different prescale

Here we have seen that at the lower prescale the value of count1 is not correct as dotted rectangular is showing. This is due to the very low count. This is resolved by taking the count1 value at higher prescale so that we can take the higher degree of precision. **The preferred scale is 1:4**.

5.5 Physical testing of power factor controller

The fabricated power factor controller has been tested on variable resistor in series with fixed inductance coil. By changing the resistance, measured value of power factor is made below LPF limits. It has been observed that the PFC commands switching on the capacitor banks at the regular interval of one second, as expected in its program. The improvement in power factor is simulated by changing the resistance again and the response is again same as programmed for i.e. there is no action on capacitor bank. A similar result of switching off the capacitor bank is obtained at late of one bank per seconds, if the power factor is simulated above UPF or becomes leading. The validation has been carried out to check the overall performance of the power factor correction.

Chapter – 6

Conclusion and future scope

6.1 Conclusion

This thesis work is an attempt to design and implement the power factor controller using PIC micro controller. In this work there is a provision to define the own current minimum range and power factor minimum and maximum range. PIC monitors both continuously and then according to the lagging or leading power factor it takes the control action. This thesis gives more reliable and user friendly power factor controller. This thesis makes possible to store the real time action taken by the PIC microcontroller.

This thesis also facilitates to monitor the power factor changes on LCD in real time.

6.2 Future work

This thesis work is not tested on power converter based systems or synchronous motor because of the requirement of huge amount of expense. It needs the further enhancement of the system. Finance is a critical issue for further enhancement.

References

1. [Ali et al. 2000] - Al-Ali, A.R.; Negm, M.M.; Kassas, M. (2000) “A PLC Based Power Factor Controller for a 3-Phase Induction Motor”, IEEE Conference on Industry Applications, Volume: 2, Pages: 1065-1072.

2. [Andersen et al. 2002] - Andersen, G.K.; Klumpner, C.; Kjaer, S.B.; Blaabjerg, F. (2002) “A New Green Power Inverter for Fuel Cells”, IEEE Conference on Power Electronics Specialists, Volume: 2, Pages: 727–733.

3. [Ayres and Babri 1996 a] - Ayres, C.A.; Barbi, I. (1996) “CCM Operation Analysis of a Family of Converters for Power Recycling During the Burn-In Test of Synchronized UPSs”, IEEE Conference on Power Electronics Specialists, Volume: 2, Pages: 986-992.

4. [Ayres and Babri 1996 b] - Ayres, C.A.; Barbi, I. (1996) “Power Recycler for DC Power Supplies Burn-In Test: Design and Experimentation”, Applied Power Electronics Conference and Exposition, Volume: 1, Pages: 72-78.

5. [Barsoum 2007] - Barsoum, Nader (2007) “Programming of PIC Micro-Controller for Power Factor Correction” IEEE Conference on Modeling & Simulation, Pages: 19-25.

6. [Borlotti et al. 2001] - Borlotti, R.; Gemme, C.; Tinggren, R. (2001) “Integrated Power Quality in Distribution Equipment”, IEEE Conference on Electricity Distribution, Volume: 2, Pages: 1-6.

7. [Cacciato et al. 2005] - Cacciato, M.; Consoli, A.; De Caro, S.; Testa, A. (2005) “Using the Dc-Bus Current to Improve the Power Factor in Low-Cost Electric Drives”, IEEE Transactions on Industry Applications, Volume: 41, Issue: 4, Pages: 1084-1090.

8. [Cereda et al. 2000] - Cereda, C.; Gemme, C.; Moratto, A.; Tinggren, R. (2000) “Innovative Solutions for Power Quality in a Deregulated Market”, IEEE Conference on Industry Applications, Volume: 2, Pages: 932 – 939.

9. [Consoli et al. 2001] - Consoli, A.; Testa, A.; Aiello, N.; Gennaro, F.; Lo Presti, M. (2001) "Unipolar Converter for Switched Reluctance Motor Drives with Power Factor Improvement", IEEE Conference on Applied Power Electronics, Volume: 2, Pages: 1103-1108.

10. [Consoli et al. 2004] - Consoli, A.; Cacciato, M.; Testa, A.; Gennaro, F. (2004) "Single Chip Integration for Motor Drive Converters with Power Factor Capability", IEEE Transactions on Power Electronics, Volume: 19, Issue: 6, Pages: 1372-1379.

11. [Dallago et. al. 1998] - Dallago, E.; Sasone, G.; Storti, M.; Venchi, G. (1998) "Experimental Analysis and Comparison on a Power Factor Controller Including a Delta – Sigma Pressing Stage", IEEE Transaction industrial electronics, Volume: 45, Issue: 4, Pages: 544–551.

12. [Fuld et al. 1991] - Berthold Fuld'; Siegfried Kern; Ray Ridley (1991) "A Combined Buck and Boost Power-Factor-Controller for Three-Phase Input", IEEE European Conference on Power Electronics and Applications, Volume: 7, Pages: 144-148.

13. [Freitas et al. 2005] - Freitas, W.; Morelato, A.; Wilsun Xu; Sato, F. (2005) "Impacts of AC Generators and DSTATCOM Devices on the Dynamic Performance of Distribution Systems", IEEE Transactions on Power Delivery, Volume: 20, Issue: 2, Pages: 1493-1501.

14. [Hurley et al. 1999] - Hurley, J.D.; Bize, L.N.; Mummert, C.R. (1999) "The Adverse Effects Of Excitation System Var and Power Factor Controllers", IEEE Transaction on Energy Conversion, Volume: 14, Issue: 4, Pages: 1636–1645.

15. [Hyp phys a]- http://hyperphysics.phy-astr.gsu.edu/hbase/electric/acres.html#c1

16. [Hyp phys b] - http://hyperphysics.phy-astr.gsu.edu/hbase/electric/phase.html#c1

17. [Hyp phys c] - http://hyperphysics.phy-astr.gsu.edu/hbase/electric/acind.html#c2

18. [Hyp phys d] - http://hyperphysics.phy-astr.gsu.edu/hbase/electric/accap.html#c2

19. [Ioannides and Papadopoulos 1991] - Ioannides, M.G.; Papadopoulos, P.J. (1991) "Speed and Power Factor Controller for AC Adjustable Speed Drives", IEEE Transactions on Energy Conversion, Volume: 6, Issue: 3, Pages: 469 – 475.

20. [Jones and Blackwell 1983] – Jones, L. D.; Blackwell, D. (1983) "Energy Saver Power Factor Controller for Synchronous Motors", IEEE Transactions on Power Apparatus and Systems, Volume: 5, Issue: 5, Pages: 1391-1394.

21. [Kim et al. 2004] - Kim, T.W.; Choi, J.H.; Kwon, B.H. (2004) "High-Performance Line Conditioner with Output Voltage Regulation and Power Factor Correction", IEE Proceedings on Electric Power Applications, Volume: 151, Issue: 1, Pages: 91- 97.

22. [Kiprakis and Wallace 2004] - Kiprakis, A.E.; Wallace, A.R. (2004) "Maximising Energy Capture from Distributed Generators in Weak Networks", IEE Proceedings on Generation, Transmission and Distribution, Volume: 151, Issue: 5, Pages: 611-618

23. [Kurachi 1995] - Kurachi, T.; Shoyama, M.; Ninomiya, T. (1995) "Analysis of Ripple Current of an Electrolytic Capacitor in Power Factor Controller", IEEE Conference on Power Electronics and Drive Systems, Volume: 1, Pages: 48–53.

24. [Machmoum et al. 2002] - Machmoum, M.; Coulibaly, P.; Abdelli, Y. (2002) "A Power Factor Controller for Three-Phase PWM Rectifiers and Shunt Active Power Filters", IEEE Conference on Harmonics and Quality of Power, Volume: 2, Pages: 626-631.

25. [Malesani 1993] - Malesani, L.; Rossetto, L.; Spiazzi, G.; Tenti, P. (1993) "Three-Phase Power Factor Controller With Minimum Output Voltage Distortion", IEEE conference on Telecommunications Energy, Volume: 2, Pages: 463–468

26. [Mandal et al. 1994] - Rakendu Mandal; Sanjoy Kumar Basu; Asim Kar; Shyama Pada Chowdhury (1994) "A Microcomputer – Based Power Factor Controller", IEEE Transactions on Industrial Electronics, Volume: 41, Issue: 3, Pages: 361–371.

27. [Masserant and Stuart 1996] - Masserant, B.; Stuart, T. (1996) "Experimental Verification of Calculated IGBT Losses in PFCs", IEEE Transactions on Aerospace and Electronic Systems, Volume: 32, Issue: 3, Pages: 1154–1158.

28. [Meza et al. 2005] - Meza, C.; Biel, D.; Martinez, J.; Guinjoan, F. (2005) "Boost-Buck Inverter Variable Structure Control for Grid-Connected Photovoltaic Systems", IEEE International Symposium on Circuits and Systems, Volume: 2, Pages: 1318–1321.

29. [Mikroe a]-www.mikroe.com/en/books/picmcubook/ch7/

30. [Mikroe b]-www.mikroe.com/en/books/picmcubook/appb/

31. [MikroC manual]-www.mikroe.com/pdf/mikrobasic/mikrobasic_manual.pdf

32. [Miller, 1993] - Miller, M.; Buffin, A.; Carlsson, U. (1993), "High Frequency ZVS for High Power Rectifiers", IEEE Conference on Telecommunications Energy, Volume: 1, Pages: 424–430.

33. [Molina and Mercado 2006] – Molina, M.G.; Mercado, P.E. (2006) "Control Design and Simulation of DSTATCOM with Energy Storage for Power Quality Improvements", IEEE Conference and Exposition on Transmission & Distribution, Pages: 1-7.

34. [Nalbant 1990] – Nalbant, M.K. (1990) "Power Factor Calculations and Measurements", IEEE Conference on Applied Power Electronics, Pages: 543 – 552.

35. [PIC18F452 manual]-ww1.microchip.com/downloads/en/DeviceDoc/39564c.pdf

36. [Rao et al. 1998] - Rao, U.M.; Vijaya, S.; Prasad, N.S.R.; Krishna Sree, G. (1998) "A Novel-Solid State Stabilizer", IEEE power quality, Pages: 243–246.

37. [Sharkawi et al. 1985] - El-Sharkawi, M.A.; Venkata S.S.; Williams T.J.; Butler N.G. (1985) "An Adaptive Power Factor Controller for Three-Phase Induction Generators", IEEE Transactions on Power Apparatus and Systems, Volume: PAS-104, Issue: 7, Pages: 1825–1831.

38. [Sharkawi et al. 1988] - El-Sharkawi, M.A.; Chen, M.; Vadari, S.V.; Fissel, G.W.; Venkata, S.S.; Butler N.G.; Yinger R.J. (1988) “Development and Field Testing of a Closed-Loop Adaptive Power Factor Controller”, IEEE Transaction On Energy Conversion, Volume: 3, Issue: 2, Pages: 235 – 240.

39. [Tinggren 1999] - Tinggren, R.; Yi Hu; Le Tang; Mathews, H.; Tyner, R. (1999) “Power Factor Controller- an Integrated Power Quality Device”, IEEE Conference on Transmission and Distribution, Volume: 2, Pages: 572-578.

40. [wiki] - en.wikipedia.org/wiki/Power_factor_correction

Appendix I

Program for zero crossing

```
 /*........... Program for calculating the time period of signal taking current voltage ...............*/
#include"built_in.h"
long vlong, clong;
unsigned cnt, cnt1;
void interrupt()
{                                               // Interrupt
  cnt++;                                   // Increment value of cnt on every interrupt
 cnt++;
  TMR0L   = 101;
  INTCON = 0x20;                             // Set T0IE, clear T0IF
}
void main()
{
  unsigned int   voltage,                    //Increases the count of speed
  voltagepre,                                //Previous value of voltage
  current,                                   //Decreases the value of count
  currentpre;
```

```
int b,c,d;                                   //Previous value of down key

unsigned char ch;                    //Character variable used to display values on LCD

voltage=0;

voltagepre=0;

current=0;

currentpre=0;

   TOCON= 0x81;                        // Assign prescaler of 1:4 to Timer0

LCD_Init(&PORTD);        // Initialize LCD on PORTD  (4-bit interface connection)

LCD_Cmd(LCD_CURSOR_OFF);            // Send command to LCD (cursor off)

LCD_Cmd(LCD_CLEAR);                         // Send command  to LCD (clear LCD)

ADCON1     = 0x82;                   // Configure VDD as Vref, and analog channels

TRISA      = 0xFF;                           // Designate port A as input

TMR0L  = 101;                // Initialize Timer0 to 101, so as to help to generate 1sec.

INTCON = 0xA0;

cnt=0;

cnt1=0;                                      // Enable TMRO interrupt

LCD_Out(1,1,"crossing time");               // Printing text on LCD

do                                            //Start

{                                            // LOOP 1 starts, infinite loop

  voltage = ADC_read(1);                      // get ADC value from 1st channel
```

```
   vlong  = voltage * 5000;              // use (int) multiplication instead of (long)
asm {                                    //   and fill the upper two bytes manually
     MOVF STACK_2,W
     MOVWF _vlong+2
     MOVF STACK_3,W
     MOVWF _vlong+3
   }
   voltage = vlong/1024;

/* For checking the signal, is it coming from negative to positive ? so that we find out
the zero crossing */

           if ((voltage!=0)&&(voltagepre==0))
              {
                    b= cnt;
                    b= (1/b)*1600;                  // It gives frequency
                    b= 1/b;                         // Gives time period
                   ch = (b / 1000) %10;             // Prepare value for display
                   LCD_Chr(2,1,48+ch);          // Write ASCII at 2nd row, 9th column
                   ch = (b / 100) %10;              // Prepare value for display
                   LCD_Chr_CP(48+ch);               // Gives the ASCII value
                   ch = (b / 10) %10;               // Prepare value for display
```

```
                LCD_Chr_CP(48+ch);          // gives the ASCII value
                ch= b % 10;                 // Prepare value for display
                LCD_Chr_CP(48+ch);          // Gives the ASCII value
                cnt=0;                      // Count is initialized
            }
        voltagepre=voltage;                 // Store the voltage as prevaltage
         }
  while(1);                                 // Infinite times run the loop
}//……
```

Appendix II

Program for power factor calculation

```
/*............ Program for calculated the power factor by taking current and voltage
...............*/

#include"built_in.h"

long vlong, clong;

unsigned cnt, cnt1;

void interrupt()

{                                                   // Interrupt

  cnt++;

  cnt1++;                                         // Increment value of cnt on every interrupt

 TMR0L   = 101;

  INTCON = 0x20;                                  // Set T0IE, clear T0IF

}

void main()

{

  unsigned int   voltage,                         //Increases the count of speed

  voltagepre,                                     //Previous value of voltage

  current,                                        //Decreases the value of count

  currentpre;
```

```
 int pwf,b,c,d;                               //Previous value of down key

 unsigned char ch;                           //Character variable used to display values on
LCD

 voltage=0;                                   // Initialize the voltage

 voltagepre=0;                                // Initialize the voltagepre

 current=0;                                   // Initialize the current

 currentpre=0;                                // Initialize the currentpre

 T0CON =0x81;                                // Assign prescaler of 1:4 to TMR0

 LCD_Init(&PORTD);        // initialize LCD on PORTD  (4-bit interface connection)

 LCD_Cmd(LCD_CURSOR_OFF);            // send command to LCD (cursor off)

 LCD_Cmd(LCD_CLEAR);                  // send command  to LCD (clear LCD)

 ADCON1     = 0x82;             // configure VDD as Vref, and analog channels

 TRISA      = 0xFF;                           // designate port A as input

 TMR0L  = 101;                  // Initialize Timer0 to 101, so as to help to generate 1sec.

 INTCON = 0xA0;

 cnt=0;

 cnt1=0;                                      // Enable TMRO interrupt

 LCD_Out(1,1,"frequency");                  // Printing charachters on LCD

 do                                          //start

 {                                            // LOOP 1 starts, infinite loop

   voltage = ADC_read(1);                     // get ADC value from 1st channel
```

```
 vlong  = voltage * 5000;                // use (int) multiplication instead of (long)
asm {                                            //   and fill the upper two bytes manually
  MOVF STACK_2,W
  MOVWF _vlong+2
  MOVF STACK_3,W
  MOVWF _vlong+3
 }
 voltage = vlong/1024;
 current = ADC_read(2);                  // get ADC value from 1st channel
 clong  = current * 5000;                // use (int) multiplication instead of (long)
asm {                                    //   and fill the upper two bytes manually
  MOVF STACK_2,W
  MOVWF _clong+2
  MOVF STACK_3,W
  MOVWF _clong+3
 }
 current = clong/1024;
   if (current!=0||voltage!=0)
      {
            if((voltage!=0)&&(voltagepre==0))       // Checking for zero crossing
```

```
{
          b=cnt;                                    // store the value of count
          b=(1/b)*1600;                             // It gives frequency
         ch = (b / 1000) %10;                       // Prepare value for display
         LCD_Chr(2,1,48+ch);              // Write ASCII at 2nd row, 9th column
         ch = (b / 100) %10;                        // Prepare value for display
         LCD_Chr_CP(48+ch);                         // Display the ASCII value
         ch = (b / 10) %10;                         // prepare value for display
         LCD_Chr_CP(48+ch);                         // Display the ASCII value

         ch= b % 10;                                // prepare value for display
         LCD_Chr_CP(48+ch);                         // Display the ASCII value
         cnt=0;                                     // Initialize the timer
}
if((current!=0)&&(currentpre==0))          // Checking for zero crossing
{
         d= cnt;                                 // Lagging of current
         ch = (d / 1000) %10;                       // Prepare value for diplay
         LCD_Chr(2,8,48+ch);              // Write ASCII at 2nd row, 9th column
         ch = (d / 100) %10;                        // Prepare value for display
```

```
                LCD_Chr_CP(48+ch);              // Display the ASCII value

                ch = (d / 10) %10;          // Prepare value for display

                LCD_Chr_CP(48+ch);              // Display the ASCII value

                ch    = d % 10;                 // prepare value for display

                LCD_Chr_CP(48+ch);              // Display the ASCII value

                cnt1=0;                         // Initialize the timer

                c=   (d/b)* 360;              // Calculation of angle

   /* Power factor calculation in term of decimal value no fraction, 0.7 is result as 700 */

                pwf= CosE3(c);                  // Power factor is calculated

                 ch = (pwf / 1000) %10;       // Prepare value for display

                LCD_Chr(2,8,48+ch);         // Write ASCII at 2nd row, 9th column

                ch = (pwf / 100) %10;         // Prepare value for display

                LCD_Chr_CP(48+ch);              // Display the ASCII value

                ch = (pwf / 10) %10;          // Prepare value for display

                LCD_Chr_CP(48+ch);              // Display the ASCII value

                ch    = pwf % 10;               // Prepare value for display

                LCD_Chr_CP(48+ch);              // Display the ASCII value

            }

        }
```

```
        voltagepre=voltage;                   //Store the value of voltage as voltagepre

        currentpre=current;                   //Store the value of current as currentpre

  }

  while(1);                                   // Endless loop

}
```