Microchip Based Embedded System Design for Achievement of High Power Factor in Electrical Power Systems

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***Abstract*—Transmission efficiency and harmonic loss reduction are among the main challenges of industrial power systems. To cope with these challenges, many control methods for Power Factor Correction (PFC) have actively been proposed. This paper explains the design of a power factor improvement circuit using PIC (Programmable Interface Controller) chip with reduced parts count to achieve desired efficiency and low cost. This involves measuring the power factor value from the load and uses an algorithm to determine and trigger switching capacitors in order to compensate for excessive reactive components to increase power factor value. MicroC compiler has been used to build a C language code and the algorithm has been implemented in Proteus ISIS simulator which gives the desired results of power factor improvement fairly close to unity to cut down excessive penalty imposed on customers with heavy industrial loads having poor power factor.**

Keywords—Power Factor Correction, Programmable Interface Controller, Reactive Components, Switching Capacitors, Transmission Efficiency

I. INTRODUCTION

Assuming *KW* to be the actual load power and *KVA* to be the apparent power drawn by an electrical load, power factor is defined as the ratio between these two quantities. Essentially, it measures how effectively the current is being converted into useful output and is an indicator of the effect of load current on the efficiency of power generation and transmission systems. When the apparent power delivered to the load is greater than the real power, it means the load has a power factor lower than unity. This in reaction causes the losses in the system to rise up. A load with a power factor of unity or fairly close to it has the most efficient loading of the supply.

One of the prime causes of poor power factor is the result of a notable phase difference between voltage and current at load terminals. This load current phase angle difference is typically the result of an inductive load such as an induction motor, furnace or a power transformer which are being used in an industrial complex [1]. If a consumer improves the power factor, there is reduction in his maximum kVA demand and hence there will be annual saving over the maximum demand charges. However, when power factor is improved, it involves capital investment on the power factor correction equipment. The consumer will incur expenditure every year in the shape of annual interest and depreciation on the investment made over the power factor correction equipment. Therefore, the net annual saving will be equal to the annual saving in maximum demand charges minus annual expenditure incurred on power factor correction equipment.

II. RELATED WORK

Several power factor correction and improvement strategies have been developed so far. A conventional approach uses capacitor banks or an induction motor with a capacitor in parallel. The disadvantage of using an induction motor is that it may not be feasible and economical to use individual shunt capacitors with each induction motor.

Modern methods include the load modeling using a chopper circuit for generating PWM signals to measure power factor and then switched connection of capacitors to compensate for reactive components elevating the power factor value [2], simulation of single phase bridgeless PFC boost rectifiers also called dual boost PFC rectifiers to improve power factor [3] and digital improvement of power factor through embedded devices. In modern power electronics, Cuk converter topology is also used to shape input current meaning the input current is chopped at high frequency [3]. Employing high frequency switching enables the converter to chop the input current and thereby shifting the lower order harmonic components far apart from the fundamental improving the power factor at the input [4].

In the proposed design, shunt capacitors in the form of a bank are used but the difference from conventional approach is that they are controlled in such a way as to vary the power factor according to the need. Fig.1 shows the benefits of controlling a capacitor bank. As far as modern methods are concerned, they have been successfully implemented for a wide range of applications yet they suffer from a little bit of

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complex design circuitry. The proposed design differs from them in certain ways. Firstly, the reliability becomes high as no switches or zero-crossing detectors are used. Secondly, as the circuit is based on programming, component and device losses inside the circuit are much less as compared to the other designs thus increasing the efficiency. Lastly, it has a reduced parts count in terms of switches and other electronic components which meet the low cost requirements rendering it optimum for customers as well as industries on large scale.

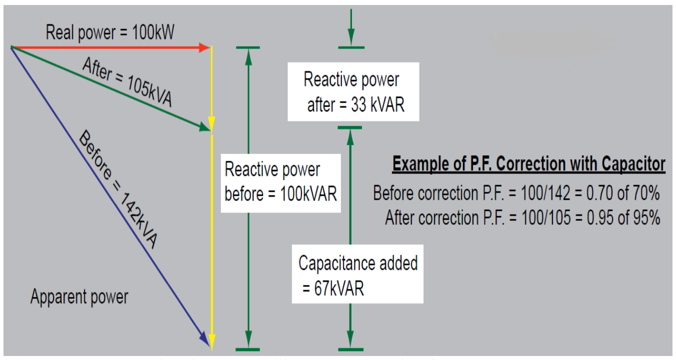

Fig.1. P.F Correction by controlling capacitor bank

III. POWER EQUATIONS

When *RMS* values of voltage and current are taken into account, the power equation is given as

$$P = |V|\,|I|\cos(\theta) \quad (1)$$

The parameter *P*, commonly called the average power, is also known as real or active power. Watt is the fundamental unit of both instantaneous and average power but due to the minuteness of watt in relation to power system quantities, P is usually measured in kilowatts or megawatts. The cosine of the phase angle θ between the voltage and the current is called the power factor [4], [11].

The term similar to mentioned above but having sine, alternates positive and negative and gives an average value of zero. This component of the instantaneous power P is called the instantaneous reactive power which expresses the flow of energy towards the load and away from the load, alternately. The maximum value of this pulsating power, designated Q, is called reactive power or reactive volt-amperes and is very useful in describing the operation of a power system [11]. Therefore reactive power is given by

$$Q = |V|\,|I|\sin(\theta) \quad (2)$$

In a simple series circuit where Z is equal to $R + jX$ we can substitute $|I||Z|$ for $|V|$ in equations (1) and (2) to obtain

$$P = |I|^2|Z|\cos(\theta) \quad (3)$$

$$Q = |I|^2|Z|\sin(\theta) \quad (4)$$

Keeping in view

$$R = |Z|\cos\theta$$

and

$$X = |Z|\sin\theta$$

Above equations offer another method of calculating power factor since we witness that $Q/P = \tan\theta$. The power factor is therefore

$$\cos(\theta) = \cos(\tan^{-1} Q/P) \quad (5)$$

or

$$\cos(\theta) = P/\sqrt{(P^2+Q^2)} \quad (6)$$

An inductive circuit has a lagging power factor and a capacitive circuit is said to have a leading power factor. The terms lagging and leading power factor indicate, respectively, whether the current is lagging or leading the applied voltage.

IV. POWER FACTOR IMPROVEMENT

The impact of different types of electrical loads can be studied by noting that a resistive load does not affect the phase relationship between the electrical current and the voltage in an AC power system because the current and voltage are in phase. However, if a voltage is applied to a purely inductive load such as an unloaded transformer, the output current would be lagging or following the output voltage. Such type of circuits would "consume" only reactive power (measured in kilovolt ampere reactive; *KVAR*). As a result, power factor would be turned to low. This can be witnessed from Fig.2.

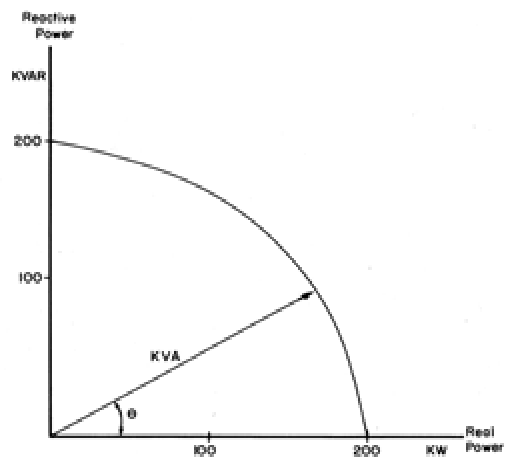

Fig.2. Real and Reactive Power [11]

So it can be concluded that low power factor is caused by inductive loads. Induction motors are a prime cause of low power factor for many customers. This is a problem especially for customers with large number of small fractional horsepower motors, those who purchase cheap or poorly made motors and those having oversized, under-loaded motors [7].

Moreover, AC motors, transformers, fans, welding equipment, extruders and injection machines, presses and stamping equipment are among those appliances whose power factor is usually low.

1) *Need for Improvement:* A consumer pays electricity bills for his maximum demand in *KVA* plus the units consumed. If the consumer's power factor is high, there happens to be a reduction in his maximum *KVA* demand and consequently there are annual savings due to maximum demand charges. Although power factor improvement involves extra annual expenditure on account of power factor correction equipment,

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yet improved power factor to proper value results in the net annual saving for the consumer.

2) *Procedure:* Power factor can be improved by installing especially designed PFC capacitors or reactive power generators into the electrical distribution system. These devices supplement the demand of reactive power for the operation of all inductive loads and reduce the amount of kVA drawn from the main transformer, registered on the meter as "peak demand". The capacitor draws a leading current and partly or completely neutralizes the lagging reactive component of load current. This raises the power factor of the load connected.

However, there are cost and efficiency issues while designing such as equipment or devices. Below mentioned design has reduced parts count keeping the cost low and efficiency high.

A. Design:

A high power factor output is the main goal of this paper which focuses on the design and implementation of power factor correction using PIC microcontroller, measures the power factor of loaded power system, performs proper action to feed sufficient capacitance to recover appropriate power loss using MikroC program and finally simulates the design with PIC controller chip. Program code has been written in C language. The process to debug the C code is cyclic and involves four major steps as shown in Fig.3.

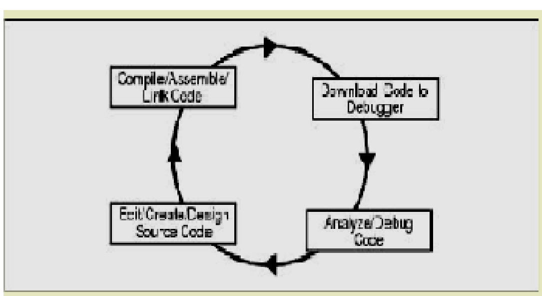

Fig.3. Steps involved in MicroC code debugging

B. Flow Chart:

Flow chart in fig.4 shows the complete design scheme.

C. Calculations:

Capacitors are connected in parallel. The function of shunt power capacitor is to provide leading (capacitive) *kVARs* to the electrical system. Lagging (inductive) *kVARs* appear when there are inductors (coils) within electrical (e.g. motor) or electronic equipment. As the amount grows, the increment of inductive *kVARs* will increase as well, consequently there is a need of capacitive *kVARs* to compensate it in order to reduce unnecessary power loss [10]. The actual capacitor in farads of the capacitor bank is calculated using

$$C = VAR / (2*pi*f*V_R^2) \quad (7)$$

where,

VAR = capacitor unit VAR rating
C = capacitance (farads)
f = frequency (cycles/second)
V_R = capacitor unit rated voltage

Capacitors of standard ratings like 240*u*F, 300*u*F and so are available that are sufficient to provide enough *kVARs* for the desired power factor improvement on the load side. They are connected in parallel with the equipment in the form of a capacitor bank. Their demand is ensured by first determining the value of power factor from the code.

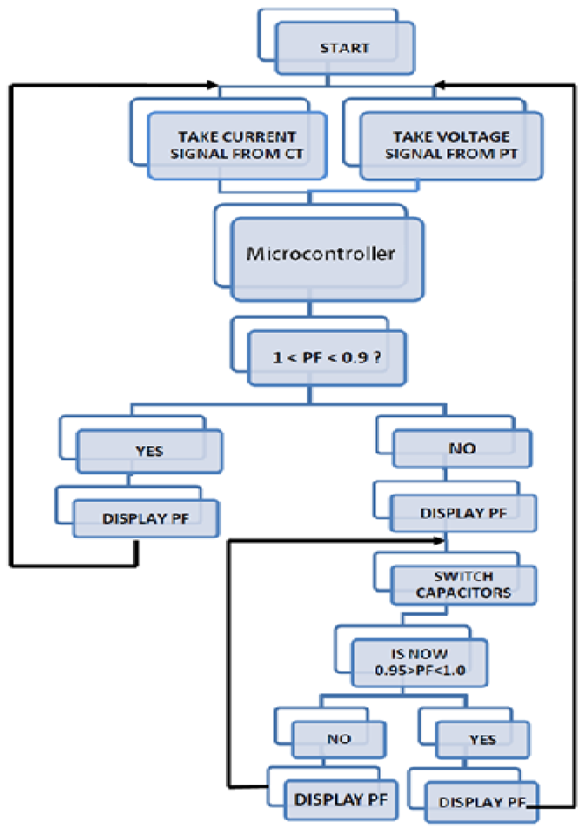

Fig.4. Flow Chart of design scheme

V. SIMULATION AND EXPERIMENTAL RESULTS

Proteus ISIS Design Suite has been used for making the simulation. The schematic can be seen from Fig.5.

Code helps to display various state vectors related to power. Voltage and current of the system are processed in PIC controller by a built-in 10 bit *A/D* converter which is provided with 8 input channels. As with all microcontrollers, crystal oscillator is required to provide operating frequency. Here 11.059 MHz crystal oscillator serves this purpose. *A/D* Converter is invoked by *ADC_Read* function. 10 bit *A/D* output is sent to LCD in a single bit fashion. Each bit is supplied by dividing by 1000, 100, 10 and then modulating with 10 afterwards.

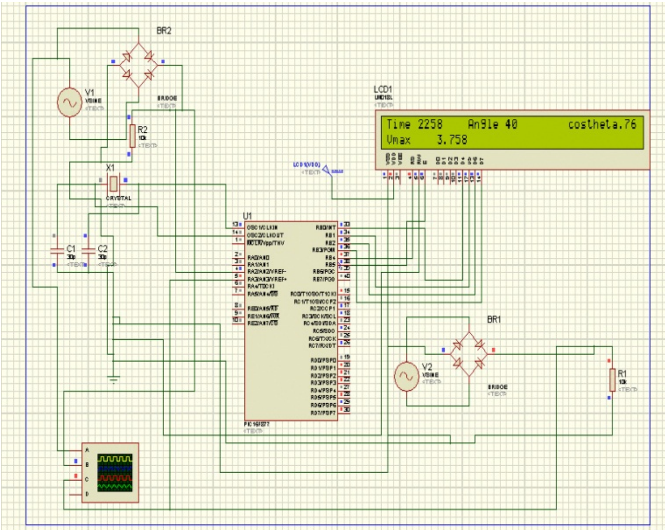

Fig.5. PFI Schematic in Proteus

Voltages and currents of three phases are sensed using transducers; potential transformer (PT) and current transformer (CT) respectively. These signals are applied to PIC 16F877 controller to measure the values of currents and voltages, to measure the angle between voltage and current and to measure the values of sine and cosine in order to determine the active and reactive powers. Using these values we calculate the ratings of capacitors. Magnetic relay is used to couple 5V DC signal from microcontroller to 220V AC to determine which particular capacitors are to be turned ON or OFF for optimum power factor.

LCD commands *Lcd_Chr_CP*, *Lcd_Chr*, *Lcd_Out* serve the purpose of displaying results on LCD. Potential Transformer turns ratio is selected to be 230:5 to make voltage at secondary side compatible with analog input of microcontroller. Similarly current transformer rating is such that we get 5V on the secondary. Zero crossing detection is an important thing to achieve without using a separate module of a typical zero crossing detector as shown in the fig.6.

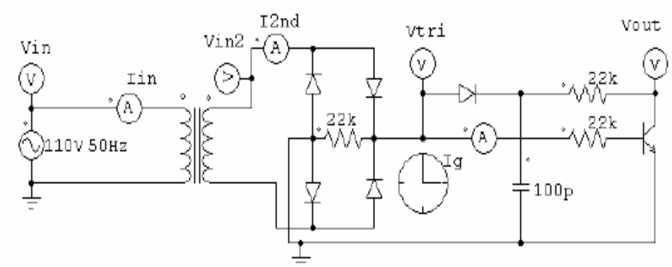

Fig.6. Module of a zero crossing detector [5]

PIC itself can be programmed for zero crossing detection of voltage and current signals. The analog inputs sensed by PT and CT are converted to digital values using built in *A/D* converter. As the output of *ADC_READ* is 10 bit so they are divided by 1023 instead of 1024 to get discretized values as these numbers are fairly close. Then using divider and remainder operators we display this signal on LCD using one digit at a time. To get the value in *ASCII* format, 48 is added to the obtained digit value. Then using comparison operator the values of voltages and currents are compared with zero to detect the zero crossing. The timer is programmed to start at zero crossing of voltage signal and goes to OFF condition at the zero crossing of current signal. Diodes rectify the signals and facilitate the measurement of zero crossings.

The value of overall time delay is fetched from two registers *TMR1H* and *TMR1L*. This value of time is displayed using the same strategy as used to display the values of currents and voltages using divider and remainder operators. From this time delay the value of angle to determine the power factor is measured. Then using sine and cosine functions we determine values of sin (θ) and cos (θ). The peak values of voltage and current waveforms are calculated to determine values of active and reactive powers. A test linear load was placed at input and its readings were taken. Results show improvement of power factor close to 0.95. Fig.7 shows rectified output voltage and currents waveforms.

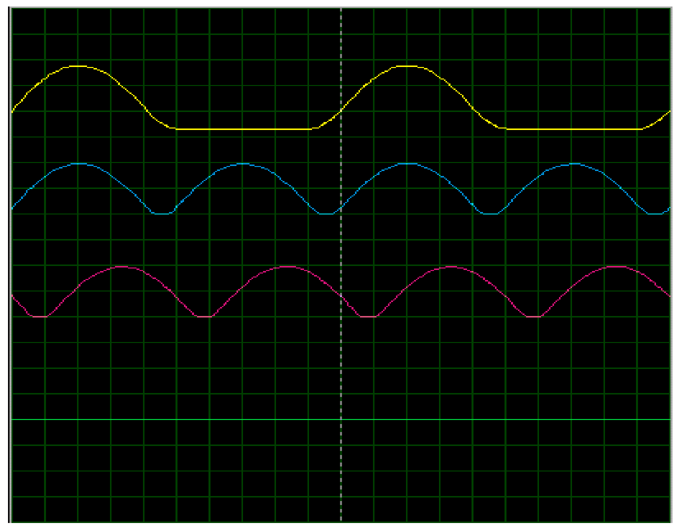

Fig.7. Yellow curve show output of PT, Blue curve shows voltage waveform after rectification, Red curve shows current waveform after rectification

VI. HARDWARE DESIGN

A typical 60Hz, 240V/10A *RMS* AC power system is taken into account for mounting the hardware setup which can manage 2.4 *KVA* power and test linear load like a motor. Programmable Interface Circuit chip (PIC) is used which is the Microchip Technologies' series of microcontrollers. PIC is an inexpensive type of single-chip computer that confines integrated circuit within it. Basically, it looks like a standard personal computer, which contains a CPU (central processing unit), RAM (Random-access memory), ROM (Read-only memory), I/O (input/output) lines, serial and parallel ports, timer, internal oscillator, and even built-in peripherals such as A/D (analogue-to digital), D/A (Digital-to-analogue) and sample/holder (S/H) converters [13].

Apart from PIC, further circuitry includes transducers CTs and PTs for sensing voltage and current signals of the input.

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These signals are fed to the controller for measurement. After making a measurement, controller sends appropriate signals to the capacitors through magnetic relays. No other electronic or electrical device has been used like zero crossing detectors or manual capacitor switches. Code performs all the tasks. Sensing of voltage and current signals having RMS values before and after the improvement is displayed on LCD. Snapshot of hardware design can be seen from fig.8.

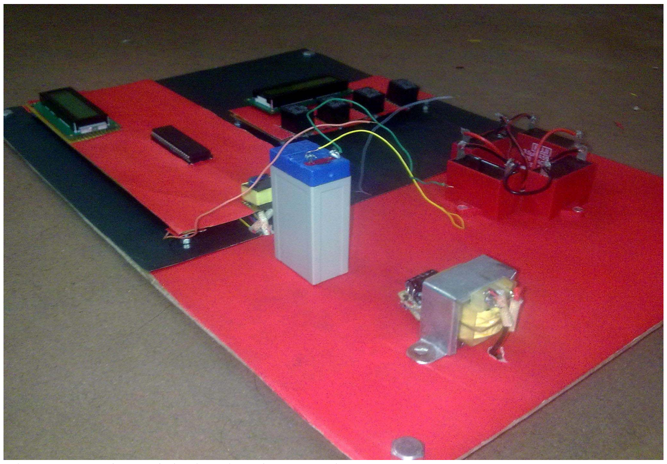

Fig.8. Snapshot of design implementation

VII. CONCLUSIONS

The fundamental goal of this work is the improvement of power factor of a load to bring it as close to unity as possible, its lower bound still remains 0.85. As the algorithm goes, it supplies sufficient reactive power through shunt capacitors gradually as per demand of improvement. As a test, we supplied the input power factors of loads in the range 0.45-0.7 to the device and got the results of improved power factor at the output.

Since our primary task was to ensure greater power factor than 0.85, to reduce the tariff imposed on electrical industries and heavy load consumers, this is successfully achieved by the application of this device. Moreover, as we are quite familiar with transmission and harmonic losses at low power factor conditions, the reduction of these losses is also served by our results. In essence, the paper and device fabrication following it acquires its desired results and it also serves as cost effective and efficient solution of low power factor problems in electrical power systems which is applicably good to linear loads. Our future work includes the fabrication of the same device which is equally good for non-linear loads.

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