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Automatic Power Factor Correction Using Capacitor Banks and 8051 microcontroller

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Abstract— **In the present technological revolution power is very precious. It is important to find out the causes of power loss and improve the stability of the power system. Due to industrialization the use of inductive load has increased and power systems lost its efficiency. Hence need to improve the power factor with a suitable method. Automatic power factor correction device reads the power factor from line voltage and line current by determining the delay in the arrival of the current signal with respect to voltage signal from the AC mains with high accuracy by using an internal timer. This time values are then calibrated as phase angle and corresponding power factor. Then the microcontroller calculates the compensation requirement and accordingly switches on different capacitor banks. Automatic power factor correction techniques can be applied to the IT industries, power systems and also house-holds to make them stable and due to that the system becomes stable and hence increases efficiency of the system.**

Index Terms— **Capacitor Banks, Microcontroller, Relay Drive and Hardware.**

I. INTRODUCTION

The increasing demand of electrical power and the awareness of the necessity of energy saving is much up to date in these days. Also the awareness of power quality is increasing, and power factor correction (PFC) and harmonic filtering will be implemented on a growing scale. Enhancing power quality improvement of power factor saves costs and ensures a fast return on investment. In power distribution, in low- and medium-voltage networks, PFC focuses on the power flow (cosϕ) and the optimization of voltage stability by generating reactive power to improve voltage quality and reliability at distribution level.

Sources of Reactive Power (inductive loads) Decrease the Power Factor:

-Transformers
-Induction Motors
-Induction generators (wind mill generators)
-High Intensity (HID) lighting

Similarly, consumers of Reactive Power Increase Power Factor:

-Capacitors
-Synchronous generators (utility & emergency)
-Synchronous motors.

The Automatic Power factor Correction is a very useful device for improving the power factor and sufficient transmission of active power. If the consumer connects an inductive load, then the power factor is lagging in nature, if the power factor goes below 0.95(lag) hence the Electric supply company charge penalty to the consumer. So it is essential to maintain the Power factor within the limit. Automatic Power factor correction device reads the power factor from line voltage and line current, calculates the compensation required and according to that switches on different capacitor banks.

A. Types of power

i.True Power:-

The actual amount of power being used, or dissipated, in a circuit is called true power. It is measured in watts and is symbolized mathematically by the capital letter P. True power is a function of the circuit's dissipative elements, such as resistances (R).

ii. Reactive Power:-

Reactive loads such as inductors and capacitors dissipate zero power, but the fact that they drop voltage and draw current gives the perception that they do dissipate power. This "dissipated power" is called the reactive power and is measured in Volt-Amps-Reactive (VAR).Reactive power is represented by the capital letter Q, and is a function of a circuit's reactance (X).

iii. Apparent Power:-

The combination of true power and reactive power is called apparent power. It is the product of a circuit's voltage and current, without reference to phase angle. Apparent power is measured in the unit of Volt-Amps (VA) and is symbolized by the capital letter S. Apparent power is a function of a circuit's total impedance (Z).

B. Power Factor satisfaction based on above types:-

Power system loads consist of resistive, inductive, and capacitive loads. Inductive and capacitive loads are opposite in nature. Equal amounts of inductive and capacitive loads within the same system will offset each other leaving only real power. This is defined as a power factor 1 or unity. When a unity power factor is achieved the real power (KW) or demand is equal to the apparent power (KVA). Achieving a unity power factor will provide the most efficient power system. In a purely resistive circuit, all circuit power is

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dissipated by the resistor, voltage and current are in phase with each other, and the true power is equal to the apparent power. In a purely reactive circuit, no circuit power is dissipated by the load. Rather, power is alternately absorbed from and returned to the AC source. Voltage and current are 90^0 out of phase with each other, and the reactive power is equal to the apparent power. In a circuit consisting of both resistance and reactance, there will be more power dissipated by the load than returned, but some power will be definitely dissipated and some will merely be absorbed and returned. Voltage and current in such a circuit will be out of phase by a value somewhere between 0^0 and 90^0. The apparent power is vector sum of the true power and the reactive power

Table 1: Maximum Inductive Load used in the collage

Sl No	More inductive load usage area	Inductive load in %
1	Mechanical Department	35
2	Electrical Department	30
3	Civil Department	10
4	Electronics Department	05
5	Computer Science Department	03
6	Information Science Department	03
7	Other Departments	14
	Total	**100%**

C. Definition Power Factor:-

In power systems, wasted energy capacity, also known as poor power factor, is often overlooked. It can result in poor reliability, safety problems and higher energy costs. Lower the power factor, the less economically system operates. Power factor is the ratio between the real power and the apparent power drawn by an electrical load. Like all ratio measurements it is a unit-less quantity and can be represented mathematically as:

$$Power\ factor = \frac{Real\ power(kW)}{Apparent\ power(kVA)} \quad (1)$$

Where,

PF = Power factor,

KW = Real power

KVA = Apparent power

Reactive power:-

In an inductive load, such as a motor, active power performs the work and reactive power creates the electromagnetic field. PF ≤ 1.0 Usually P.F is always “Lag” (Inductive) Sometime P.F can be “Lead” (Capacitive).

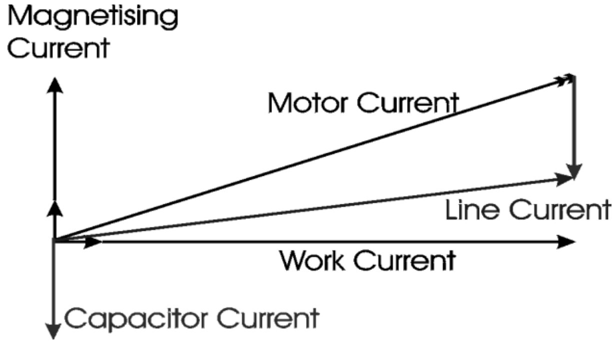

Figure 2: Inductor Current Vector Diagram

II. PROPOSED SYSTEM

Microcontroller base automatic controlling of power factor with monitoring system is shown in fig.1.A capacitive load bank is used which develops an electric load, applied to an electrical power source and converts or dissipates the resultant power output of the source. This way helps to improve power factor. The status of APFC system is displayed on the LCD such as lagging or leading, calculated power factor etc. If there is any error then buzzer is used to indicate the information to user.

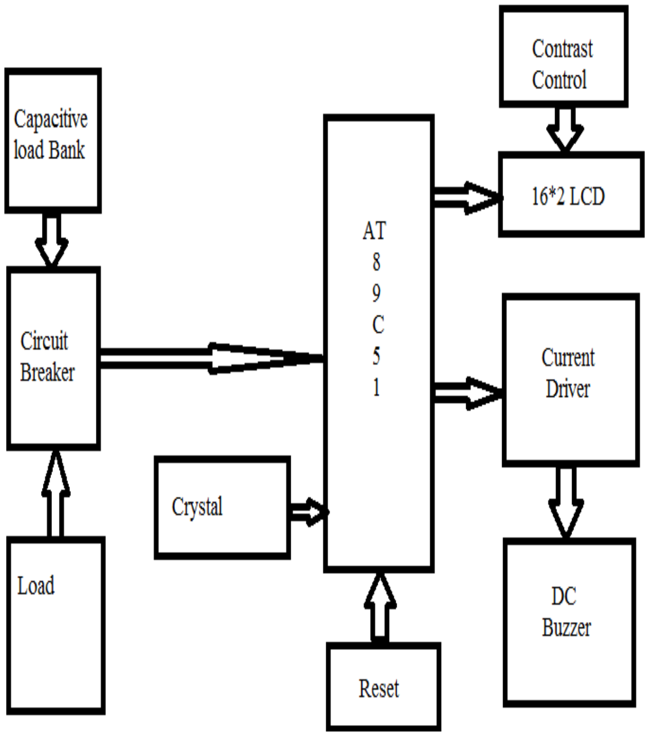

Figure 1: Block diagram of PFC using 8051 microcontroller

Microcontroller used is AT89C51 which is heart and brain of the entire APFC system. It takes input from user and zero crossings of current, voltage waveforms. It controls the capacitor bank as required to compensate for leading or lagging power factor.

III. CALCULATING CAPACITOR BANK REQUIREMENTS

Capacitors are commonly used within a lot of power system, especially electronic constructed circuitry. In three phase power system, capacitors normally installed within an isolating non-conductor metal box, which is called capacitor bank, they are fixed and switched. Fixed banks are connected permanently to the primary conductors through fused switches. Switch capacitors banks are tied to primary system through automated switch, allowing them to be put on line and taken off line as needed. Distribution power system usually connects capacitor in parallel rather connecting in series. The function of shunt power capacitor is to provide leading KVAR to an electrical system when and where needed. The actual capacitor in farads of a capacitor bank can be calculated using the following Equation (2).

Table 2 : Calculating Capacitor Value in Specific Application

Existing PF cos Φ Before applying capacitor	Target Power Factor Required COSΦ					
	0.80	**0.85**	**0.90**	**0.95**	**0.98**	**1.0**
0.75	0.13	0.26	0.40	0.55	0.68	0.88
0.80	--	0.13	0.27	0.42	0.55	0.75
0.85	--	--	0.14	0.29	0.42	0.62
0.87	--	--	0.08	0.24	0.36	0.57
0.89	--	--	0.03	0.18	0.13	0.51
0.90	--	--	--	0.16	0.28	0.48
0.92	--	--	--	0.10	0.22	0.43

$$C = \frac{VAR}{2\pi f * VR^2} \quad (2)$$

Where,

VAR = capacitor unit VAR rating
C= capacitor in farad
F = frequency
VR = capacitor unit rated voltage

Example No: 1

1. Convert the plant load to kW (kVA x PF = kW)
   286.87 kVA x 0.80 Pf = 229.5 kW (useful power per Day)

2. To correct a load of 229.5 kW at 0.80 PF to 0.98 PF.
   Follow the 0.80 value (**Table 2,** column-1) horizontally until below the 0.98 value (**Table 2,** row-1). The Correction factor value is 0.68.

3. Capacitor required correcting from 0.80 to 0.98
   (Power x capacitor from the table value)
   229.5 kW x 0.55 = 126.225 kVAr

IV. SAVINGS

286.87 kVA @ 0.80 PF=9.5625KWh
224.91 kVA @ 0.98 Pf = 9.3712KWh
Reduction of = 2.5810KWh

i. Cost Savings of a Power Factor Correction Unit:

Let us assume that the penalty is 37.57 cents per day per kVAr, for the kVAr necessary to improve the power factor to 0.98 lagging.

The Power factor correction unit will cost installed about Rs.500.00 per kVAr (assumption: cost depends upon companies)

Therefore 183.6 kVAr x 500 = Rs. 91,800.00

ii. Rebate and Penalties:

Table3:Payback and penalities applied from karnataka state electricity board

SL No	Power factor (cosϕ)	Rebate in %	Penalties paisa/unit
1	0.50	-	30
2	0.60	-	25
3	0.70	-	20
4	0.80	-	15
5	0.85	-	-
6	0.90	-	-
7	0.92	-	-
8	**0.95**	**1**	-
9	**0.96**	**2**	-
10	**0.97**	**3**	-
11	**0.98**	**4**	-
12	**0.99**	**5**	-

Payback period is about 6 to 7 months and the cost for power factor correction is recovered and if the power factor is above 0.95 hence Karnataka electricity board will provide Rebate and if power factor is below 0.95 lagging, the penalties applied by KEB are mentioned as in Table 3.

V. HARDWARE CONNECTIONS

The controller operates on +5 V dc, so the regulated +v 5 v is supplied to pin no. 40 and ground at pin no. 20. The controller is used here need not required to handle high frequency signals, so as 12 MHz crystal is used for operating the processor The pin no. 9 is supplied with a +5V dc through a push switch. To reset the processor .As prepare codes are store in the internal flash memory the pin no. 31 is connected to + Vcc.

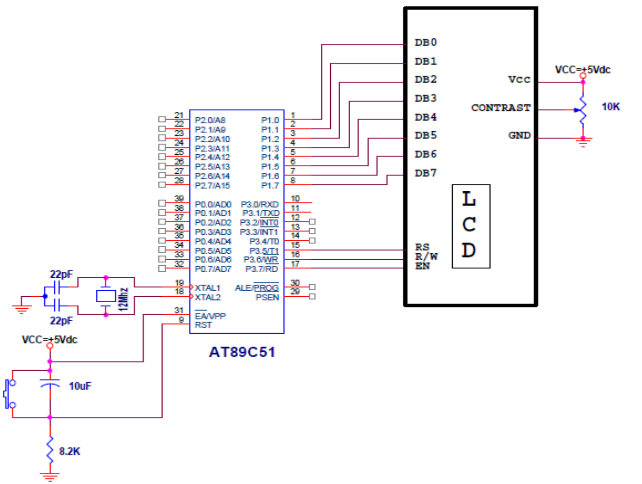

Figure 2: Mother Board Connection to LCD

Port Assignment:

Port 1:-Input to LCD.
Port 2:- Input to relay driver
Port3.0 & Port3.1:- Input port from the function generator.
P1.6 is used as input port increment
P1.7 is used as on input port decrement

VI. Software

Algorithm:

(a)Altering phase of two signals

Step-1:- Timer0 set and run till Timer1 is set or Vice-versa.
Step-2:- Two signals (current & voltage) are introduced.
Step-3:- Phase angle between the two signals altered by incrementing or Decrementing delay between two.
Step-4:- Delay of 0.1 ms is given while incrementing or decrementing.
Step-5:- Accumulator stores the number of incrementing or decrementing operations.
Step-6:- Delay is called according to the number stored in the accumulator.
Step-7:- The signals, altered in phase are sent to the motherboard for power factor Detection.

(b) Phase angle Detection:

Step-1:- Microcontroller started on interrupt mode.
Step-2:-INTX0 & INTX1 are enabled.
Step-3:-INTX0 given VOLTAGE (V), INTX1 given CURRENT (I) from sampling Circuit.
Step-4:-Timer measures time interval between two interrupts.
Step-5:-Time interval calibrated as 0-5ms = 0-90 degree.
Step-6:-Calibrated data is converted from HEX to BCD, then to ASCII for display on LCD.

VII. BENEFITS

The benefits that can be achieved by applying the correct power factor correction are:

- Reduction of power consumption due to improved energy efficiency.
- Reduced power consumption results less greenhouse gas emissions and fossil fuel depletion by power stations.
- Reduction of electricity bills.
- Extra kVA can be accessible from the existing supply only.
- Reduction of I^2R losses in transmission and distribution equipment.
- Reductions of voltage drop in long cables.
- Extended equipment life – Reduced electrical burden on cables and electrical components.

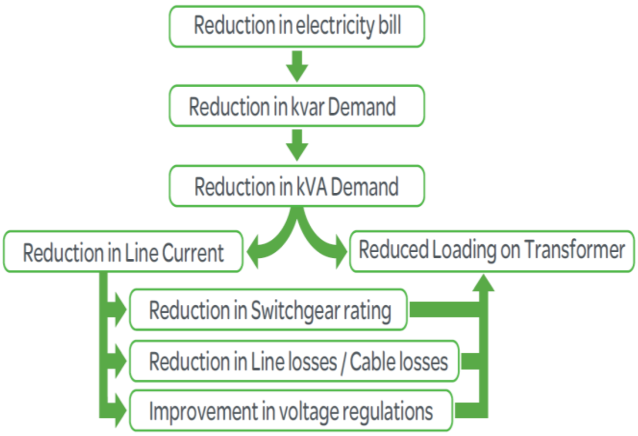

Figure 3: Benefits in Flow Chart

VIII. Results and Discussion

Figure 4: Practical observations before switching ON the capacitor

Microcontroller senses the Delay between voltage and current produced by the load, according to the delay it connects the desired value of capacitor to improve the power factor of the system.

Table 4 :Calculation of Capacitor Required for Motor

Power Factor		Current (Amps)		Capacitor Required(μF)
Before	After	Before	After	
.86	.88	1.93	1.8995	1.2878
.86	.92	1.93	1.8169	4.0193
.86	.95	1.93	1.759	6.356
.86	.98	1.93	1.705	9.375

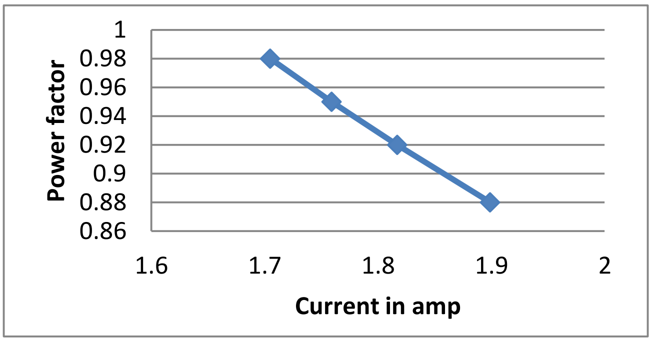

Figure 5 Graphical Representation of Power factor Vs Current

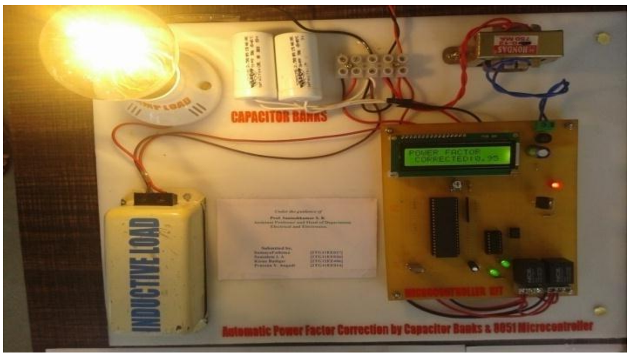

Figure 6: Practical observation after switching ON the capacitor

When the desired value of the capacitors added the required reactive power to the system, the current and voltage waveforms are in phase. After the insertion of required value of capacitor, the V and I zero cross detector signals are also in phase in accordance with the set referenced value of power factor (0.95).

Table 5 :Calculation of Capacitor Required for Inductive load (Choke)

Power Factor		Current (Amps)		Capacitor Required(µF)
Before	After	Before	After	
0.77	0.86	0.54	0.5285	1.4153
0.77	0.88	0.54	0.51652	1.7378
0.77	0.92	0.54	0.49407	2.5625
0.77	0.95	0.54	0.47846	3.00802
0.77	0.98	0.54	0.4638	3.76345

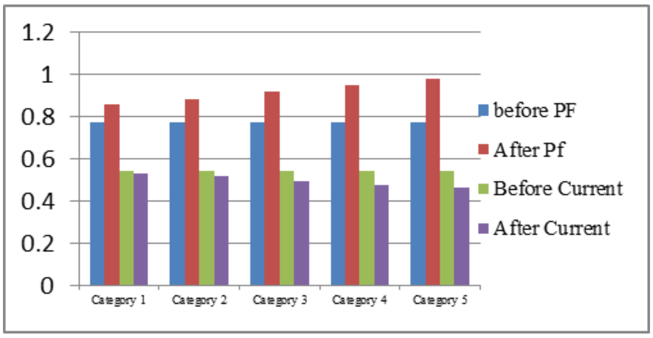

Figure 7: Graphical Representation of Variations in Power factor and Current

IX. CONCLUSION AND FUTURE SCOPE

By observing all aspects of the power factor it is clear that power factor is the most significant part for the utility company as well as for the consumer. Utility companies get rid from the power losses while the consumers are free from low power factor penalty charges. By installing suitably sized power capacitors into the circuit the Power Factor is improved and the value becomes nearer to 0.9 to 0.95 thus minimizing line losses and improving the efficiency of a plant. By using this APFC system the efficiency of the system is highly increased.

The automatic power factor correction using capacitive load banks is very efficient as it reduces the cost by decreasing the power drawn from the supply. As it operates automatically, manpower are not required and this Automated Power factor Correction using capacitive load banks can be used for the industries purpose in the future.

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