

Microcontroller Based Automatic Power Factor Correction System

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Abstract—This paper deals with the design and construction of power factor correction (PFC) system using solid state switched capacitors that are controlled by the Arduino UNO controller. The main objectives are to reduce the line losses, reactive power flows on the line and to avoid switching surge overvoltage due to switching on/off the capacitors. The power factor from the load is measured by using zero crossing circuit and phase shift detector, and then calculate the power factor according to the program and LCD will be used for display. This paper provides implementation done on Arduino UNO microcontroller using C language software to program the microcontroller. Arduino program to determine time lag between current and voltage, and control the power factor to get target point by the program according to the load. This system senses the power factor and with the help of microcontroller switches, required number of capacitors in the capacitor bank to achieve target power factor. In this system, the reactive power will be generated by the bank of static capacitors. Design and construction will be done by using the LM 358, CD4070BC, MOC 3052, BTA 41 ICs, Arduino UNO Microcontroller and LCD display in this system.

Keywords —Power Factor, LM358, CD4070 BC, MOC 3052, BTA 41 ICs LCD, C language, Arduino UNO microcontroller.

I. INTRODUCTION

In electrical plants, the loads draw from the network electric power (active) as power supply source (e.g. personal computers, printers, diagnostic equipment, etc.) or convert it into other form of energy (e.g. electrical lamps or stoves) or into mechanical output (e.g. electrical motors). To get this, it is often necessary that the load exchanges with the network (with net null consumption) and the reactive energy is produced mainly from inductive type. This energy, even if not immediately converted into other forms, contributes to increase the total power flowing through in the electrical network, from the generators, all along the conductors, to the users. To smooth such negative effect, the power factor correction of the electrical plants is carried out. The power factor correction obtained by using capacitor banks to generate locally the reactive energy necessary for the transfer of electrical useful power, allows a better and more rational technical-economical management of the plants.[1]

There are so many industries around the world and so are in Myanmar. Most of the industrial plants are using the inductive loads in infrastructure such as transformers and motors. Among them, the large industrial motors are essentially used in the industrial plants. Induction motors receive the grate reactive power from network for their proper function. Reactive power consumption causes the reduction of voltage of feeder in the plants and on the other hand, it causes the reduction of power factor of the whole plants.

Therefore, to improve the power factor is very important for all of the plants and even in the domestic industries and home appliances. According to that point, one of the best methods for the power factor improvement is the power factor

correction (PFC) technique. The block diagram of power factor correction system is shown in Fig.1.

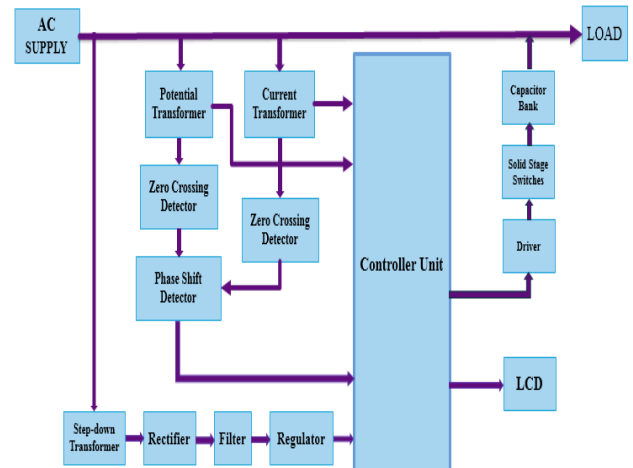


Figure 1: Block diagram of power factor measuring system

II. TECHNOLOGY

This system presents power factor correction (PFC) technique using solid state switched capacitors. This system describes the design and simulation of power factor correction using Arduino UNO controller. Measuring the power factor from the load by using LM358 zero crossing circuit and CD4070BC phase shift detector, and then calculating the power factor have been done according to the program and LCD will be used for display. If the power is not in the range, the switches are on/off conditioned by the controller unit and capacitors are activate/deactivate and improve the power factor. This system provides implementation done on Arduino UNO microcontroller using C language software to program the microcontroller, Arduino program to determine time lag between current and voltage and Proteus 7.7 to simulate the power factor according to the load.

A. Power Factor

Power factor represents the percentage of electricity that is being used to do useful work. It is defined as the ratio of active or actual power used in the circuit measured in watts or kilowatts (W or kW), to the apparent power expressed in volt-amperes or kilo volt-amperes (VA or kVA).

$$\text{Power factor} = \frac{\text{Active Power}}{\text{Apparent Power}} \text{ or } \frac{W}{VA}$$

The apparent power also referred to as total power delivered by utility company has two components.

- Productive Power that powers the equipment and performs the useful work. It is measured in kW (kilowatts).
- Reactive Power that generates magnetic fields to produce flux necessary for the operation of induction devices (AC motors, transformer, inductive furnaces, ovens etc.). It is measured in kVAR (kilovolt-Ampere-Reactance).[1]

Reactive Power produces no productive work. An inductive motor with power applied and no load on its shaft should draw almost nil productive power, since no output work is being accomplished until a load is applied. The current associated with no-load motor readings is almost entirely "Reactive" Power. As a load is applied to the shaft of the motor, the "Reactive" Power requirement will change only a small amount. The Productive Power is the power that is transferred from electrical energy to some other form of energy (i.e. such as heat energy or mechanical energy). The apparent power is always in excess of the productive power for inductive loads and is dependent on the type of machine in use. The working power (kW) and reactive power (kVAR) together make up apparent power, which is measured in kilovolt amperes (kVA). Graphically it can be represented as:

$$\text{Power factor} = \frac{\text{kW (Productive Power)}}{\text{kVA (Total Power)}}$$

The cosine of the phase angle θ between the kVA and the kW components represents the power factor of the load. kVAR represents the non-productive reactive power and θ is lagging phase angle [1].

Benefits of Power Factor Correction are:

1. Reduce Utility Power Bills,
2. Increase System Capacity,
3. Improve System Operating Characteristics (Gain Voltage), and
4. Improve System Operating Characteristics (Reduce Line Losses).[2]

B. Zero Crossing Detector

Zero crossing detector is used to detect sine wave zero crossing from positive half cycle to negative half cycle or negative half cycle. To measure time difference between two waves is to detect zero crossing of two waves. The 230 V, 50 Hz is step downed using voltage transformer and current transformer is used to extract the waveforms of current.

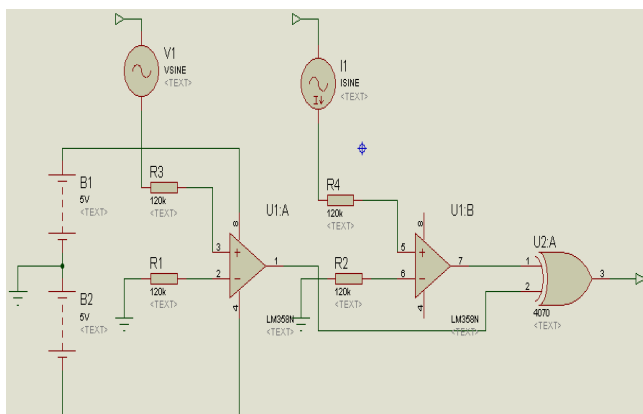


Figure 2: Zero crossing detector using LM358 as a comparator

The output of the voltage transformer is proportional to the voltage across the load and output of current transformer is proportional to the current through the load. These waveforms are fed to voltage comparators constructed using operational amplifier. It is a zero crossing detector, and its output changes during zero crossing of the current and voltage waveforms. These outputs are fed to the controller unit which does the further power factor calculations. Zero crossing detector using LM 358 as a comparator is shown in Fig.2.[3]

C. Solid State Switch

Solid state switches are electronic switching devices that can operate on or off positions when a small external voltage is

applied from the microcontroller. In AC circuits, solid state relays (SCR or TRIAC) switch on at the points of zero load current. The circuit will never be interrupted in the middle of a sine wave peak, preventing the large transient voltages that would otherwise occur due to sudden collapse of the magnetic field around the inductance. This feature is called zero-crossing switching. Many advantages appear by using the solid state switches in this system. There is slimmer profile, allowing tighter packing, totally silent operation and switch faster than electromechanical relays, the switching time of a typical optically coupled SSR is dependent on the time needed to power the LED on and off of the order of microseconds to milliseconds. It can increase lifetime, even if it is activated many times, as there are no moving parts to wear and no contacts to pit or build up carbon. Output resistance remains constant regardless amount of use. Clean, bounce less operation, no sparking, allows it to be used in explosive environments, where it is critical that no spark is generated during switching. It is inherently smaller than a mechanical relay of similar specification. It is much less sensitive to storage and operating environment factors such as mechanical shock, vibration, humidity, and external magnetic fields.

D. Capacitor Bank

There are two categories of connecting capacitor bank. They are shunt and series connecting. Among these two categories, shunt capacitors are more commonly used in the power system of all voltage levels. There are some specific advantages of using shunt capacitors such as:

1. It reduces line current of the system.
2. It improves voltage level of the load.
3. It also reduces system losses.
4. It improves power factor of the source current.
5. It reduces load of the alternator.
6. It reduces capital investment per megawatt of the load.

All the above-mentioned benefits come from the fact that the effect of capacitor reduces reactive current flowing through the whole system. Shunt capacitor draws almost fixed amount of leading current which is superimposed on the load current and consequently reduces reactive components of the load and hence improves the power factor of the system. Series capacitor on the other hand has no control over flow of current. As these are connected in series with load, the load current always passed through series capacitor bank. The capacitive reactance of series capacitor neutralizes the inductive reactance of the line hence, reduces, effective reactance of the line.[4]

E. Controller Unit

Controller unit which represented Arduino UNO is the heart of this Automatic Power Factor Controller, it finds, displays and controls the Power Factor. To correct power factor, first finding the current power factor is needed. It displays the calculated power factor in the LCD display and switches ON the capacitors. The controller calculates the time difference between the zero crossing points of current and voltage, which is directly proportional to the power factor. Moreover, it determines the power factor according to the program and to get the desired values by using the compensation of the capacitors. Depending on the power factor range the switches are activating the on stage with the control of the program. The required numbers of capacitors are connected in parallel to the load as required.

F. Circuit Diagram of the System

Complete circuit diagram of this system is shown in Fig. 3.

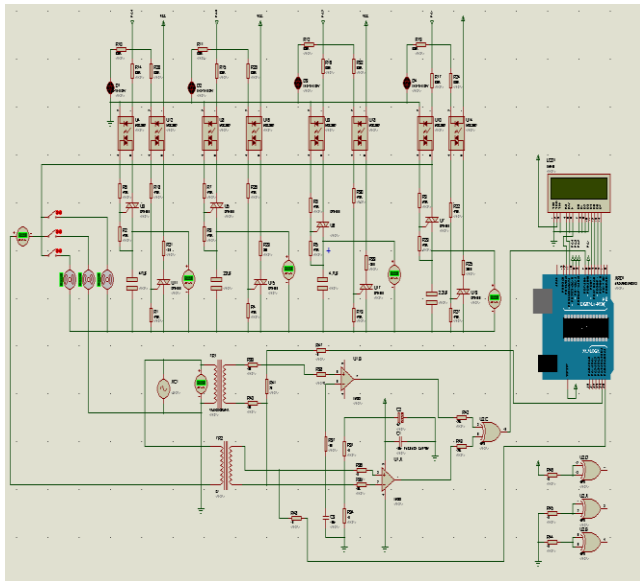


Figure 3: Circuit Diagram of the System

III. DESIGN CALCULATION

A. Calculation of Compensated Capacitor Units

This calculation describes the compensated capacitors for different conditions. To calculate the required PFC capacitance it is necessary to know the existing reactive power Q_L of electrical system and choose desired PF. There are several ways of estimating Q_L , discussed below. It is important to point out the fact that reactive power of a motor slightly varies with the load. Therefore, to avoid over correction, ideally VAR value of the motor should be determined at no load. Phasor diagram for inductive load is shown in Fig. 4.

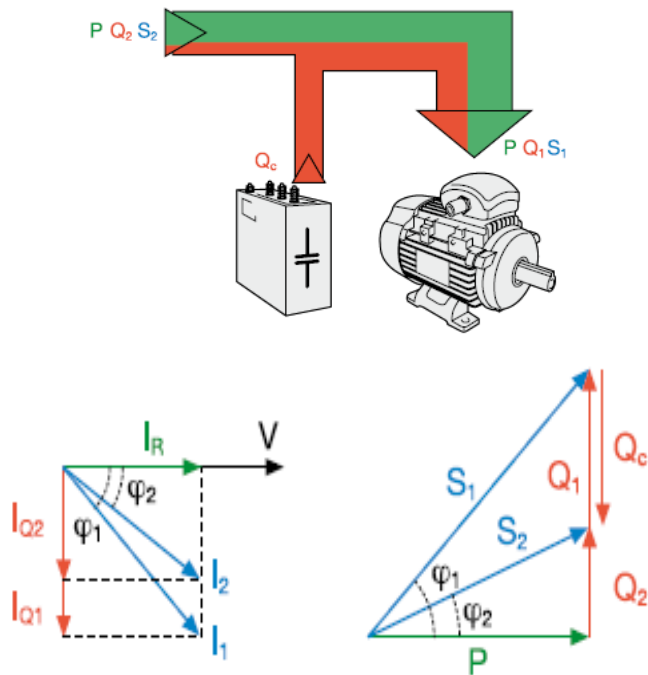


Figure 4: Phasor Diagram for Inductive Load Source: [5]

$$\begin{aligned}
 Q_{\text{uncorrected}} &= P \times \tan \theta_1 \\
 Q_{\text{corrected}} &= P \times \tan \theta_2 \\
 Q_c &= Q_{\text{uncorrected}} \\
 Q_{\text{corrected}} &= P \times (\tan \theta_1 - \tan \theta_2) \\
 Q_c &= P \times K
 \end{aligned}$$

Where,
P is the active power;

Q_1, θ_1 are the reactive power and the phase displacement angle before power factor correction;

Q_2, θ_2 are the reactive power and the phase displacement angle after power factor correction;

Q_c is the reactive power for power factor correction.

$$K = \text{factor } K \text{ (kvar/kW)}$$

Motor 2 ON

$$V = 230V, I = 2.5205A$$

$$\text{Initial power factor} = \cos \theta_1 = 0.42$$

$$\theta_1 = 65.1654^\circ$$

$$\text{Target power factor} = \cos \theta_2 = 0.92$$

$$\theta_2 = 23.0739^\circ$$

$$\begin{aligned}
 P_1 &= VI \cos \theta_1 = 230 \times 2.5205 \\
 &\quad \times 0.42 \\
 &= 243.4803W
 \end{aligned}$$

$$Q_c = Q_1 - Q_2$$

$$\begin{aligned}
 &= P (\tan \theta_1 - \tan \theta_2) \\
 &= 243.4803 (\tan 65.1654 - \tan 23.0739) \\
 &= 422.3830\text{Var}
 \end{aligned}$$

$$\begin{aligned}
 \text{For capacitor } C &= \frac{k \text{ Var}}{2\pi f V^2 \times 10^{-3}} \\
 &= \frac{422.3830 \times 10^{-3}}{2\pi \times 50 \times 230^2 \times 10^{-3}} \\
 &= 25.4156 \mu\text{F}
 \end{aligned}$$

Motor 1,2 and 3 ON

$$V=230V, I=5.8791$$

$$\text{Initial power factor} = \cos \theta_1 = 0.46$$

$$\theta_1 = 62.6129^\circ$$

$$\text{Target power factor} = \cos \theta_2 = 0.92$$

$$\theta_2 = 23.0739^\circ$$

$$P = VI \cos \theta_1$$

$$\begin{aligned}
 &= 230 \times 5.8791 \\
 &\quad \times 0.46 \\
 &= 622.0088 \text{ W} \\
 Q_c &= Q_1 - Q_2
 \end{aligned}$$

$$\begin{aligned}
 &= P (\tan \theta_1 - \tan \theta_2) \\
 &= 622.0088 (\tan 62.6219 - \tan 23.0739) \\
 &= 936.1256\text{Var}
 \end{aligned}$$

$$\begin{aligned}
 \text{For capacitor } C &= \frac{k \text{ Var}}{2\pi f V^2 \times 10^{-3}} \\
 &= \frac{936.1256 \times 10^{-3}}{2\pi \times 50 \times 230^2 \times 10^{-3}} \\
 &= 56.32855 \mu\text{F}
 \end{aligned}$$

In table 1, shows the compensated capacitors' values for different loads on conditions and table 2 describes the selected capacitors' values of this system.

Table 1: Capacitance Values of Different Loads

Motor	Initial PF	Target PF	K kvar/kW	P W	Q _c Var	C μF
Motor 1	0.56	0.92	1.05	119.33	125.30	7.56
Motor 2	0.42	0.92	1.73	243.48	421.22	25.42
Motor 3	0.38	0.92	2.01	212.57	427.27	25.69
Motor 1,2	0.46	0.92	1.50	379.73	569.60	34.37
Motor 1,3	0.47	0.92	1.45	393.74	570.92	34.40
Motor 2,3	0.42	0.92	1.73	478.42	827.67	49.94
Motor 1,2,3	0.46	0.92	1.50	622.01	936.24	56.33

Table 2 Selected Capacitor Values

SW 4 (50μF)	SW3 (20 μF)	SW2 (10 μF)	SW1 (5μF)	Total capacitor (μF)
0	0	0	0	0
0	0	0	1	5
0	0	1	0	10
0	0	1	1	15
0	1	0	0	20
0	1	0	1	25
0	1	1	0	30
0	1	1	1	35
1	0	0	0	50
1	0	0	1	60
1	0	1	0	57
1	0	1	1	65
1	1	0	0	70
1	1	0	1	75
1	1	1	0	80
1	1	1	1	85

B. Calculation of Capacitor Discharge Circuit

This section describes the calculation of capacitor discharge circuit:

Supply Voltage, $V_{max} = \sqrt{2} \times 230 = 325 V$,
 $V_{C(max)} = 325V$

Select Discharge Time $t = 2 \text{ sec}$
 $V_{C(min)} = 10\% \text{ of } V_{C(max)}$
 $= 10\% \text{ of } 325 V$
 $= 32.5 V$

$V_{C(t)} = V_0 e^{-t/\tau}$
 $= V_0 e^{-t/RC}$

$V_{C(min)} = V_0 e^{-2/RC}$
 $32.5 = 325 e^{-2/RC}$

$e^{-2/RC} = 0.1$
 $\frac{-2}{RC} = \ln 0.1$
 $R = \frac{2}{\ln 0.1 \times C} = \frac{2}{2.3 \times C}$

For $C_1 = 5 \mu F$,

Discharge Resistor, $R_1 = \frac{2}{2.3 \times 5 \times 10^{-6}} = 173.91 k\Omega$

Select $R_1 = 180 k\Omega$

For $C_2 = 10 \mu F$,

Discharge Resistor, $R_2 = \frac{2}{2.3 \times 10 \times 10^{-6}} = 86.956 k\Omega$

Select $R_2 = 82 k\Omega$

For $C_3 = 20 \mu F$,

Discharge Resistor, $R_3 = \frac{2}{2.3 \times 20 \times 10^{-6}} = 43.47 k\Omega$

Select $R_3 = 43 k\Omega$

For $C_4 = 50 \mu F$,

Discharge Resistor, $R_4 = \frac{2}{2.3 \times 50 \times 10^{-6}} = 17.39 k\Omega$

Select $R_4 = 18 k\Omega$

Select delay time = 3 sec

IV. SOFTWARE DEVELOPMENT

A. Design Flow of the System

Software implementation is an important part of this system.

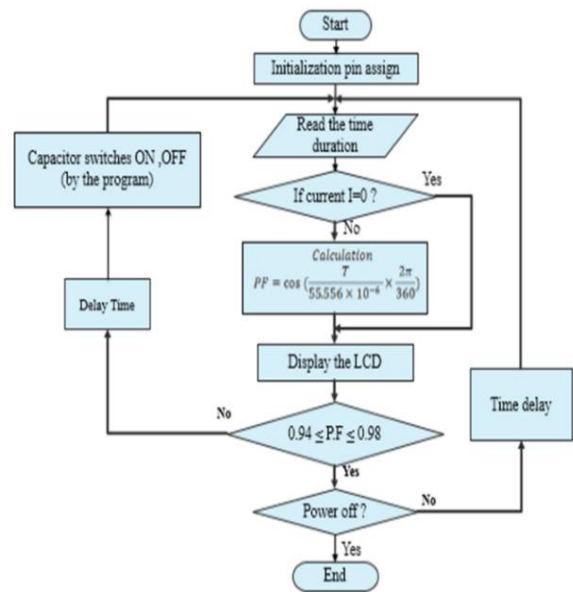


Figure 5: Flow Chart of the Power Factor Measuring System

B. How to Find the Phase Angle by Using the Time Difference

For example,

$V = 230 \angle 0^\circ V$
 $I = 20 \angle 60^\circ A$ (Lagging)
 $f = 50 \text{ Hz}$
 $T = \frac{1}{f} = \frac{1}{50} = 20 \text{ ms}$

For half cycle, $\frac{T}{2} = 10 \text{ ms}$

$180^\circ \rightarrow 10 \text{ ms}$

$1^\circ \rightarrow 10 \times \frac{1}{180} = 0.055556 \text{ ms} = 55.556 \mu s$
 $55.556 \mu s$ time difference is the 1° phase shift.

60° phase shift $\rightarrow T_{difference} = 55.556 \mu s \times 60 = 3333.36 \mu s$

C. Power Factor Equation for Using Program

T= Time duration between V and I waveform

θ = Phase shift

$P.F = \cos \theta$

$\theta = \frac{T}{55.556 \mu s} \text{ (Deg:)} \theta = \frac{T}{55.556 \times 10^{-6}} \times \frac{2\pi}{360} \text{ (Rad:)}$

$P.F = \cos \theta$

$= \cos \left(\frac{T}{55.556 \times 10^{-6}} \times \frac{2\pi}{360} \right)$

V. TEST AND RESULTS

In this section, the overall testing and results are described in detail with some figures. No Load condition. In Fig. 6, because the total loads are off condition, LCD displays “No Load”.



Figure 6: No Load Condition

Motor 1 ON condition

In Fig. 7, the load 1 is on condition and load 2& 3 off. The power factor 0.94 is seen on LCD and the capacitor C1 is activate.

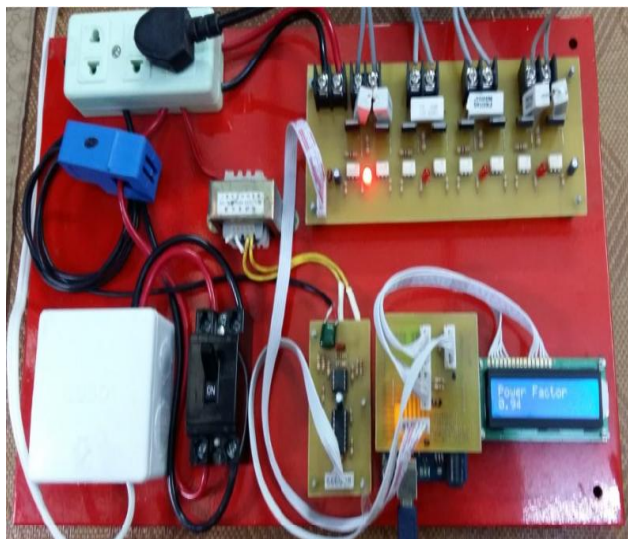


Figure 7: Motor 1 ON Condition

Switch 1 ON
C = 5µF
Power Factor =0.94

Motor 2 ON Condition

In Fig. 8 shows (Motor 2) on condition Load 2 is on condition, the compensated capacitors 1 and 3 are activated and the power factor increases from 0.42 to 0.98.

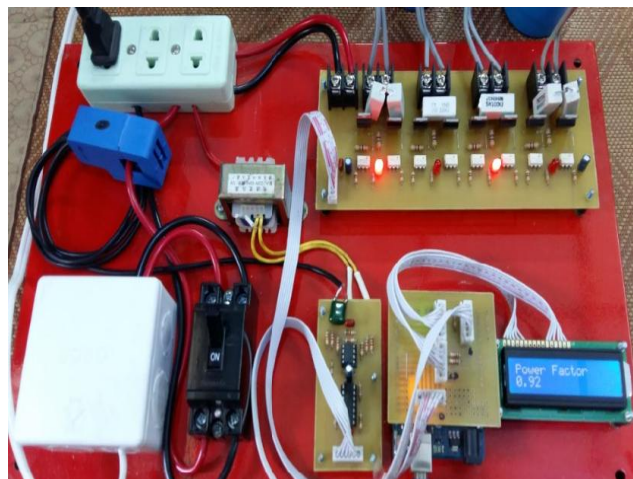


Figure 8: Motor 2 ON Condition

Switch 1 and 3 ON
C= 5 µF + 20 µF= 25 µF
Power Factor = 0.98

Motor 1 & 2 ON Condition

In Fig. 9 shows Motor 1& 2 on condition. In this condition the compensated capacitors 1 and 3 are activated and the power factor increases from 0.46 to 0.94.

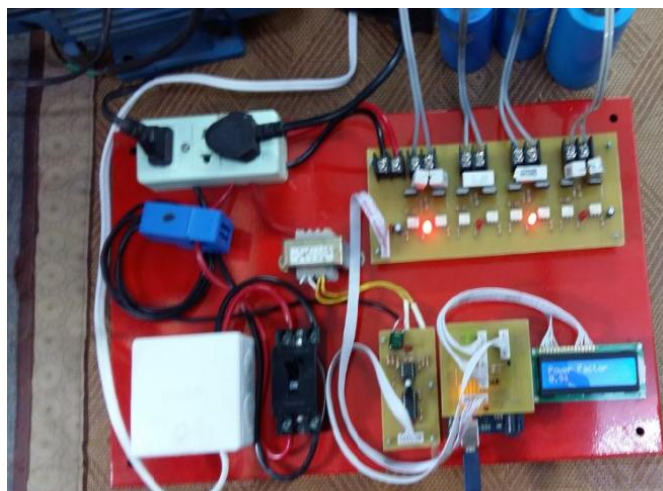


Figure 9: Motor 1,2 ON with Compensated Capacitors

Switch 3 and 1 ON
C = 5µF +20µF = 25µF
Power Factor =0.94

Tested Values of Compensated Capacitors

The improved power factor and the values of compensated capacitors are shown in Table 3.

Table 3 Compensated Capacitors Values for Different Loads

On Condition	Initial Power Factor	Target Power Factor	Actual Final Power Factor	Compensated Capacitors (µF)
Motor1	0.56	0.92	0.94	5
Motor2	0.42	0.92	0.95	20
Motor3	0.38	0.92	0.98	25
Motor1,2	0.46	0.92	0.92	25

Motor1,3	0.47	0.92	0.97	30
Motor2,3	0.42	0.92	0.94	35
Motor1,2,3	0.46	0.92	0.94	50

CONCLUSIONS

The PFC System with solid state switched capacitor is constructed completely. Compensated capacitor's value may be changed according to the current condition even the same load. This system senses the power factor and with the help of microcontroller switches, required number of capacitors in the capacitor bank to achieve target power factor. Arduino UNO controller is very popular at this event, likewise easily to write the program by using the high level language. By the using of solid state switches, it can compare with the mechanical relays, so many reliable and efficient outcomes are appearing. This is the very efficient system for various loads, by using the different sizes capacitors and trigger the switches which was controlled by the program.

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References

- [1] A.Bhatia, 2012, "Power Factor in Electrical Energy Management", 5272 Meadow Estates Drive, Fairfax, VA 22030-6658, Phone & Fax: 703-988-0088, www.PDHonline.org , www.PDHcenter.com.
- [2] NOKIAN CAPACITORS, September, 2015, "Power Factor Correction", Tel: +358 3 388 311, Telefax: +358 3 3883 360, [Online]. Available: <http://www.nokiancapacitors.com>
- [3] Rod, E. 2005. "Zero Crossing Detectors and Comparators", The Umsung Heroes of Modern Electronics Design, June 2015. [Online]. Available: <http://sound.westhost.com/appnotes/an005.htm>
- [4] Anonymous. 2011. "Shunt Capacitors and Their Applications", Power Quality in Electrical Systems, June 2011.
- [5] Anonymous. 2010. "Power Factor Correction and Harmonic Filtering in Electrical Plants", Technical Application Papers, no. 8, August 2010 www.abb.com
- [6] Brian Evans. 2011. "Beginning Arduino Programming". February 2015. <[www.it-ebooks-info](http://www.it-ebooks-info.com)>
- [7] Anonymous. 2015. "Datasheet of LM358". January 2015. www.onsemi.com
- [8] Anonymous. 2002. "CD4070BC Quad 2-Input EXCLUSIVE-OR Gate". July 2015. www.fairchildsemi.com
- [9] Anonymous. 1995. "6-Pin DIP Random-Phase Optoisolators Triac Drivers". <http://Design-NET.com>
- [10] Anonymous. 2009. "Data sheet of BTA 40, BTA 4, BTB 41". www.st.com