

MICROCONTROLLER BASED AUTOMATIC POWER FACTOR CORRECTION IN MINES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

**MASTER OF TECHNOLOGY
IN
MINING ENGINEERING**

BY

**SMRUTI SUMAN ROUTRAY
ROLL NO- 213MN1497**



**Department of Mining Engineering
National Institute of Technology
Rourkela -769008
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**UNDER THE GUIDANCE OF
Prof. D.P. TRIPATHY**



**Department of Mining Engineering
National Institute of Technology
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2015**



National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the thesis entitled, “**MICROCONTROLLER BASED AUTOMATIC POWER FACTOR CORRECTION IN MINES**” is being submitted by **SMRUTI SUMAN ROUTRAY, Roll No-213MN1497**, in partial fulfillment of the requirements for the award of degree of **Master of Technology in Mining Engineering** at National Institute of Technology, Rourkela and is an authentic study analysis work carried out by him under my supervision. To the best of my knowledge, the matter exemplified in the thesis has not been submitted to any other university/institute for the award of any degree/diploma.

Date: 29th May, 2015
Place: Rourkela

Dr. Debi Prasad Tripathy
Professor
Department of Mining Engineering
National Institute of Technology
Rourkela, Odisha-769008, India

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SMRUTI SUMAN ROUTRAY

Roll No: 213MN1497

ABSTRACT

With the mining industry moving from traditional manual methods to the advanced mechanised mining, the focus is also shifting to the energy efficiency of the equipment and system being employed. Most of the equipment used in mining like shovel, drill, elevator, continuous miner, conveyor, pumps etc. runs on electricity. Electric energy being the only form of energy which can be easily converted to any other form plays a vital role for the growth of any industry. The Power Factor gives an idea about the efficiency of the system to do useful work out of the supplied electric power. A low value of power factor leads to increase in electric losses and also draws penalty by the utility. Significant savings in utility power costs can be realized by keeping up an average monthly power factor close to unity. To improve the power factor to desired level, reactive power compensators are used in the substations. The most common used device is capacitor bank which are switched on and off manually based on the requirement. If automatic switching can be employed for the correction devices, not only it will improve the response time but also removes any scope for error.

The work carried out is concerned with developing power factor correction equipment based on embedded system which can automatically monitor the power factor in the mining electrical system and take care of the switching process to maintain a desired level of power factor which fulfils the standard norms. The Automatic Power Factor Correction (APFC) device developed is based on embedded system having 89S52 microcontroller at its core. The voltage and current signal from the system is sampled and taken as input to measure the power factor and if it falls short of the specified value by utility, then the device automatically switch on the capacitor banks to compensate for the reactive power. The number of capacitors switched on or off is decided by the microcontroller based on the system power factor and the targeted power factor.

The measurement and monitoring of three different possible load types suggested that only the inductive loads required power factor correction. After employing the correction equipment the targeted power factor of 0.95 is achieved and the increase in power factor varied from 9% to 19% based on the combination of load. There is also a decrease of 1.7% in the total energy consumption due to reduction in load current. The economic analysis for power factor improvement considering the data from a local coal mine suggested the payback period to be around 9 months if the correction equipment is implemented.

ACRONYMS

A	Ampere
ATP	Alternative Transient Program
APFC	Automatic Power factor Correction
CT	Current Transformer
KVA	Kilo Volt Ampere
KVAR	Kilo Volt Ampere Reactive
KW	Kilo Watt
kWh	kilo Watt Hour
LCD	Liquid Crystal Display
MCL	Mahanadi Coalfields Limited
MSHA	Mine Safety and Health Administration
PCB	Printed Circuit Board
PF	Power Factor
PFC	Power Factor Correction
PT	Potential Transformer
R	Resistive
R-L	Resistive-Inductive
RMS	Root Mean Square
THD	Total Harmonic Distortion
V	Volt
WESCO	Western Electricity Supply Company of Odisha
ZCS	Zero Current Sensor
ZVS	Zero Voltage Sensor

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Chapter-1

Introduction

1.1 INTRODUCTION

The power factor of an electrical system gives the idea about the efficiency of the system to do useful work out of the supplied electric power. A low power factor leads to increase in losses and also draws penalty by the utility. Modern mining industry using mechanized methods suffers from low power factor due to the use of different electric equipment which requires more reactive power. Significant savings in utility power costs can be realized by keeping up an average monthly power factor close to unity. Utilizing shunt capacitor banks for Power Factor Correction (PFC) is an exceptionally established methodology. The recent trend is to automate the switching procedure of capacitors to get greatest advantage in real time basis. Embedded systems based on microcontrollers can be used to monitor and control the switching of correction devices because of its dependability and execution.

1.2 MOTIVATION FOR THE PRESENT RESEARCH WORK

Electricity plays a pivotal role in almost all businesses, above all in the mining engineering. Without it, it would be hard or nearly impossible for miners to do their task. But since mine sites are often located at the end of the grid and operated with the use of heavy mining machineries, they are particularly susceptible to power issues. With the constantly increasing cost of energy, mining sites are struggling to remain competitive in the market and keep their operation as smooth as conceivable. And since they are also considered very large power users, mines are usually being targeted by electrical companies and related establishments. Retaining the power quality is crucial in mines to maximize production and avoid any technical problems while lowering energy cost. If the power factor approaches 1, it reflects that all the energy supplied in the system is being used resourcefully. But then mine sites often use complex equipment, power factor 1 is not usually obtained. In the mining business, any power factor over .95 is accepted and considered to be an efficient use of energy. The typical uncorrected power factor for a coal mine ranges from 0.65 to 0.8 [1]. Amendment of power factor close to unity have the points of interest of diminished utility bills, technical issue evacuation, decreased carbon foot prints, meeting lawful commitment and so forth. Henceforth suitable correction equipment must be designed to monitor the system power factor and make the necessary improvement when it goes underneath the specified limit set as per the standards.

1.3 OBJECTIVES OF THE PROJECT

The primary objective of the project was to design correction equipment which can monitor the power factor of the mine electrical framework and enhance the power factor to a desired value. The research investigations were carried out with the following objectives:

- To conduct an electrical survey of the existing system in an opencast mine to study the system configuration and load patterns, variation of power factor during the mine operation hours and analyze power factor correction facility, if any.
- Design a microcontroller based correction equipment to improve the power factor of the system to desired value of greater than 0.95.
- Implement the system and monitor different electrical load models and diverse load patterns to verify the result.
- To carry out economic analysis for power factor improvement.

1.4 LAYOUT OF THE THESIS

Chapter-1 gives a brief overview of the research area, inspiration driving the work, objectives identified and organization of the thesis.



Chapter-2 consists of literature review for comprehensive interpretation of the concepts associated with power factor and its correction accompanied by the prior research work carried out in this area.



Chapter-3 involves the proposed principle to design the correction equipment and the algorithm to work for achieving the required outcome along with the technique to measure and monitor.



Chapter-4 gives detail idea about construction and working of each component associated with the power factor correction equipment and the final hardware implementation.



Chapter-5 shows the results obtained by measuring and monitoring the designed loads under different conditions and load patterns.



Chapter-6 involves the economic analysis and viability of the correction equipment considering data obtained from a coal mine (MCL).



Chapter-7 concludes the findings of the study and proposes scope for future work.

Chapter-2

Literature Review

2.1 INTRODUCTION

Efficient utilization of energy is now considered as one of the primary motives in any mechanized industry. The power factor of any electrical system suggests how efficient it is to do the useful work. Most mining machines have notoriously poor power factors because of under-utilization of induction motors. This specifically identifies poor system efficiency and utilization. The large load currents drawn result in poor voltage regulation of the system besides contributing to large joule losses in lines. Diminished voltage levels directly translate into heating of motor windings in this way decreasing the life and reliability of the machine. The decline in available torque, corresponding to the less than nominal voltage, will result in poorer machine performance. The maximum kilovolt-ampere demand charge increases as a consequence of poor power factor, and in most cases forms a rather large part of the monthly utility service charge.

2.2 POWER FACTOR

The power factor (PF) of an AC electrical power system is defined as “the ratio of the real power flowing to the load, to the apparent power in the circuit” [2]. Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power. It is schematically shown in Figure 2.1.

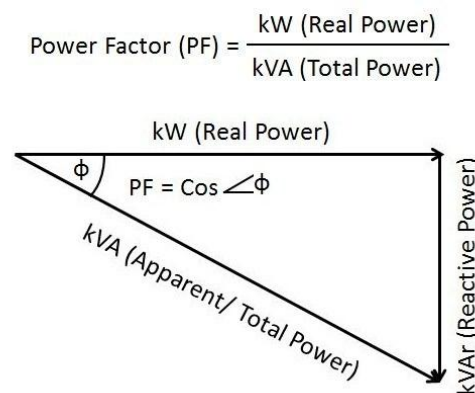


Figure 2.1: Schematic Diagram for Power Factor

A load with a power factor of 1.0 result in the most efficient loading of the supply and a load with a power factor of 0.5 will result in much higher losses in the supply system.

A poor power factor can be the result of either a significant phase difference between the voltage and current at the load terminals, or it can be due to a high harmonic content or distorted/ discontinuous current waveform. Poor load current phase angle is generally the result of an inductive load such as an induction motor, power transformer, lighting ballasts, welder or induction furnace. A poor power factor due to an inductive load can be improved by the addition of power factor correction, but, a poor power factor due to a distorted current waveform requires a change in equipment design or expensive harmonic filters to gain an appreciable improvement. To have an efficient system the power factor should be maintained near to 1. Utilities typically charge additional costs to commercial customers who have a power factor below some limit, which is typically 0.9 to 0.95.

2.2.1 Reasons of Low Power Factor

- Mercury vapour lamps or lamps operated with chokes
- Power and distribution Transformers. A complete unloaded transformer is very inductive and has a very low power factor.
- Induction motors (Load and unload condition)

The inductive load equipment causing low power factor in the mines includes Hoists, Shovel, Drill, Pump, Shearer, Conveyors etc.

2.3 POWER FACTOR CORRECTION

Power factor correction (PFC) is a technique of counteracting the undesirable effects of electric loads that create a power factor (PF) that is less than 1. 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.

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. Capacitors connected at each starter and controlled by each starter are known as "Static Power Factor Correction".

Resistive constituent of motor current are:

- Load current
- Loss current

Inductive constituent of motor current are:

- Leakage reactance
- Magnetizing current

2.3.1 Static Power Factor Correction

Static power factor 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.

2.4 STRATEGIES FOR POWER FACTOR CORRECTION

Following are different methods of power factor improvement which can be implemented according to the type of load such as constant or variable [4].

- a. Individual power factor correction
- b. Group power factor correction.
- c. Central power factor corrections.
 - i. Fixed power factor regulation
 - ii. Automatic power factor regulation
 - iii. Mixed power factor correction

2.5 POWER FACTOR COMPENSATING DEVICES

The power factor compensating devices essentially supplies the required reactive power of the system to improve the power factor and system voltage profile. Shunt capacitors are the most commonly used compensation device in the industry.

2.5.1 Capacitive Compensators

Shunt capacitors are being extensively used in industrial distribution systems. They supply reactive power to counteract the out-of-phase component of current required by an inductive load. The application of shunt capacitor banks results in a decrease in the magnitude of the source-current, improves the power factor and consequently improves voltage regulation throughout the system. However, shunt capacitor banks do not affect current or power factor beyond their point of application. Capacitor banks can be fixed, switched, or a combination of both. The switching process can be manual or automatic. Capacitor banks are rugged and simple to configure and install [7].

It should be noted that Mine Safety and Health Administration (MSHA), U.S. Department of Labor, is concerned with the installation of power-factor correction capacitors in high-voltage power centers. Even though the capacitors have bleeder resistors, MSHA feels that each capacitor bank should have an alternative built-in means for discharging the capacitors [8].

2.5.2 Synchronous Condensers

The synchronous motor has long been used as a compensator with fixed ratings (known as a synchronous condenser). Compensation is achieved by setting the field excitation to arrive at a particular rating. A disadvantage of this device is that it is electromechanical and requires some maintenance. Since the degree of compensation is predetermined, as with a fixed capacitor bank, synchronous condensers have little appeal over capacitors [7]. Accordingly, their application in the mining industry has been limited, except in cases where salvaged ones were available, at an attractive price.

The points to be considered in any installation are:

- i. Reliability of the equipment to be installed.
- ii. Probable life.
- iii. Capital cost.
- iv. Maintenance cost.
- v. Running Costs.
- vi. Space required and ease of installation.

2.6 LOCATION OF THE CORRECTING DEVICE

Strategic location of power factor compensators is necessary to achieve all the aforementioned benefits of power factor correction. There are three possible locations in the mine power system: the distribution side of the main substation transformer; at each motor or on each motor powered machine; in load centers [9].

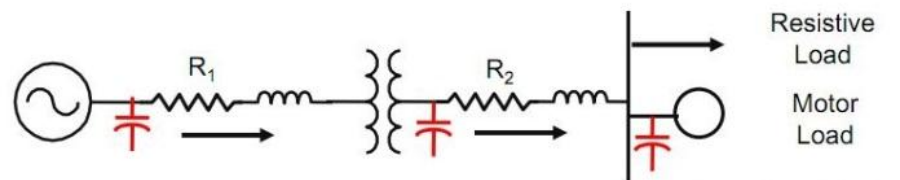


Figure 2.2: Different Possible Locations for Capacitor [9]

The location can be near the load, near the transformer or at the utility side. The location needs to be decided based on the system, voltage regulation (Figure 2.2).

2.7 BENEFITS OF POWER FACTOR CORRECTION

Improving a facility's power factor can have the following benefits [10]:

- a. Power Factor Surcharges Encourage Higher Efficiency
- b. Reduced Demand Charges

- c. Increased Load Carrying Capabilities in Existing Circuits
- d. Improved Voltage
- e. Reduction in Power-System Losses

Capacitors are effective in reducing only that portion of the losses that is due to the kilovars current. Losses are proportional to current squared, and since current is reduced in direct proportion to power factor improvement, the losses are inversely proportional to the square of the power factor. The capacitors have losses, but they are relatively small—only one third of 1 per cent of the KVAR rating.

2.8 OVERVIEW OF PREVIOUS RESEARCH WORK

A limited number of studies have been attempted on the effect of poor power factor in mines and the corrective measures to mitigate the problem.

Oommen and Kohler (1988) explored the advantages that can be accomplished by proper implementation of power factor compensation. Different compensators along with the sizing and strategic location was also considered. A brief study on the economic analysis was carried out to show the economic viability of compensation [7].

Jiang et al. (1993) proposed a novel single-phase power factor correction scheme based on parallel power factor correction concept which was described to be more efficient than convention two-cascade stage scheme [14].

Qureshi and Aslam (1995) outlined the different methods for power factor correction and carried out an experimental case study to explore the areas which will be suitable for compensation. After a practical demonstration to have a significant improvement in power factor was completed, they found that it would release the capacity of distribution transformer and the problem of over voltage under condition of low load was avoided [6].

Novak and Kohler (1998) pointed out the importance of power factor improvement for technological innovation and advancement in deep coal mine power systems. Different protection equipment to check the inherent electrical faults in the mining system were argued. The power factor correction near loads for improved voltage regulation was emphasized within the constraints of high voltage distribution in underground coal mines [8].

Shwehdi and Sultan (2000) suggested some mathematical calculations for power factor and reactive power requirement of the system along with the capacitor size estimation methods. Different problems

associated accompanied by essentials and cautions for capacitor used for correction purpose were discussed in details [9].

Celtekligil (2008) discussed the application of a method for dynamic power factor correction and voltage regulation in light rail transportation system. Main reactors have been switched on through thyristors using automatic power controllers by sensing the power factor and constantly monitoring the current and voltage, calculating the power factor and switching inductance banks as required. The system proposed connects inductive loads in parallel with the capacitive system to improve the power factor [16].

Choudhury (2008) gave a design and implementation of a low cost power factor improvement device for small signal low power loads. The design involved designing of a small signal model load, selecting appropriate capacitors, and designing appropriate switching circuits to select proper combination of capacitors [17].

Shahid and Anwar (2013) offered 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. The solution involves ensuring 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 [19].

Sharma and Haque (2014) carried out a simulation and analysis study for power factor correction for metal halide high intensity discharge lamps. A modified boost converter using active devices was proposed along with PI controller to stabilize the control loops. The capacitor and inductor with voltage and current ripple with minimum ripple values was designed and to absorb sinusoidal input current to reduce total harmonic distortion (THD) in the input current with output voltage regulation [20].

Allah (2014) suggested an automatic power factor correction based on Alienation technique. An alienation technique was developed for calculations of original power factor on-line, active and compensation reactive powers and determination of the required number of capacitor banks to get the desired power factor. Alienation coefficients were calculated between phase voltage and current signals of power supply. Alternative transient program (ATP) and MATLAB programs were used to implement the proposed technique [21].

Chapter-3

Design Methodology

3.1 INTRODUCTION

The Automatic Power Factor correction device is developed built on embedded system having 89S52 at its core. The voltage and current signal from the system is sampled and taken as input where the difference between the arrivals of wave forms indicates the phase angle difference. The difference is measured by the internal timer and calibrated as phase angle to calculate the corresponding power factor. The system power factor is compared with the desired level and the difference is measured for switching of required number of capacitors from the bank. The values of power factor and phase lag are shown on a display for convenience.

3.2 BLOCK DIAGRAM

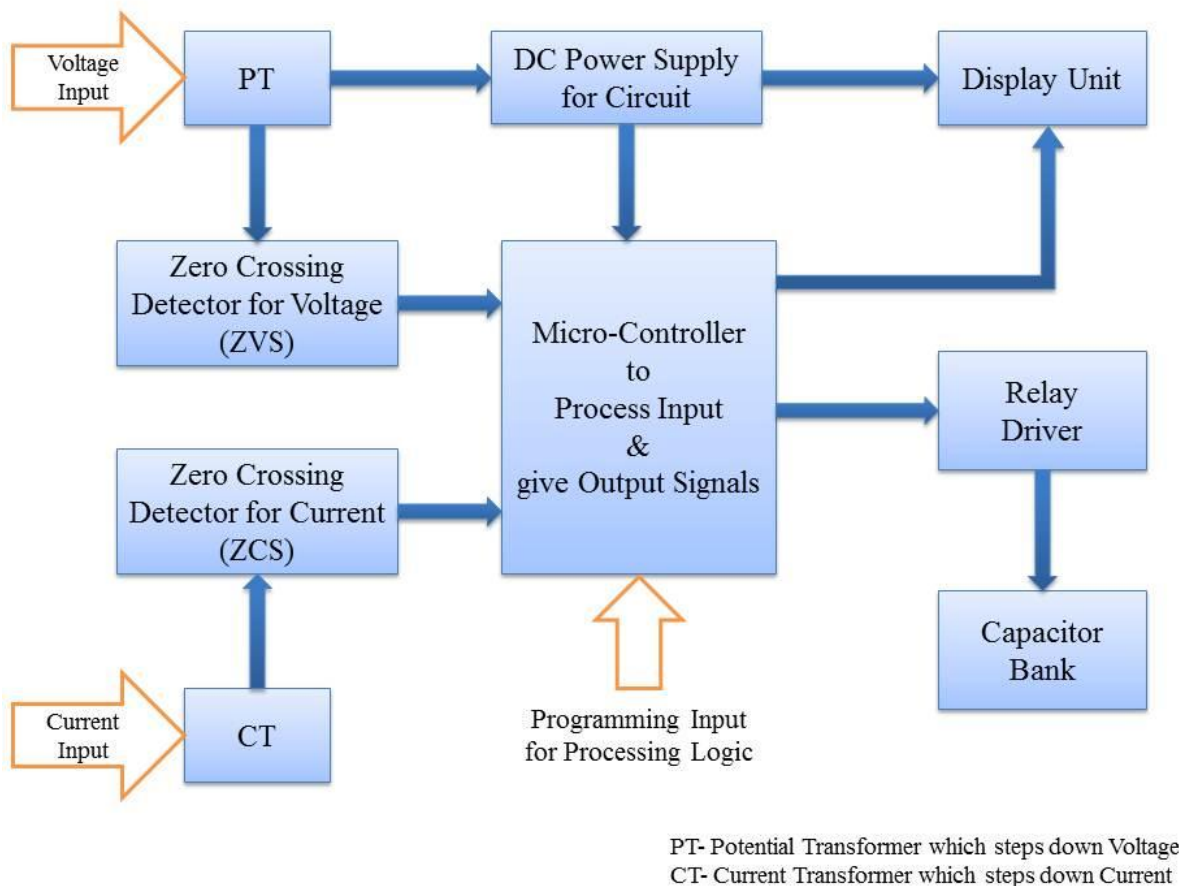


Figure 3.1: Block Diagram of the Correction Equipment

3.3 ALGORITHM

Step-1: Take input for voltage and current in the circuit.

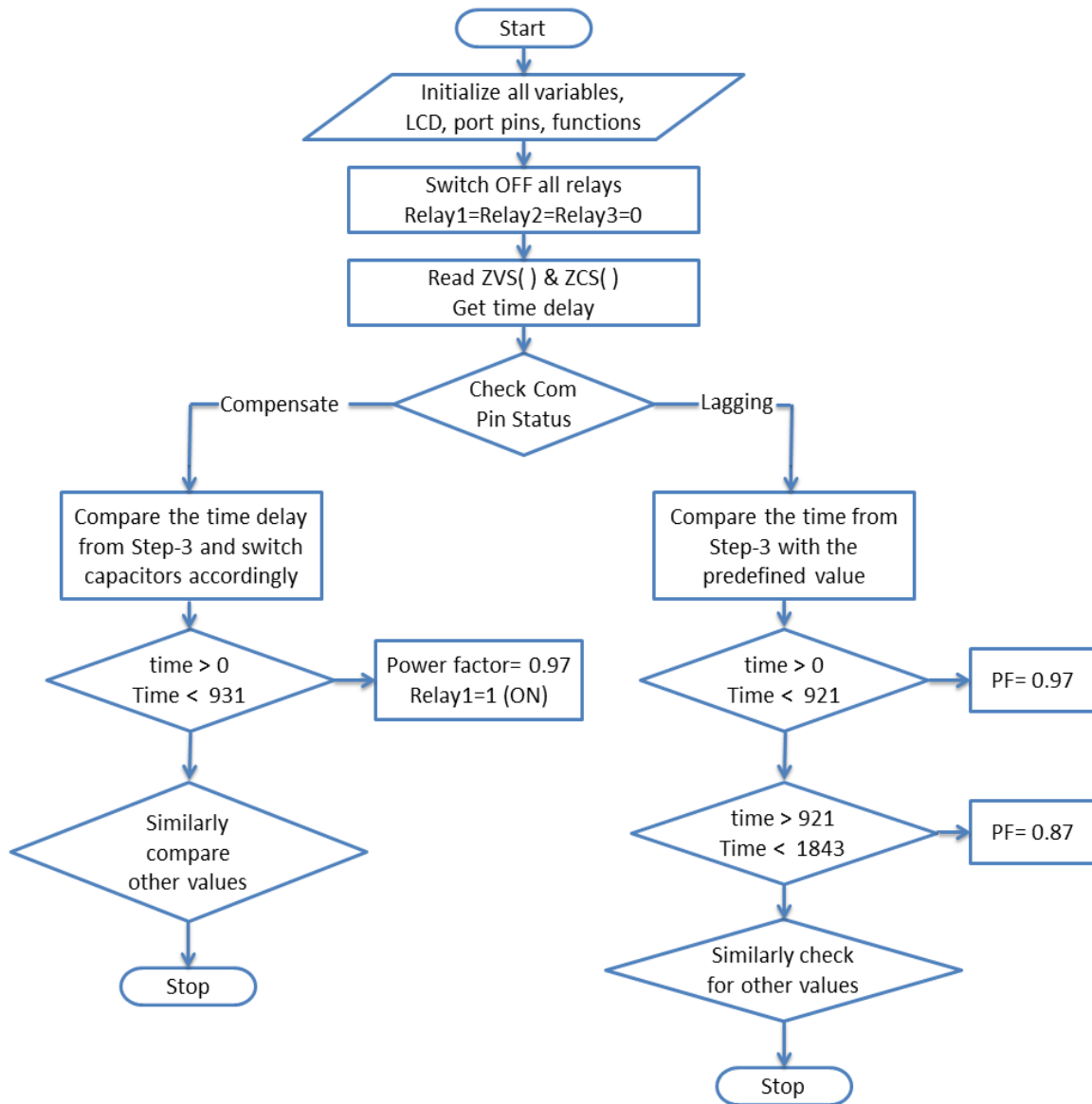
Step-2: Measure the phase lag and calculate the power factor.

Step-3: Differentiate from the targeted power factor and calculate the reactive power requirement.

Step-4: Switch ON or OFF appropriate number of capacitors from capacitor bank depending on reactive power supplied by each step.

Step-5: Again compare the power factor with targeted PF and continue from step-1.

3.4 FLOWCHART



3.5 MEASUREMENT

The primary quantities to be measured are power factor and energy consumed. Along with these, the voltage level, current flowing and active power will also be helpful for monitoring the load. The instruments used for all required purpose is Meco Power Guard Model PG08 [22].

3.5.1 Meco Power Guard PG08

Using high-integration microcomputer chips and special Energy Metering IC, with high-accuracy current sensor and LCD, this product can monitor electric equipments in every way. It can be used in monitoring domestic appliances such as air conditioner; fridge and microwave oven. This product is suitable for home, rental house, office, laboratory and various places.



Figure 3.2: Meco Power Guard PG08 [22]

3.6 DESIGN OF DIFFERENT LOADS

To verify and monitor the working of the correction device three different types of loads are designed corresponding to actual loads in a typical power system. These will replicate the loading pattern, power consumption, power factor etc.

3.6.1 Design of Resistive(R) Load

To design a pure resistive load, a light bulb or incandescent lamp of 100W can be used. The circuit connection is shown below.

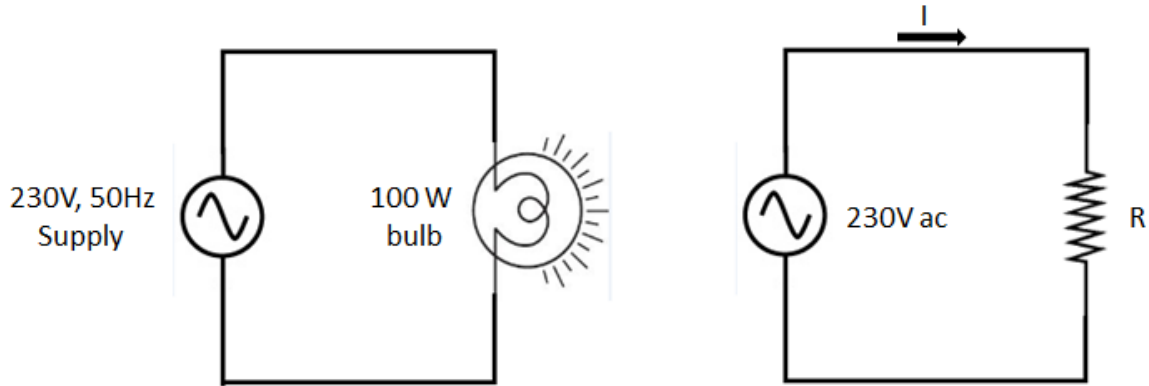


Figure 3.3: Connection Diagram & Circuit Diagram for Pure R Load

The resistor R represents the resistance value of the bulb filament.

$$\text{Here } V=230\text{V, } R=550\text{K}\Omega$$

According to Ohms Law,

$$\text{Current, } I = \frac{V}{R} = \frac{230}{550} = 0.41 \text{ mA}$$

3.6.2 Design of Series R-L Load

To model an inductive load, a tube light choke can be used. The choke and the bulb connected in series will behave as a series R-L load. The circuit connection is shown below. The voltage available for the bulb will be less than the supply voltage due to the drop in the choke.

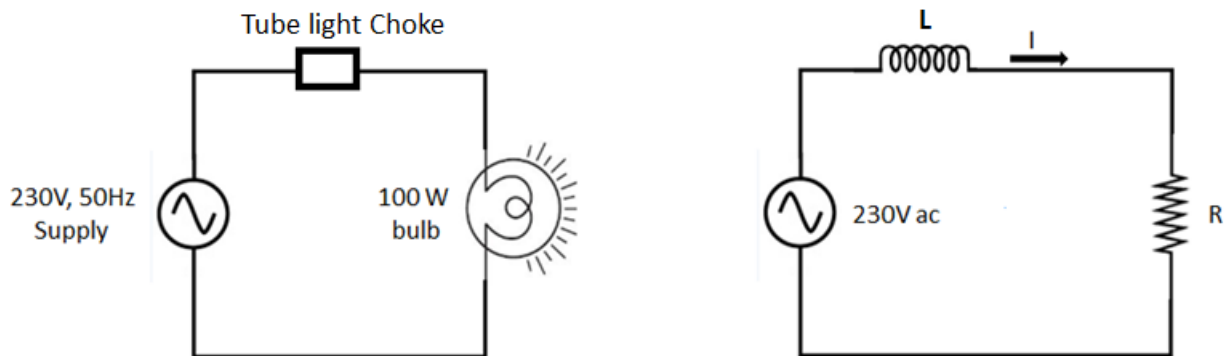


Figure 3.4: Connection Diagram & Circuit Diagram for Series R-L Load

The impedance of the circuit will be, $Z = R + jX_L$

$$\text{Current, } I = \frac{V}{Z}$$

3.6.3 Design of Parallel R-L Load

The choke and the bulb when connected in parallel will behave as a parallel R-L load. The bulb will get the same voltage as the supply. The circuit connection is shown below.

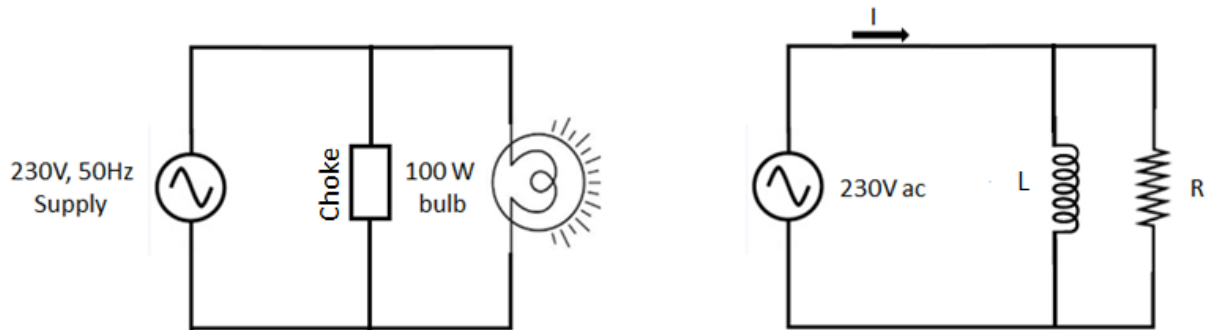


Figure 3.5: Connection Diagram & Circuit Diagram for Parallel R-L Load

The impedance of the circuit will be, $Z = \frac{R \times jX_L}{R + jX_L}$

$$\text{Current, } I = \frac{V}{Z}$$

Chapter-4

Design & Implementation

4.1 INTRODUCTION

This chapter describes the detailed design of each block of the proposed power factor correction equipment along with the working of each part. Each block consists of several components connected in the required way to give the desired output. The complete circuit diagram is provided at the end based on which the fabrication was completed. Special care was taken during the fabrication to avoid any short circuit of paths during crossing of paths.

4.2 POTENTIAL TRANSFORMER

Transformers convert AC electricity from one voltage to another with a little loss of power. The potential transformer (PT) essentially uses a step-down transformer to reduce the dangerously high voltage to a safer low voltage (typically 110 Volts) in any substation. The PT used here steps-down the supply voltage of 230 Volts to 12 Volts as required by the circuit to operate. The output of a PT is used for all measurement and monitoring purposes in conjunction with relay operation

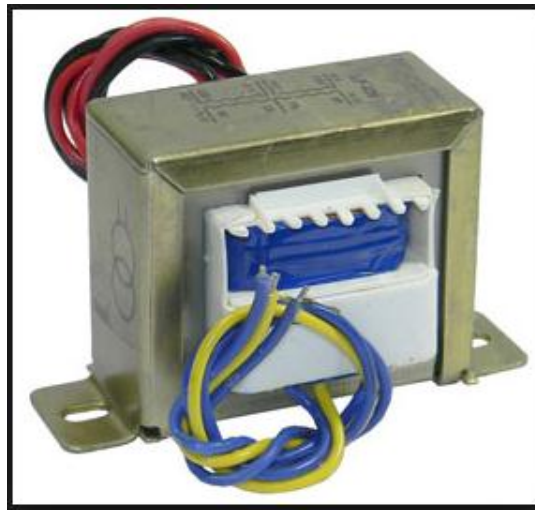


Figure 4.1: A 230/12 Volt Transformer [24]

The ratio of the number of turns on each coil, called the turn's ratio, determines the ratio of the voltages. A step-down transformer has a large number of turns on its primary (input) coil which is connected to the high voltage mains supply, and a small number of turns on its secondary (output) coil to give a low output voltage.

$$\text{Turns ratio} = \frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

Where,

V_p = primary (input) voltage.

V_s = secondary (output) voltage

N_p = number of turns on primary coil

N_s = number of turns on secondary coil

I_p = primary (input) current

I_s = secondary (output) current.

4.3 CURRENT TRANSFORMER

In an electrical circuit, a current transformer (CT) is used for measurement of electric currents. Current transformers, together with voltage transformers (VT) (potential transformers (PT)), are known as instrument transformers. When current in a circuit is too high to directly apply to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments. It also isolates the measuring instruments from what may be very high voltage in the monitored circuit. They are commonly used in metering and protective relays in the electrical power industry.

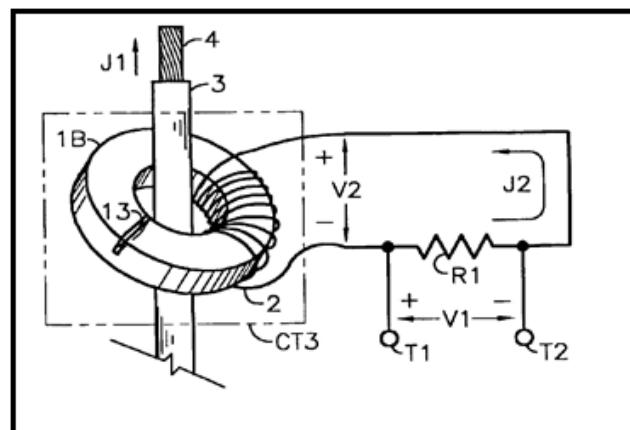


Figure 4.2: Schematic working of a Current Transformer [26]

4.4 ZERO CROSSING DETECTOR

The zero crossing detector is a sine-wave to square-wave converter. To calculate the phase lag between the voltage and current, two detectors are used to find the arrival instance of each signal. Then the difference in the arrival instance calibrated to angle gives the phase angle lag. By taking the cosine of this phase lag, power factor of the circuit is calculated. The reference voltage in this case is set to zero. The output voltage waveform shows when and in what direction an input signal crosses zero volts. If input

voltage is a low frequency signal, then output voltage will be less quick to switch from one saturation point to another. And if there is noise in between the two input nodes, the output may fluctuate between positive and negative saturation voltage V_{sat} . The LM339 IC is used as the comparator circuit to function as zero crossing detector.

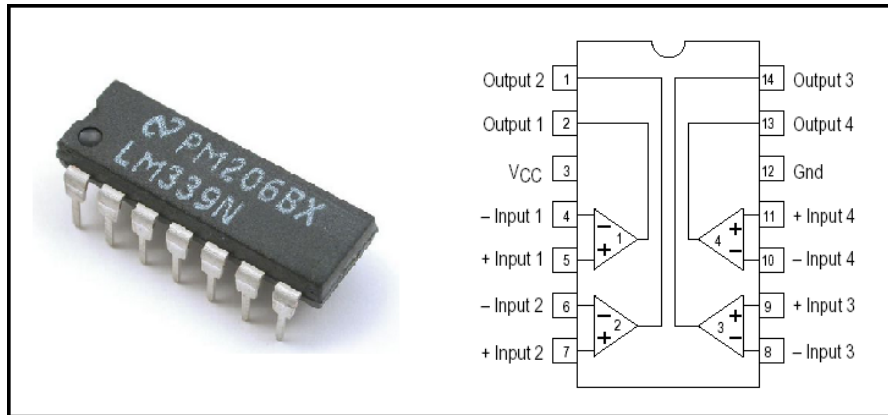


Figure 4.3: LM339 IC and its Pin Diagram [27]

4.5 POWER SUPPLY FOR CURCUIT

The embedded system circuit typically uses 12 volt and 5 volt DC as its operating voltage. Therefore, there is a need to convert the 230 Volt AC supply to the required DC supply. In the 1st stage the 230 V AC is step-down to 12 V AC by using a transformer. In this case the output from the potential transformer (PT) can be utilized instead of going for another step-down transformer. The 2nd stage is the rectification process. By using a full bridge rectifier circuit, the 12 V AC is rectified to a 12V pulsating DC voltage. This pulsating DC is passed through a capacitive filter for smoothing in the 3rd stage and gives a normal 12V DC as output. The 4th stage consists of using a 12 V and a 5 V voltage regulator for generating the required stable supply voltage to be used in the control circuit.

4.5.1 Rectifier

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), current that flows in only one direction, a process known as rectification. It converts A.C. into pulsating D.C. The rectifier may be a half wave or a full wave rectifier. Most of the cases, a bridge rectifier is used because of its merits like good stability and full wave rectification. In positive half cycle only two diodes (1 set of parallel diodes) will conduct, in negative half cycle remaining two diodes will conduct and they will conduct only in forward bias only.

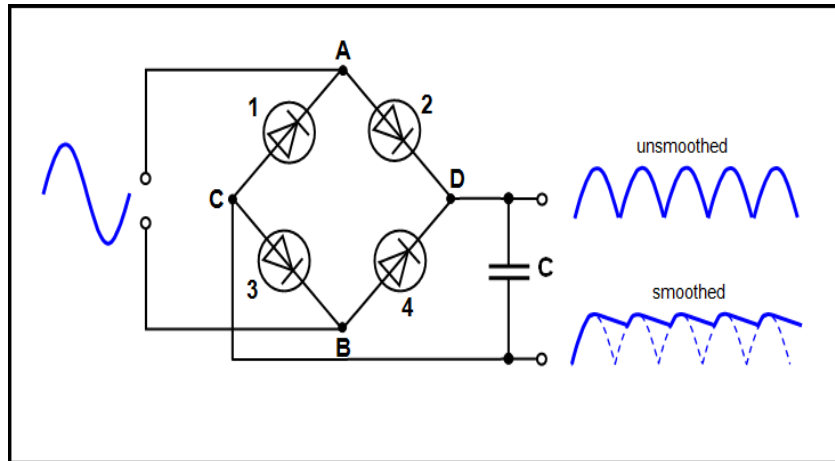


Figure 4.4: A Full Bridge Rectifier with Input and Output [29]

4.5.2 Filter

Capacitive filter is used in this project. It removes the ripples from the output of rectifier and smoothens the D.C. Output received from this filter is constant until the mains voltage and load is maintained constant. The simple capacitor filter is the most basic type of power supply filter.

4.5.3 Voltage Regulator

The LM78XX/LM78XXA series of three-terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shutdown and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output Current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents. In the LM78XX, the output voltage is specified by the last 2 digits XX. The output of LM7805 will be 5 Volts and the same for 7812 will be 12 volts.

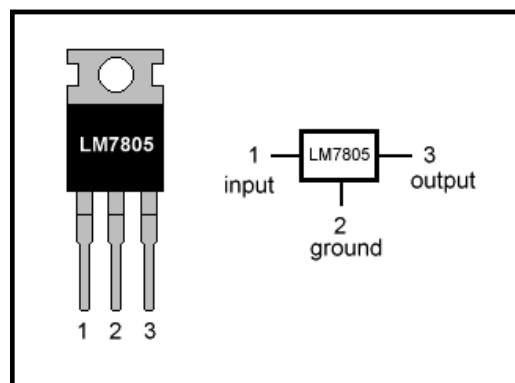


Figure 4.5: LM7805 and its Connection Diagram [30]

4.6 DISPLAY UNIT

In an embedded system, the microcontroller interacts with the outside world using input and output devices that communicate directly with a human being. One of the most common devices attached to the microcontroller is an LCD display. Some of the most common LCDs connected to the microcontroller are 16x2 and 20x4 displays. This means there will be 16 characters per line by 2 lines and 20 characters per line by 4 lines, respectively available to use. In this project a 16x2 LCD, model JHD 162A which shows the power factor and the phase lag between voltage and current in milliseconds.



Figure 4.6: A 16x2 LCD Display

4.6.1 LCD Connection

The connection to microcontroller requires 3 control lines as well as either 4 or 8 I/O lines for the data bus. The user may select whether the LCD is to operate with a 4-bit data bus or an 8-bit data bus. If a 4-bit data bus is used the LCD will require a total of 7 data lines (3 control lines plus the 4 lines for the data bus). If an 8-bit data bus is used the LCD will require a total of 11 data lines (3 control lines plus the 8 lines for the data bus).

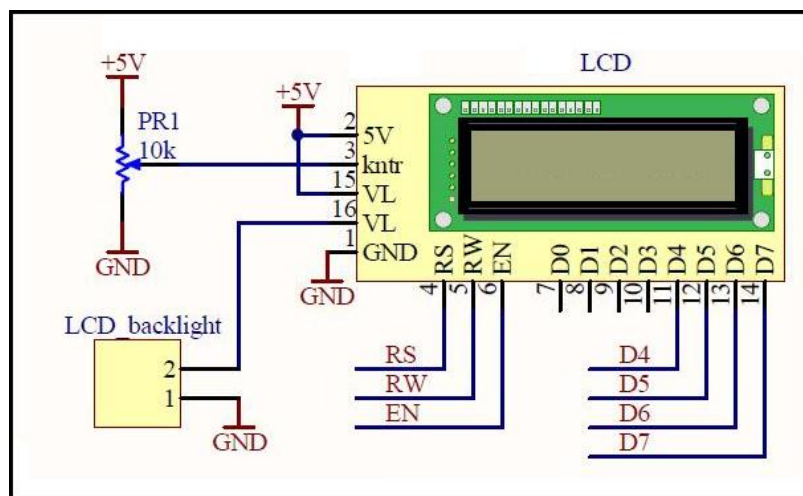


Figure 4.7: Pin Description and Connection Diagram of 16x2 LCD in 4-bit Mode [31]

4.7 MICRONTROLLER

The heart of any embedded system is a microcontroller which is responsible for all the logical processing. It takes input, processes it according to the program written to it and then gives the processed output. It also has some on chip memory which is utilized to store some temporary variables during processing is going on. The microcontroller used here is AT89S52 which is a 8-bit controller.

The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8K bytes of in-system programmable flash memory. The device is manufactured using Atmel's high-density nonvolatile memory technology and is compatible with the industry standard instruction set and pin out. The on-chip flash allows the program memory to be reprogrammed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with in-system programmable flash on a monolithic chip, the Atmel AT89S52 is a powerful microcontroller which provides a highly-flexible and cost-effective solution to many embedded control applications. The AT89S52 provides the following standard features: 8K bytes of flash, 256 bytes of RAM, 32 I/O lines, watchdog timer, two data pointers, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry.

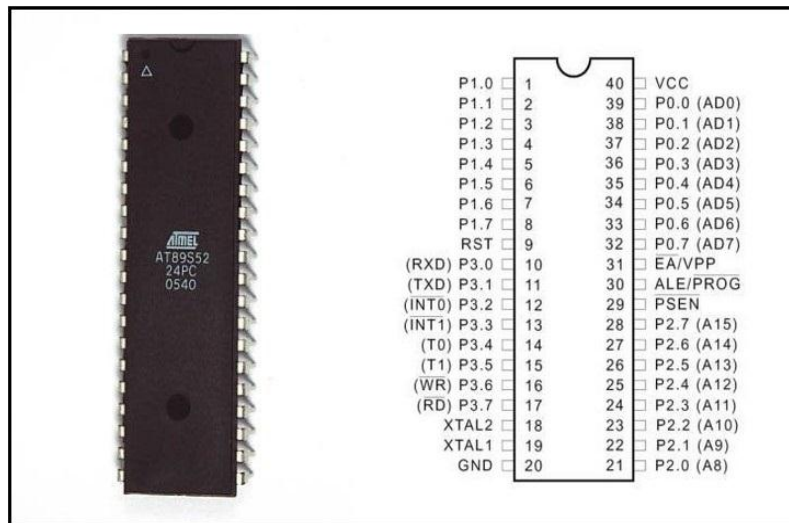


Figure 4.8: 89S52 Microcontroller and its Pin Diagram [32]

4.8 RELAY UNIT

This unit consists of a relay driver and some relays. As the output of the microcontroller cannot control the switching of capacitors directly, this unit is responsible for controlling the high power circuit from a low power circuit.

4.8.1 Relay

A relay is an electrically operated switch. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. Current flowing through the coil of the relay creates a magnetic field which attracts a lever and changes the switch contacts.

The relay's switch connections are usually labelled COM, NC and NO:

- COM = Common, always connect to this; it is the moving part of the switch.
- NC = Normally Closed, COM is connected to this when the relay coil is off.
- NO = Normally Open, COM is connected to this when the relay coil is on.

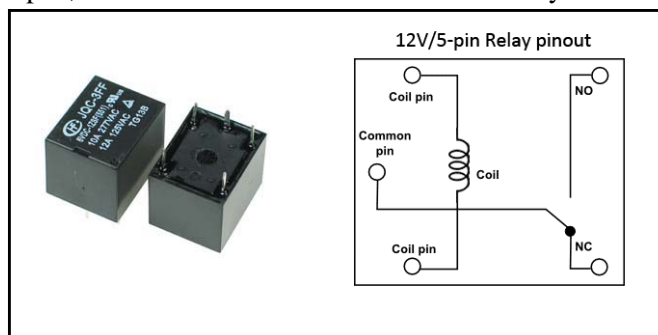


Figure 4.9: 12 Volt Relay and its Internal Connection [33]

4.8.2 Relay Driver

As the current supplied by the output pin of microcontroller is not sufficient for the relay coil to operate the relay, a relay driver ULN2003 is used. ULN2003 is a high voltage and high current Darlington transistor array. The ULN2003 is a monolithic high voltage and high current Darlington transistor arrays. It consists of seven NPN Darlington pairs that feature high-voltage outputs with common-cathode Clamp diode for switching inductive loads. The collector-current rating of a single Darlington pair is 500mA. The Darlington pairs may be paralleled for higher current capability. Applications include relay drivers, hammer drivers, lamp drivers, display drivers (LED gas discharge), line drivers, and logic buffers.

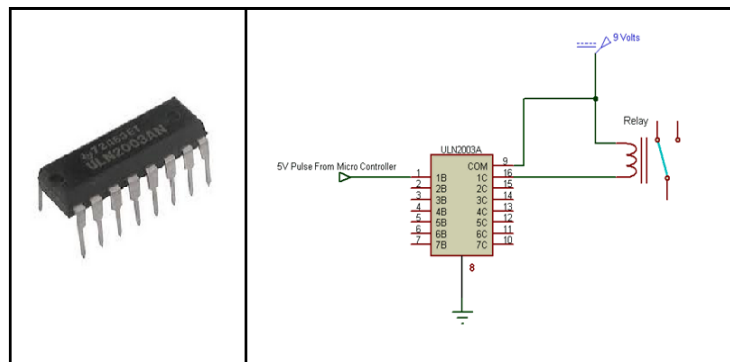


Figure 4.10: ULN2003 Relay Driver and its Pin Connection Diagram [34]

4.9 CAPACITOR BANK

Shunt capacitor banks are used to improve the quality of the electrical supply and the efficient operation of the power system. Studies show that a flat voltage profile on the system can significantly reduce line losses. Shunt capacitor banks are relatively inexpensive and can be easily installed anywhere on the network. The capacitor bank consists of number of shunt capacitors which are switched ON or OFF depending on the reactive power requirement. The switching of capacitors can be done manually or automatically by using relays.



Figure 4.11: Shunt Capacitors [35]

Shunt capacitors, either at the customer location for power factor correction or on the distribution system for voltage control, dramatically alter the system impedance variation with frequency. Capacitors do not create harmonics, but severe harmonic distortion can sometimes be attributed to their presence.

A shunt capacitor at the end of a feeder results in a gradual change in voltage along the feeder. Ideally, the percent voltage rise at the capacitor would be zero at no load and rise to maximum at full load. However, with shunt capacitors, percent voltage rise is essentially independent of load. Thus, automatic switching is often employed in order to deliver the desired regulation at high loads, but prevent excessive voltage at low loads. Moreover, capacitor switching may result in transient overvoltage inside customer facilities.

4.11 HARDWARE IMPLEMENTATION

The PCB was fabricated according to the VRP diagram for the complete circuit and all the components are soldered on it. The connection for potential transformer, current transformer, capacitor bank was done at the respective places. Continuity check using the multimeter was carried out to avoid any accidental short-circuits. The program was written to the microcontroller by using a burner. The complete hardware is shown in the below diagrams (Figs. 4.18 & 4.19).

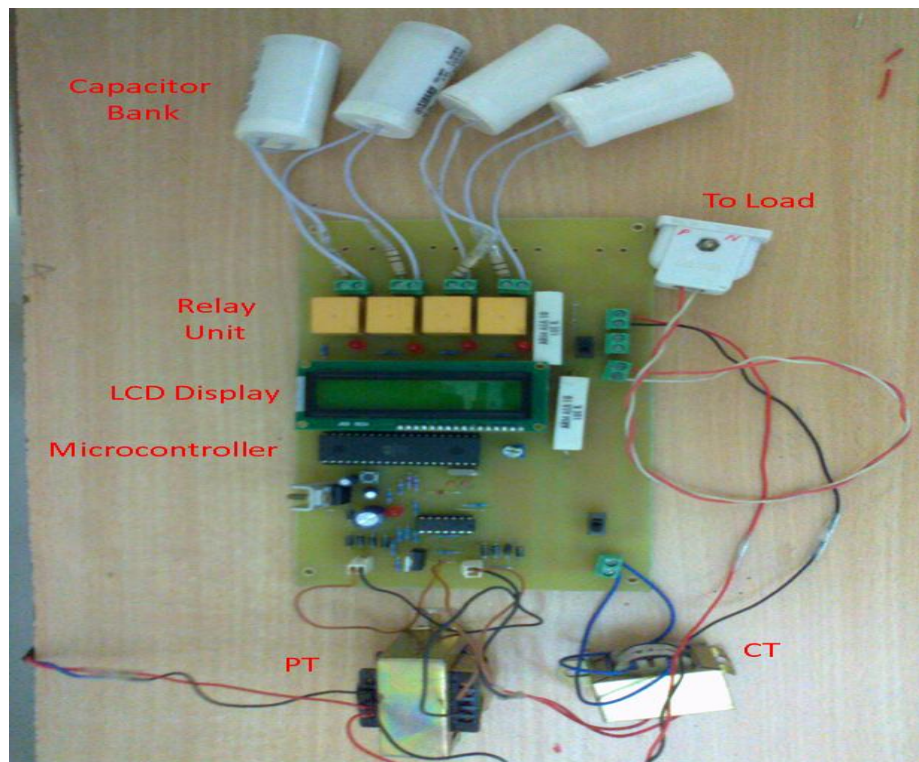


Figure 4.13: The Realized PF Correction Equipment

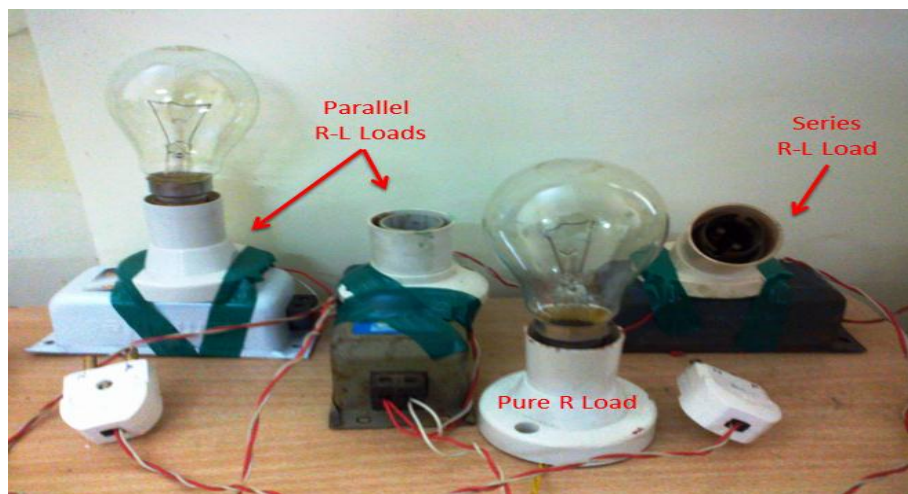


Figure 4.14: The Three Different Types of Load Designed

Chapter-5

Results & Discussions

5.1 INTRODUCTION

The usefulness of any device designed can only be verified after it is used and expected result is achieved. After the power factor correction circuit is fabricated, it is required to verify the working and desired correction in power factor. For this purpose the measurement of suitable electrical parameters is necessary accompanied by a periodical monitoring of desired outcome.

5.2 MEASUREMENT

All the measurements need to be done for the three different types of load designed; separately with and without the correction equipment. The quantities like supply voltage, frequency, current drawn by the load, power consumed, power factor are essential to be measured for each cases. The energy utilized is also necessary to monitored for a particular duration of time to confirm for the consequent energy savings, if any. The Meco power guard instrument was employed for all the measurement and monitoring.

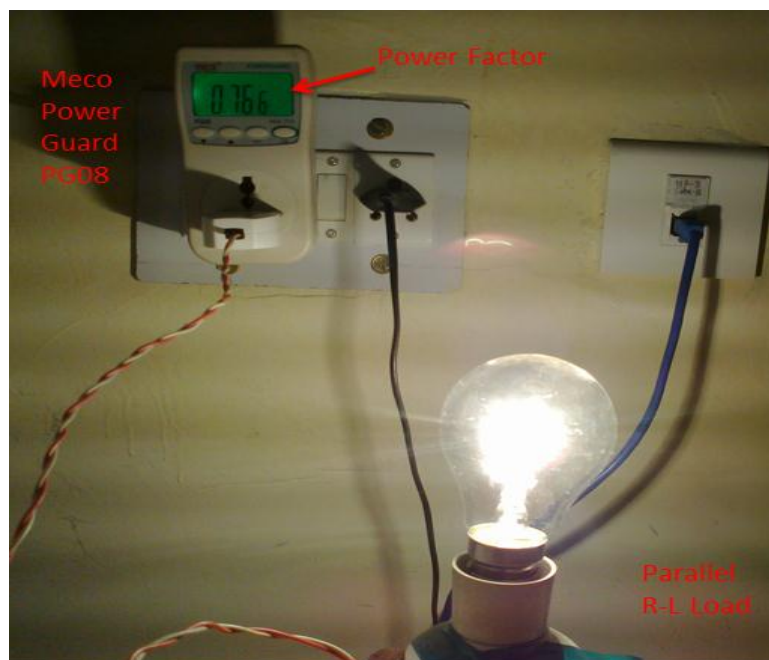


Figure-5.1: Measuring the PF of a Parallel R-L Load

5.2.1 ANALYSIS OF LOAD WITHOUT CORRECTION

The analysis of the pure restive load (R Load), series resistive-inductive loads (Series R-L Load) and parallel resistive-inductive (Parallel R-L Load) was done without using the correction equipment. The designed loads were connected through the PG08 power guard and the readings for different electrical parameters were recorded.

Table 5.1: Load Analysis without Correction

Sl. No.	Load Type	Supply Voltage (Volts)	Supply Frequency (Hz)	Load Current (mA)	Power Drawn (Watts)	Power Factor	Remarks
1	Pure R	234	49.87	437	101.2	0.99	No Correction Required
2	Series R-L	235	49.92	318	55.3	0.73	Correction Required
3	Parallel R-L	235	49.89	730	129.1	0.76	Correction Required

5.2.2 ANALYSIS OF LOAD WITH CORRECTION

As there is a need for power factor improvement for Series R-L load and Parallel R-L load, they were connected to the supply along with the correction equipment designed to verify the expected correction. The correction equipment is plugged in to the PG08 power guard and the loads are connected to the output point of the equipment. All the three loads designed were tried and the observed values were recorded.

Table 5.2: Load Analysis accompanied by Correction Equipment

Sl. No.	Load Type	Supply Voltage (Volts)	Supply Frequency (Hz)	Load Current (mA)	Power Drawn (Watts)	Power Factor	Remarks
1	Pure R	230	50.02	424	96.6	0.99	No Improvement in PF
2	Series R-L	234	50.10	267	59.9	0.96	31.5% Increase in PF
3	Parallel R-L	232	50.06	602	134.2	0.97	29.3% Increase in PF

5.3 MONITORING

Monitoring generally means to be aware of the state of a system and may refer to observe a situation for any changes which may occur over time, using a monitor or measuring device. To measure the energy consumed, it is necessary to monitor the load for a specific period of time. The Meco PG08 power guard can be used to monitor the time as well as measure the energy consumption for each type of load. The loads are connected continuously for the definite time and continuous monitoring was done with extreme care.

5.3.1 MONITORING OF LOAD WITHOUT CORRECTION

The monitoring of the pure resistive load (R Load), series resistive-inductive loads (Series R-L Load) and parallel resistive-inductive (Parallel R-L Load) was done without using the correction equipment. The designed loads were connected through the PG08 power guard and the readings for energy consumption, time and average power factor were recorded.

Table 5.3: Monitoring of Load without Correction

Sl. No.	Load Type	Time (Hour)	Energy Consumed (kWh)	Average PF
1	Pure R	2	0.20	0.99
2	Series R-L	2	0.11	0.73
3	Parallel R-L	2	0.26	0.76

5.3.2 MONITORING OF LOAD WITH CORRECTION

Because there is a scope for power factor improvement for Series R-L load and Parallel R-L load, they were connected to the supply along with the correction equipment designed to verify the expected correction. The correction equipment is plugged in to the PG08 power guard and the loads are connected to the output point of the equipment. All the three loads designed were monitored over a period of time and the observed values were recorded.

Table 5.4: Monitoring of Load accompanied by Correction Equipment

Sl. No.	Load Type	Time (Hour)	Energy Consumed (kWh)	Average PF
1	Pure R	2	0.19	0.99
2	Series R-L	2	0.12	0.96
3	Parallel R-L	2	0.27	0.97

5.4 MONITORING OF A REAL TIME FLUCTUATING LOAD

To witness the actual working of the correction unit under a real time fluctuating load, different load patterns of duration 10 hours each was designed and the corresponding values of energy and average power factor were monitored. To visualize the change in power factor; graphs are plotted for each load pattern taking the pre and post power factor improvement for the respective time of operation.

The three load patterns A, B and C over an operation of 10 hours is shown below. The loads are changed accordingly to observe the automatic change in the switching of capacitors by the control circuit based on the reactive power requirement and power factor.

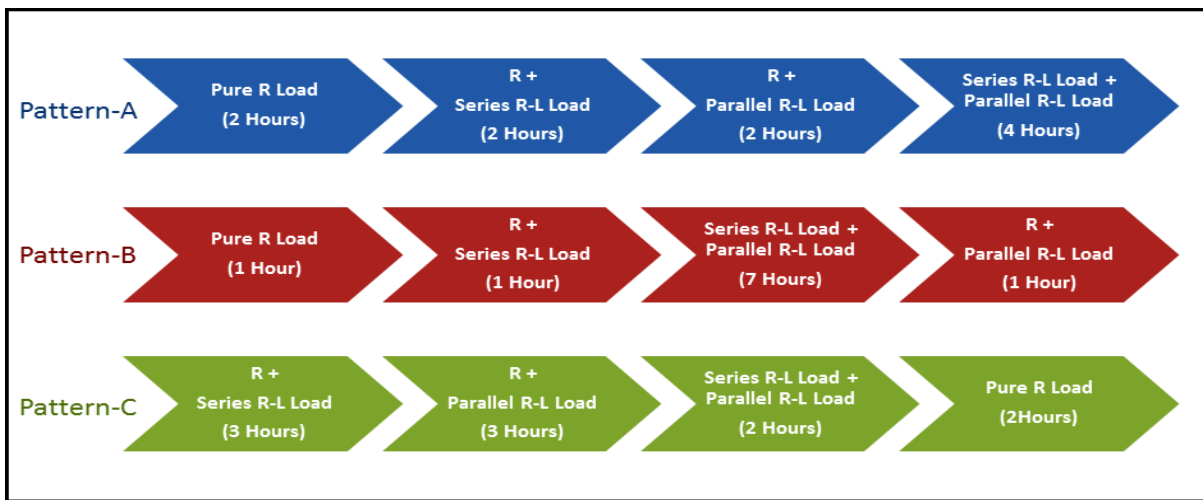


Figure 5.2: Three Sample Load Patterns for Monitoring

The energy consumed over the time period along with the average power factor is recorded in the table below for the conditions without and with power factor correction.

Table 5.5: Monitoring of Real Time Fluctuating Load

Sl. No.	Pattern	Without Correction		With Correction	
		Energy Consumed (kWh)	Average PF	Energy Consumed (kWh)	Average PF
1	A	1.72	0.874	1.69	0.976
2	B	1.80	0.817	1.77	0.973
3	C	1.71	0.898	1.68	0.977

There is a decrease of 1.7% of energy consumption on an average with an improvement of power factor ranging from 9% to 19% depending on the type of load. The targeted power factor of 0.95 is achieved in all the three cases.

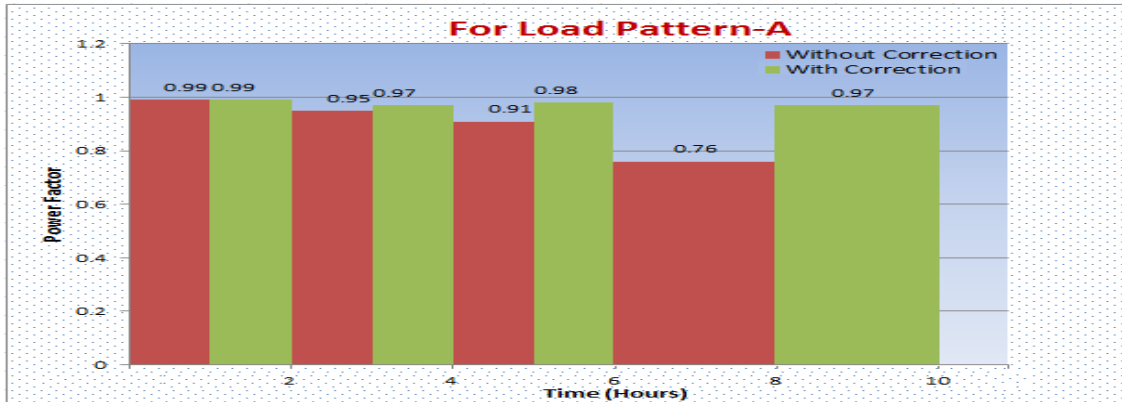


Figure 5.3: Power Factor Variation for Load Pattern A

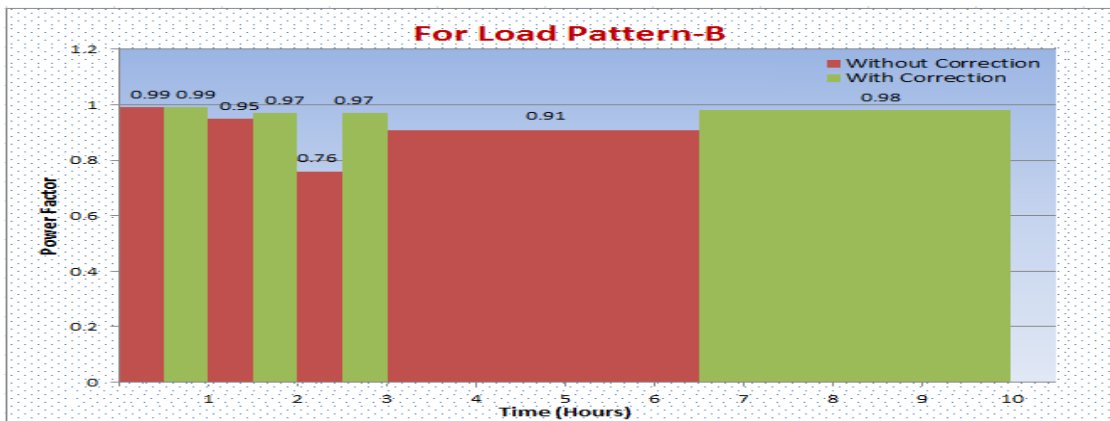


Figure 5.4: Power Factor Variation for Load Pattern B

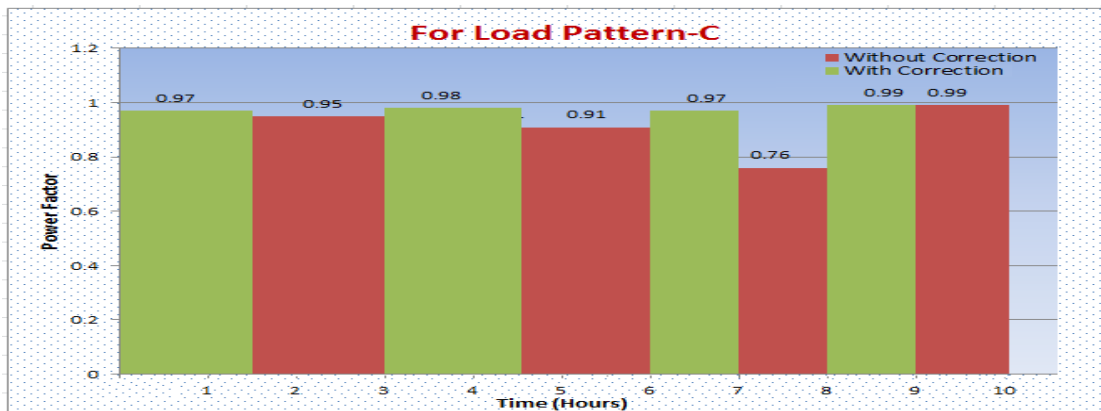


Figure 5.5: Power Factor Variation for Load Pattern C

Chapter-6

Economic Analysis for Power Factor Improvement

6.1 INTRODUCTION

In this chapter, the financial feasibility study will be discussed for the proposed power factor correction equipment. A cost effective study is required to show that the proposed system will be helpful for industry to have an efficient operation and reduced energy consumption. All the calculations will be made based on electricity consumption of Lakhanpur Area of Mahanadi Coalfields Limited. The cost of implementation and payback period will play the key role in deciding the usefulness of the power factor correction in mining industry.

6.2 OVERVIEW OF THE LAKHANPUR AREA OF MCL

The Lakhanpur OCP of MCL is situated in Jharsuguda district of Odisha with 15MTY of yearly approved quantity by Department of Steel and Mines, Govt. of Odisha [36]. The area is supplied by a HT line of 132KV from WESCO. The HT side connected transformer rating is 52.5 MVA with a contract demand of 22.25MVA. The 132 KV primary sub-station is having a static power factor compensator for supplying the reactive power. The average power factor is 0.999 at the 132 KV sub-station from which different feeders are out for secondary substations near the mines. The electricity consumption of Lakhanpur area for the month of March, 2015 is shown below.

Table 6.1: Meter Readings and Consumption of Lakhanpur Area in March, 2015

Sl. No.	Meter	Present Reading	Last Reading	Difference	Multiplying Factor	Consumption
1	KWH	4997626.0000	4939363.0000	58263.0000	150/1	8739450.00
2	KVA	111.2180		111.2180	150/1	16682.70
3	KVAH	4235799.0000	4177480.0000	58319.0000	150/1	8747850.00
4	KVARH	1617230.0000	1616603.0000	627.0000	150/1	94050.00
5	TOD	1318359.0000	1301298.0000	17061.0000	150/1	1559150.00
6	KVAOFF	94.1560		94.1560	150/1	14123.40

6.3 CALCULATIONS WITH A LOW POWER FACTOR

To make the bill calculation simple, let us consider only the no. of units consumed and penalty for power factor. Based on the above data, the average units consumed can be taken as 8740000 units in a month.

Considering the uncorrected power factor to be 0.70, the total cost of electricity consumption is calculated.

For power factor of 70%, the penalty is 0.5% for every 1% fall from 92% up to and including 70% plus [37].

Total charges= Energy Cost + Penalty= 45448000 + 4999280 = Rs. 50447280

6.4 CALCULATIONS WITH IMPROVED POWER FACTOR

The correction equipment used was able to improve the power factor to 0.97. Considering an average reduction of 1.7% in power consumption due to PF correction, the total cost is calculated.

As the power factor is 0.97, there will be no penalty for low PF.

Total charges= Energy Cost + Penalty = 44675384+ 0 =Rs. 44675384

Savings in energy consumptions= 50447280 - 44675384=Rs. 5771896.

This is the amount that will be saved per month if power factor correction equipment is employed which is 11.4% of the monthly electricity charges.

6.5 CALCULATIONS FOR COST OF CORRECTION EQUIPMENT

The size and cost of the correction equipment will depend on the reactive power requirement. It is required to calculate the amount of compensated reactive power to raise the power factor from 0.70 to 0.97.

$$\begin{aligned}\text{Required KVAR} &= \text{KW} \times (\tan \phi_i - \tan \phi_o) \\ &= 12140 \times (1.02 - 0.25) \\ &= 9350 \text{ KVARs}\end{aligned}$$

Considering a safety factor of 1.25, the required KVARs will be= 9350 x 1.25 = 11686 ≈ 12000 KVARs.

Considering the option **etaSYS-FU3** of 500 KVARs of capacity, a product from L&T Switchgear Company [38],

Total cost of correction equipment= 24 x 2058200 =Rs. 49396800

$$\text{Payback period} = \frac{\text{Total Investment}}{\text{Total Savings}} = \frac{49396800}{5771896} = 8.56 \approx 9 \text{ Months}$$

The payback period of APFC equipment is around 9 months in this case. The initial cost of installation is high, but the savings realized suggests that it should be implemented.

Chapter-7

Conclusions

7.1 CONCLUSIONS

Power factor correction equipment designed based on microcontroller and capacitor banks was used for measurement and monitoring of modeled electrical load and the following deductions were obtained:

- ✦ The power factor correction device designed was able to improve the power factor from 0.76 to 0.97 under the test load conditions.
- ✦ The average savings in energy consumption was about 1.7% for the designed load and different load patterns.
- ✦ With the proper amount of reactive power compensation, the system capacity is released as there is a reduction in current drawn.
- ✦ The economic analysis suggested the payback period to be around 9 months with a significant amount of savings in energy cost.

7.2 SUGGESTIONS FOR FUTURE WORK

- The designed equipment was studied in the laboratory scale; it can be implemented in the mine substations with proper protection to verify the operation in a real time environment.
- In case of automatic PF correction, if the load is changing frequently, the numerous switching of capacitor bank may cause harmonic problem. Suitable filter design as well as an optimum algorithm design can be done based on the frequent load change pattern to avoid regular switching of capacitor bank.
- A comparative study on the location of correction equipment may be employed in the field to find out the optimum location referring to maximum utilization and savings.

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