Microcontroller Based Automatic Power Factor Correction

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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, continues 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 is 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.

Keywords— Automatic Power Factor Correction, APFC using Microcontroller, Microcontroller Based APFC System, Power Factor Improvement, Intelligent Power Factor Controller, Automatic Capacitor Bank Switching, Reactive Power Compensation, Power Factor Monitoring System, Real-Time Power Factor Correction, Embedded System for Power Factor Correction.

I. 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. 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.

2. 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.

II. LITERATURE REVIEW

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. 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.

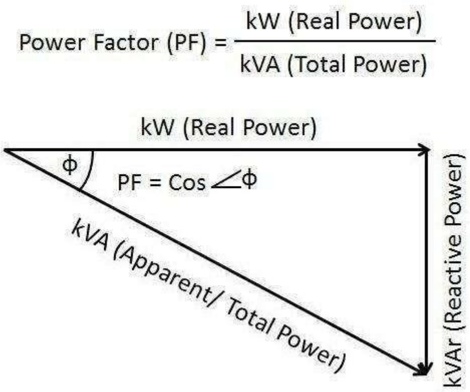


Figure 1: Schematic Diagram for Power Factor

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.

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.

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

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.

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].

- Individual power factor correction
- Group power factor correction.
- Central power factor corrections.
- Fixed power factor regulation
- Automatic power factor regulation
- Mixed power factor correction

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.

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].

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:

- Reliability of the equipment to be installed.
- Probable life.
- Capital cost.
- Maintenance cost.
- Running Costs.
- Space required and ease of installation.

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].

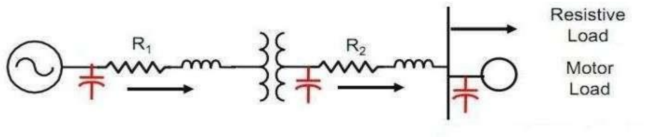


Figure 2.: Different Possible Locations for Capacitor [9]

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).

Benefits of Power Factor Correction

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

- Power Factor Surcharges Encourage Higher Efficiency
- Reduced Demand Charges

III. DESIGN METHODOLOGY

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.

2. Block Diagram

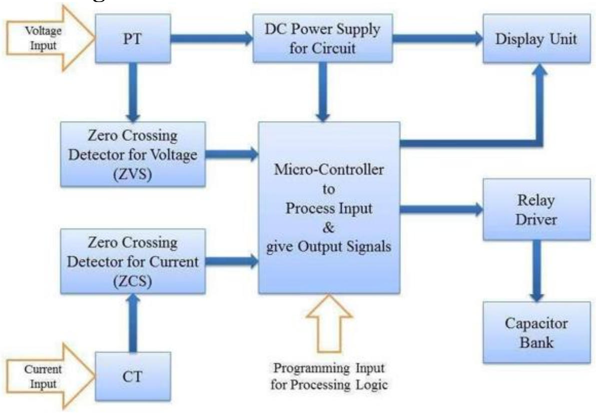
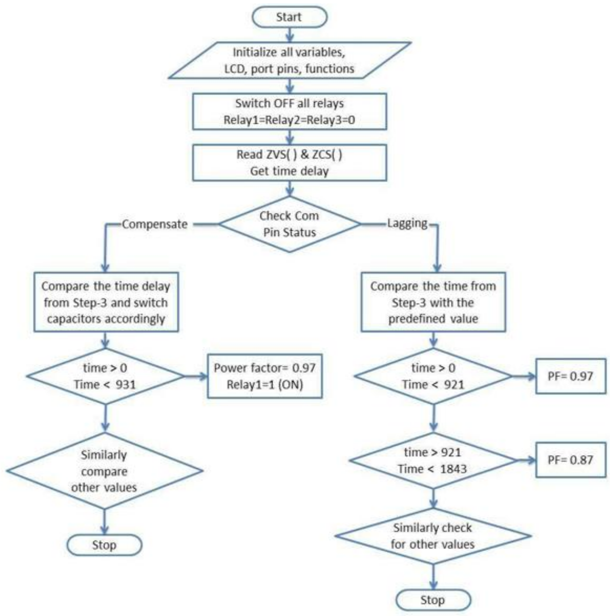


Figure 3: Block Diagram of the Correction Equipment

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.

4. Flowchart



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].

5. 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 4: Meco Power Guard PG08 [22]

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.

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.

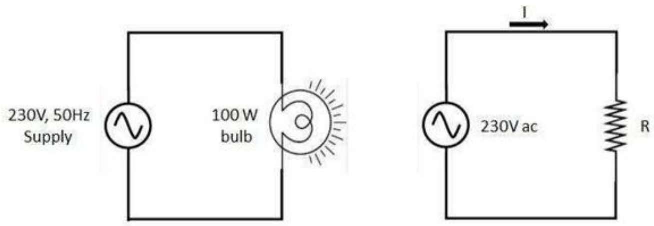


Figure 5: Connection Diagram & Circuit Diagram for Pure R Load The resistor R represents the resistance value of the bulb filament.

Here V=230V, R=550KΩ

According to Ohms Law,

Current, I = = = 0.41 mA

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.

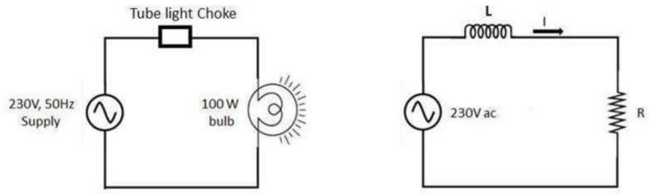


Figure 6: Connection Diagram & Circuit Diagram for Series R-L Load

The impedance of the circuit will be, Z= R+jXL Current, I =

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.

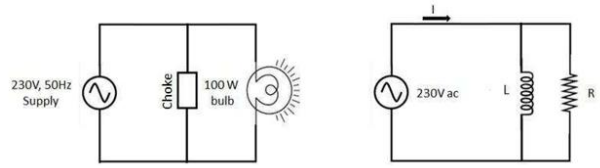


Figure 7: Connection Diagram & Circuit Diagram for Parallel R-L Load The impedance of the circuit will be, Z = Current, I =

Circuit Diagram

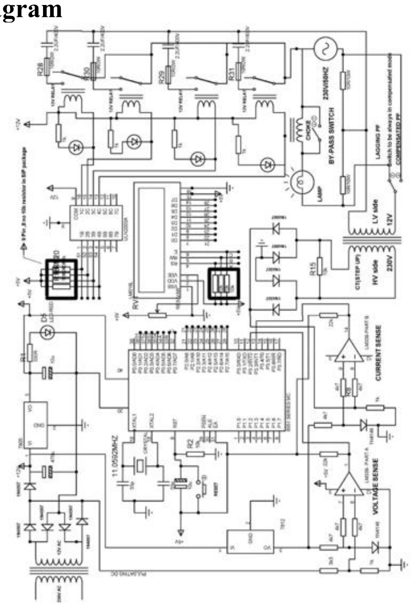


Figure 8: Complete Circuit Diagram for the Correction Equipment

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).

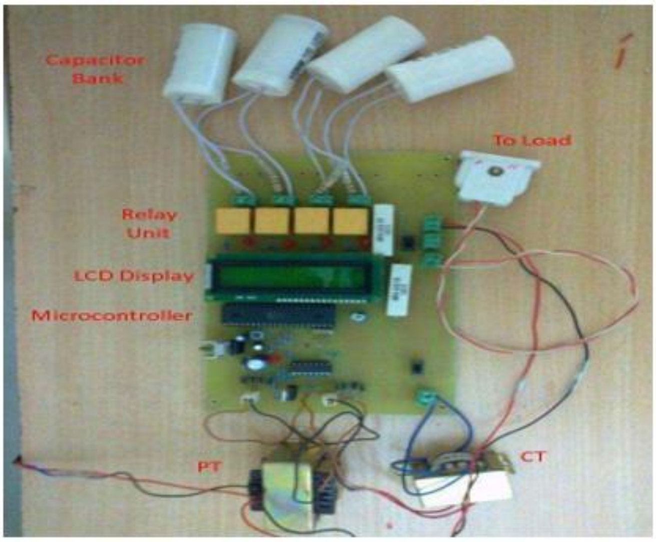


Figure 9: The Realized PF Correction Equipment

Figure 10: The Three Different Types of Load Designed

IV. RESULTS & DISCUSSIONS

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.

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-11: Measuring the PF of a Parallel R-L Load

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 1: Load Analysis without Correction

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

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 2: Load Analysis accompanied by Correction Equipment

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

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.

Monitoring Of Load Without Correction

The monitoring 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 energy consumption, time and average power factor were recorded.

Table 3: Monitoring of Load without Correction

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

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 4: Monitoring of Load accompanied by Correction Equipment

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

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.

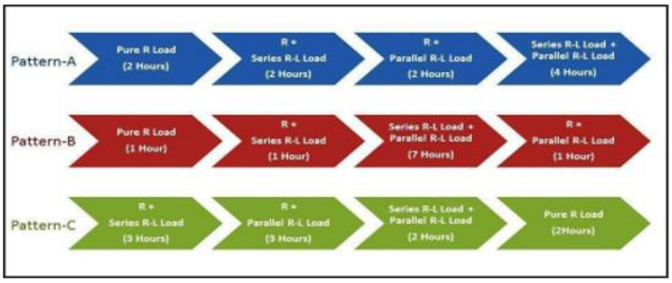


Figure 12: Three Sample Load Patterns for Monitoring

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: Monitoring of Real Time Fluctuating Load

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 13: Power Factor Variation for Load Pattern A

Figure 14: Power Factor Variation for Load Pattern B

Figure 15: Power Factor Variation for Load Pattern C

V. CONCLUSIONS

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.

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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