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Automatic Power Factor Correction

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ABSTRACT: Electricity is indispensable for industrial growth, with its versatility in conversion to various forms of energy. The Power Factor serves as a metric for the efficiency of electric systems in utilizing supplied power for useful work. A low power factor not only escalates electric losses but also invites penalties from utility providers. Maintaining an average monthly power factor close to unity can yield substantial savings in utility costs. Reactive power compensators, particularly capacitor banks, are commonly employed in substations to improve power factor. However, manual switching of these devices can be inefficient and prone to errors. Employing automatic switching mechanisms not only enhances response time but also minimizes errors. Our work focuses on developing Automatic Power Factor Correction (APFC) equipment based on embedded systems. This equipment automatically monitors power factor in mining electrical systems and adjusts capacitor banks to maintain desired levels, meeting standard norms. The APFC device is powered by an 89S52 microcontroller, sampling voltage and current signals from the system to measure power factor. If the power factor falls below the utility-specified value, the device switches on capacitor banks to compensate for reactive power. The microcontroller determines the number of capacitors to switch based on system power factor and the target. Our analysis of three different load types indicates that only inductive loads require power factor correction. Implementing correction equipment achieves the targeted power factor of 0.95, resulting in a power factor increase ranging from 9% to 19%, depending on the load combination. Additionally, there is a 1.7% decrease in total energy consumption due to reduced load current. Economic analysis using data from a local coal mine suggests a payback period of around 9 months for implementing correction equipment.

KEYWORDS: Power factor, Automated, Microcontroller, Power efficiency, Power saving

I. INTRODUCTION

The power factor of an electrical system reflects its efficiency in converting supplied electric power into useful work. A low power factor not only increases losses but also incurs penalties from utility providers. In modern mining industries employing mechanized methods, the use of various electric equipment often leads to a low power factor, as these devices require more reactive power. Maintaining an average monthly power factor close to unity can result in substantial savings in utility costs.

Utilizing shunt capacitor banks for Power Factor Correction (PFC) is a well-established method. A recent trend is the automation of capacitor switching procedures to maximize real-time benefits. Embedded systems based on microcontrollers offer reliability and efficient execution, making them suitable for monitoring and controlling correction device switching.

II. PROJECT OBJECTIVES

The primary aim of the project was to develop correction equipment capable of monitoring the power factor of the mine's electrical system and improving it to a desired level. The research objectives included:

- Conducting an electrical survey of the existing system in an opencast mine to examine system configuration, load patterns, and variations in power factor during mine operation hours, along with analyzing existing power factor correction facilities, if any.
- Designing correction equipment based on microcontrollers to enhance the power factor of the system to a desired value exceeding 0.95.
- Implementing the system and monitoring various electrical load models and diverse load patterns to validate the results.
- Performing an economic analysis to assess the benefits of power factor improvement.

III. LITERATURE REVIEW

The power factor (PF) of an AC electrical power system represents the ratio of the actual power consumed by the load to the total power in the circuit. Real power is the ability of a circuit to do work in a given time period, while apparent power is the product of the circuit's current and voltage. When the energy stored in the load or non-linear loads causes distortion in the current waveform pulled from the source, the perceived power is greater than the true power. Figure 2.1 presents a schematic diagram that illustrates this concept. An electrical load with a power factor of 1.0 maximizes the efficiency of the power supply, while a power factor of 0.5 results in much greater losses in the supply system.

A low power factor might result from a substantial phase disparity between voltage and current at the load terminals or from a high level of harmonic content or a distorted/discontinuous current waveform. Inductive loads, such as induction motors, power transformers, lighting ballasts, welders, or induction furnaces, sometimes result in a low power factor due to a delay in the phase angle between voltage and current. Power factor correction can help improve power factor caused by inductive loads, but to address power factor issues produced by distorted current waveforms, equipment design changes or costly harmonic filters are required to make significant improvement. In order to ensure optimal performance, it is essential to maintain a power factor that is as close to 1 as possible. Utility companies frequently impose extra charges on commercial clients whose power factor falls below a certain threshold, usually ranging from 0.9 to 0.95.

Low power factor can be attributed to several factors, such as the utilization of mercury vapor lamps or lamps operated with chokes, power and distribution transformers (particularly when they are not loaded), and induction motors operating under loaded or unloaded situations. Inductive load equipment commonly found in mines, such as hoists, shovels, drills, pumps, shearers, and conveyors, is responsible for causing a low power factor.

Power factor correction (PFC) involves mitigating the adverse consequences of electric loads that result in a power factor below 1. Electrical power transmission utilities can utilize it to improve the stability and efficiency of their transmission network, while individual electrical customers can use it to lower the expenses imposed by their electricity supplier. Capacitive power factor correction (PFC) is frequently used in circuits that have induction motors to decrease the inductive current and, as a result, minimize supply losses. Capacitors that are connected to each starter and regulated by each starter are referred to as "Static Power Factor Correction."

To perform static power factor correction, it is common to use a single contactor to control both the motor and the capacitors. However, it is advisable to use two separate contactors, one for the motor and one for the capacitors, in order to reduce resonance problems that may occur between the motor and the capacitors. Different techniques for enhancing power factor, such as individual, group, and central power factor corrections, can be implemented according to the load's characteristics, whether it is constant or variable.

Power factor compensating devices are essential for providing the required reactive power to improve power factor and system voltage profile. Shunt capacitors are commonly used in industrial distribution systems to neutralize the reactive power needed by inductive loads. These capacitor banks improve power factor, reduce the amount of source current, and boost voltage regulation across the system. Capacitor banks can be either fixed, switched, or a combination of both, with switching procedures being either human or automatic. Installation of capacitors in high-voltage power

centers is regulated by organizations like the Mine Safety and Health Administration (MSHA), which require the inclusion of built-in methods for capacitor discharge.

Due to their electromechanical nature and maintenance needs, synchronous condensers have limited utility in the mining industry, despite formerly being utilized as compensators with fixed ratings. When planning an installation, it is important to take into account factors such as the reliability of the equipment, the projected lifespan, the initial and ongoing expenditures, the space needed, and the convenience of installation.

Oommen and Kohler (1988) investigated the benefits that can be achieved via the effective use of power factor adjustment. Various compensators, as well as their sizing and strategic placement, were also taken into account. A concise examination of the economic analysis was conducted to demonstrate the economic feasibility of compensation [7]. In 1993, Jiang et al. introduced a new single-phase two-cascade stage scheme. In their work, Qureshi and Aslam (1995) described various techniques for power factor correction and conducted an empirical investigation to identify eligible locations for compensation. Following a practical demonstration, it was determined that there was a substantial enhancement in power factor. This resulted in the release of the distribution transformer's capacity and effectively resolved the issue of excess voltage during low load conditions [6]. Novak and Kohler (1998) emphasized the significance of enhancing power factor in deep coal mine power systems to drive technological innovation and progress. The discussion revolved around various protective equipment used to detect the inherent electrical flaws in the mining system. The need of power factor correction near loads to enhance voltage management was highlighted in the context of high voltage distribution in underground coal mines [8].

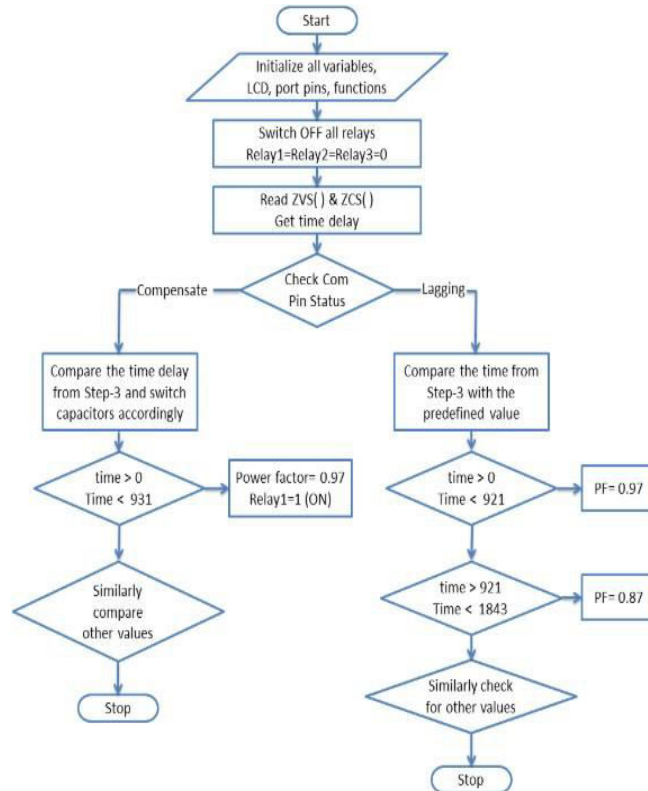
In their study, Shwehdi and Sultan (2000) proposed mathematical formulas to determine the power factor and reactive power requirements of the system, as well as methods for estimating the size of capacitors. The paper extensively examined several issues and precautions related to the usage of capacitors for corrective purposes [9]. Celtekliligil (2008) examined the implementation of a technique for actively adjusting power factor and regulating voltage in a light rail transportation system. The main reactors have been activated using thyristors, which are controlled by automatic power controllers. These controllers sense the power factor and continuously monitor the current and voltage. They calculate the power factor and activate inductance banks as needed. The suggested method connects inductive loads in parallel with the capacitive system in order to enhance the power factor.

Choudhury (2008) presented a design and execution of an affordable power factor enhancement device for small signal low power loads. The task entailed creating a tiny signal model load, choosing suitable capacitors, and building appropriate switching circuits to pick the correct mix of capacitors.

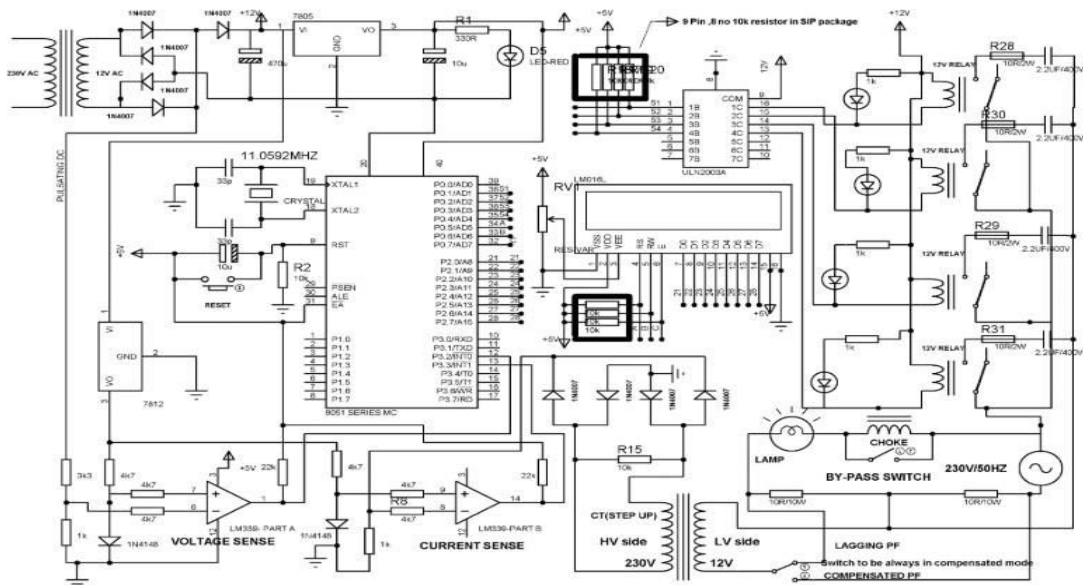
In their study, Shahid and Anwar (2013) proposed a power factor enhancement circuit design that utilizes a PIC (Programmable Interface Controller) chip. The design aims to achieve the desired efficiency and cheap cost by reducing the number of components required. The approach entails verifying the power factor value of the load and employing an algorithm to identify and activate switching capacitors to counterbalance excessive reactive components, hence enhancing the power factor value.

Sharma and Haque (2014) conducted a simulation and analysis study on power factor adjustment for metal halide high intensity discharge lamps. An enhanced boost converter employing active components was suggested, along with a PI controller to provide stability in the control loops. The capacitor and inductor were developed to minimize voltage and current ripple. Their purpose is to absorb sinusoidal input current and reduce total harmonic distortion (THD) in the input current, while also regulating the output voltage. Allah (2014) proposed an automated power factor correction system via the Alienation technique. A technique of alienation was devised to calculate the original power factor in real-time, as well as the active and compensatory reactive powers. It also determines the necessary number of capacitor banks needed to achieve the target power factor. Alienation coefficients were computed by analyzing the relationship between the phase voltage and current signals of the power source. The proposed technique was implemented using Alternative Transient Program (ATP) and MATLAB programs.

IV. FLOW CHART



V. CIRCUIT DIAGRAM



VI.METHODOLOGY

Each block comprises multiple interconnected components arranged in the necessary manner to produce the intended output. The fabrication process was performed based on the circuit schematic provided at the end. Extra precautions were implemented during the fabrication process to prevent any instances of short circuits when routes intersected. Transformers efficiently convert alternating current (AC) electricity from one voltage level to another with minimal power loss. The potential transformer (PT) employs a step-down transformer to decrease the hazardous high voltage to a more secure low voltage (usually 110 Volts) within any substation. The power transformer (PT) utilized in this context reduces the input voltage from 230 Volts to the desired 12 Volts, which is necessary for the proper functioning of the circuit. The result of a PT (Potential Transformer) is utilized for all measurement and monitoring functions in combination with relay operation.

The turn's ratio, which is the ratio of the number of turns on each coil, directly impacts the ratio of the voltages. A step-down transformer is designed with a high number of turns on its primary coil, which is linked to the high voltage mains supply. On the other hand, it has a low number of turns on its secondary coil, resulting in a low output voltage. A current transformer (CT) is employed in an electrical circuit to measure electric currents. Current transformers, along with voltage transformers (VT) (sometimes known as potential transformers (PT)), are referred to as instrument transformers. A current transformer is used when the current in a circuit is too large to be directly measured by instruments. It produces a smaller current that is proportionate to the current in the circuit, which can then be easily linked to measuring and recording devices. Additionally, it separates the measuring equipment from potentially hazardous high voltage present in the monitored circuit. They are frequently utilized in metering and protection relays within the electrical power industry. Figure 4.2 illustrates the schematic operation of a Current Transformer, as referenced by source.

The zero crossing detector is a device that converts a sine wave into a square wave. In order to determine the phase lag between the voltage and current, two detectors are employed to ascertain the precise moment at which each signal arrives. The phase angle lag is determined by the difference between the calibrated arrival instance and the angle. The power factor of the circuit is determined by calculating the cosine of the phase lag. The reference voltage is set to zero in this instance. The output voltage waveform indicates the precise timing and direction in which an input signal crosses the zero-volt threshold. If the input voltage is a low frequency signal, the output voltage will exhibit a slower transition between saturation points. If there is any interference between the two input nodes, the output may oscillate between the positive and negative saturation voltage V_{sat} . The LM339 integrated circuit (IC) is utilized as a comparator circuit in order to operate as a zero crossing detector.

The operating voltage for the embedded system circuit commonly consists of 12 volts and 5 volts of direct current (DC). Hence, it is necessary to convert the 230 Volt AC power source into the desired DC power supply. During the initial phase, the 230 V AC voltage is reduced to 12 V AC by means of a transformer. In this scenario, the output generated by the potential transformer (PT) can be employed instead of acquiring an additional step-down transformer. The second stage involves the correction process. The 12 V AC is converted into a 12V pulsing DC voltage by employing a complete bridge rectifier circuit. The pulsating direct current (DC) is directed via a capacitive filter in the third stage to get a smoother output. The result is a standard 12V DC output. In the 4th stage, a 12 V and a 5 V voltage regulator are utilized to produce a consistent supply voltage for the control circuit.

A rectifier is an electrical apparatus that transforms alternating current (AC), which cyclically changes direction, into direct current (DC), a type of electricity that flows in a single direction, through a process called rectification. It transforms alternating current (A.C.) into pulsating direct current (D.C.). The rectifier can be either a half-wave or a full-wave rectifier. In the majority of circumstances, a bridge rectifier is utilized due to its advantageous characteristics such as excellent stability and the capacity to perform full wave rectification. During the positive half cycle, just a pair of parallel diodes will conduct. In the negative half cycle, the other pair of diodes will conduct, but only in forward bias. Page 21 of the National Institute of Technology, Rourkela displays a Full Bridge Rectifier with Input and Output, as referenced by source.

Filter This project utilizes a capacitive filter. It eliminates the fluctuations in the output of the rectifier and creates a steady direct current (D.C.) signal. The output obtained from this filter is consistent as long as both the mains voltage and load are kept constant. The simple capacitor filter is the most fundamental form of power supply filter. The voltage regulator is a component used to regulate the voltage. The LM78XX/LM78XXA series consists of three-terminal

positive regulators that come in the TO-220/D-PAK package. These regulators have multiple fixed output voltages, making them suitable for a broad variety of applications. Every variety of this product utilizes internal current limiting, thermal shutdown, and safe operating area protection, rendering it virtually impervious to damage. With sufficient heat dissipation, these devices are capable of delivering an output current exceeding 1A. While their primary purpose is to function as fixed voltage regulators, these devices have the capability to be utilized in conjunction with external components to achieve adjustable voltages and currents. The LM78XX specifies the output voltage using the final two digits XX. The LM7805 will provide an output of 5 volts, whereas the 7812 will produce an output of 12 volts.

The LM7805 component together with its corresponding connection diagram. The reference number [30] is provided for further identification. Within an embedded system, the microcontroller engages with external devices that facilitate communication with a person through input and output mechanisms. An LCD display is a frequently connected peripheral to the microcontroller. The microcontroller commonly interfaces with LCDs of sizes 16x2 and 20x4. Consequently, there will be a total of 16 characters per line across 2 lines and 20 characters per line across 4 lines, respectively, that can be utilized. This project utilizes a 16x2 LCD, namely the JHD 162A model, to display the power factor and the phase lag between voltage and current in milliseconds.

The microcontroller connection necessitates 3 control lines and either 4 or 8 I/O lines for the data bus. The user has the option to choose between operating the LCD with either a 4-bit data bus or an 8-bit data bus. When a 4-bit data bus is utilized, the LCD will necessitate a sum of 7 data lines, which includes 3 control lines in addition to the 4 lines dedicated to the data bus. When an 8-bit data bus is utilized, the LCD will necessitate a combined total of 11 lines.

A microcontroller serves as the central component of an embedded system, responsible for executing all logical operations.

The system receives input, executes the program written for it, and produces the processed output. The device also contains on-chip memory that is used to store temporary variables during processing. The microcontroller utilized in this context is the AT89S52, which is an 8-bit controller.

The AT89S52 is a CMOS 8-bit microcontroller that offers great performance and low power consumption. It is equipped with 8K bytes of in-system programmable flash memory. The device is fabricated with Atmel's high-density nonvolatile memory technology and is fully compatible with the instruction set and pin configuration that is widely accepted in the industry. The on-chip flash enables the program memory to be reprogrammed either in-system or by using a typical nonvolatile memory programmer. The Atmel AT89S52 is a powerful microcontroller that offers a highly-flexible and cost-effective solution to a wide range of embedded control applications. It achieves this by integrating a versatile 8-bit CPU with in-system programmable memory on a single chip. The AT89S52 offers the following standard features: The microcontroller has 8 kilobytes of flash memory, 256 bytes of RAM, 32 input/output lines, a watchdog timer, two data pointers, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full duplex serial interface, an on-chip oscillator, and clock circuits.

This item comprises a relay driver and several relays. Since the microcontroller's output is unable to directly control the switching of capacitors, this unit is tasked with regulating the high power circuit using a low power circuit. A relay is a switch that is operated by electricity. Relays are employed in situations when it is imperative to regulate a circuit using a low-power signal, while ensuring complete electrical isolation between the control and controlled circuits. They are also utilized when multiple circuits need to be controlled by a single signal. The flow of electric current through the coil of the relay generates a magnetic field that pulls a lever and alters the position of the switch contacts.

The switch connections of the relay are often labeled as COM, NC, and NO.

- COM stands for Common, and it is the part of the switch that is always connected and moves.
- NC stands for Normally Closed. The COM terminal is connected to the NC terminal when the relay coil is not energized.

NO stands for Normally Open. When the relay coil is activated, COM is connected to this terminal. The number 33 is enclosed in square brackets.

Due to insufficient current from the microcontroller's output pin, a relay driver ULN2003 is employed to activate the relay coil. The ULN2003 is a Darlington transistor array that operates at high voltage and high current levels. The ULN2003 is a single integrated circuit that has several Darlington transistor arrays capable of handling high voltage and high current. The device comprises seven NPN Darlington pairs, each equipped with high-voltage outputs and a common-cathode clamp diode. This configuration allows for efficient switching of inductive loads. The maximum

current that can flow through a single Darlington pair is 500mA. It is possible to connect many Darlington pairs in parallel to increase their ability to handle higher currents. Some examples of applications for these components are relay drivers, hammer drivers, lamp drivers, display drivers (for LED gas discharge), line drivers, and logic buffers. The diagram illustrates the ULN2003 Relay Driver and its corresponding Pin Connection Diagram. This information is referenced from source. The institution is called the National Institute of Technology, Rourkela. 25th page

Shunt capacitor banks are utilized to enhance the electrical supply's quality and optimize the power system's efficiency. Research indicates that maintaining a consistent voltage level across the system can greatly decrease the amount of energy lost in transmission lines. Shunt capacitor banks are cost-effective and may be conveniently deployed at any location on the network. The capacitor bank is comprised of many shunt capacitors that can be activated or deactivated based on the need for reactive power. Capacitors can be switched either manually or automatically using relays. Figure illustrates the presence of shunt capacitors, as referenced by the citation.

Shunt capacitors, whether installed at the customer's premises to rectify power factor or on the distribution system for voltage control, significantly modify the changes in system impedance with frequency. Capacitors do not generate harmonics, although their presence can occasionally contribute to significant harmonic distortion. Placing a shunt capacitor at the end of a feeder causes a progressive variation in voltage along the feeder. Ideally, the voltage increase percentage at the capacitor would be zero when there is no load and would reach its maximum value when there is a full load. Nevertheless, when shunt capacitors are used, the percentage increase in voltage remains unaffected by the load. Therefore, automatic switching is frequently used to achieve the desired control under heavy loads, while also preventing excessive voltage under light loads. Additionally, the act of switching capacitors might lead to the occurrence of transient overvoltage within the premises of customers.

The printed circuit board (PCB) was manufactured in accordance with the virtual reality prototype (VRP) diagram for the entire circuit, and all the components have been connected onto it. The connection for the potential transformer, current transformer, and capacitor bank was established at their appropriate locations. A continuity check was performed using the multimeter to prevent any inadvertent short-circuits. The program was transferred to the microcontroller using a burner. The comprehensive hardware is depicted in the following schematics.

VII. RESULT

LOAD ANALYSIS WITHOUT CORRECTION

An analysis was conducted on three types of loads: pure resistive load (R Load), series resistive-inductive load (Series R-L Load), and parallel resistive-inductive load (Parallel R-L Load). This analysis was performed without the use of correcting equipment. The designed loads were linked via the PG08 power guard, and measurements were taken for several electrical properties.

LOAD ANALYSIS WITH CORRECTION

In order to improve the power factor of both the Series R-L load and the Parallel R-L load, they were connected to the power supply along with the correction equipment. This equipment was developed to check the expected correction. The correction equipment is connected to the PG08 power guard, and the loads are connected to the equipment's output point. Three loads were constructed and tested, with the resulting values recorded. SURVEILLANCE Monitoring often involves being cognizant of the condition of a system and can involve observing a situation for any temporal changes, via a monitor or measuring instrument. In order to quantify the amount of energy used, it is important to observe and track the electrical load during a designated time interval. The Meco PG08 power guard is capable of monitoring time and measuring energy consumption for various types of loads. The loads were linked constantly for a specific duration and were closely monitored with great caution. Load monitoring without correction

The monitoring of the pure resistive load (R Load), series resistive-inductive loads (Series R-L Load), and parallel resistive-inductive loads (Parallel R-L Load) was conducted without the utilization of corrective equipment. The designed loads were linked via the PG08 power guard, and measurements were taken for energy consumption, time, and average power factor

LOAD MONITORING WITH CORRECTION

Both the Series R-L load and Parallel R-L load were connected to the power supply, together with the correction equipment, in order to assess and confirm the anticipated power factor improvement. The correction equipment is linked to the PG08 power guard and the loads are connected to the output terminal of the equipment. The three loads

were continuously measured and the corresponding values were recorded. Real-time monitoring of a fluctuating load. In order to observe the functioning of the correction unit in real-time conditions with varying loads, various load patterns lasting 10 hours each were created and the related measurements of energy and average power factor were recorded. Graphs are generated to visually represent the change in power factor for each load pattern. These graphs compare the power factor before and after the improvement, corresponding to the time of operation. The load patterns A, B, and C for a 10-hour operation are displayed below. The loads are adjusted in response to the automatic switching of capacitors by the control circuit, which is based on the reactive power need and power factor.

VIII. CONCLUSION

Power factor correction equipment, utilizing microcontroller technology and capacitor banks, was employed to measure and monitor a simulated electrical demand. The subsequent deductions were obtained: The power factor correction device successfully enhanced the power factor from 0.76 to 0.97 during the test load circumstances. The mean reduction in energy consumption was around 1.7% for the specified load and various load patterns. By implementing the appropriate level of reactive power compensation, the system's capacity is unleashed due to a decrease in the quantity of current being pulled. Based on the economic study, the payback period is estimated to be around 9 months, resulting in substantial energy cost reductions.

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