

Automated System for Power Factor Correction

D.Vijay Arun, K.Hemalatha,B.Hema Naga Latha,J.Sravani, D.Jaya sri

Department of Electrical & Electronics Engineering

Sheshadri Rao Gudlavalleru Engineering college, Gudlavalleru, Krishna District,

Pin code-521356, AP.

Keywords

Power Factor Correction
Arduino
PZEM Sensor
Relay Module
Capacitor Bank
IoT Monitoring
ESP8266
Automatic Control
Manual Control
Energy Efficiency

ABSTRACT

Efficient power usage has become essential in both industrial and domestic electrical systems, making power factor correction (PFC) highly important. This project presents a smart Arduino-based PFC system with both automatic and manual control, along with IoT monitoring capabilities. A PZEM sensor is used to measure key electrical parameters such as voltage, current, power, energy, and power factor in real time. Based on these readings, the system identifies the type of load and activates capacitor banks when an inductive load is detected to improve the power factor. A relay module is used for switching, offering a simple, reliable, and cost-effective solution. In automatic mode, the system maintains the power factor close to unity by controlling relays on its own, while in manual mode, users can adjust the system as needed. An LCD displays real-time data, and an ESP8266 WiFi module enables remote monitoring and control through a mobile application. Overall, the system enhances energy efficiency, reduces power losses, and provides an economical and flexible approach to power factor correction. This project proposes a smart and efficient approach to power factor correction using an Arduino-controlled system with IoT integration. Electrical parameters are continuously monitored using a PZEM module, enabling accurate detection of power factor and load type. Based on this analysis, capacitor banks are switched using a relay module to improve the power factor. The system operates in both automatic mode, where corrections are made without user intervention, and manual mode, where users can control the process.

1. INTRODUCTION

In modern electrical power systems, efficient energy utilization and improved power quality are critical for reliable operation and economic performance. The increasing use of inductive loads such as induction motors, transformers, fluorescent lighting, and industrial equipment introduces a significant amount of reactive power into the system, resulting in a low power factor. A poor power factor leads to increased line current, higher I²R losses, voltage regulation issues, reduced system capacity, and penalties from utility providers due to inefficient power usage. To overcome these challenges, power factor correction (PFC) is widely implemented to compensate reactive power and maintain the system power factor close to unity. Conventional PFC methods often involve fixed capacitor banks or complex power electronic converters, which may increase system cost and complexity. In this context, the proposed project presents a microcontroller-based solution using an Arduino platform for real-time power factor monitoring and correction. The system integrates a PZEM sensor module to accurately measure key electrical parameters, including RMS voltage, current, active power, energy consumption, and power factor. Based on continuous data acquisition and analysis, the system identifies the nature of the load and dynamically controls capacitor banks through a relay switching mechanism to provide reactive power compensation. The use of relays offers a simple, robust, and cost-effective alternative to thyristor-based switching. Furthermore, the system is designed with dual-mode operation: an automatic mode that performs closed-loop control for continuous optimization, and a manual mode that allows user intervention for customized operation. An LCD display unit is incorporated for real-time visualization of system parameters, enhancing usability and monitoring. Additionally, IoT capability is enabled through the integration of an ESP8266 WiFi module, allowing remote data access, monitoring, and control via a mobile or web-based interface. The proposed system not only improves power factor and reduces energy losses but also enhances voltage stability, system efficiency, and overall power quality. Its low-cost implementation, flexibility, and scalability make it suitable for both industrial and domestic applications, contributing to smarter and more energy-efficient electrical systems.

The proposed system employs a PZEM sensor module for accurate and continuous measurement of electrical parameters such as RMS voltage, load current, active power, energy consumption, frequency, and power factor. The measured data is processed by the Arduino controller, which determines the magnitude of reactive power and identifies whether the load is inductive or capacitive. Based on this analysis, the system dynamically switches capacitor banks using a relay module to provide the required reactive power compensation. The relay-based switching approach offers simplicity, electrical isolation, ease of implementation, and reduced cost compared to thyristor or TRIAC-based switching methods, while still providing reliable performance for discrete control applications.

To enhance system flexibility, the design incorporates dual operating modes. In automatic mode, the system functions as a closed-loop control system, continuously monitoring the power factor and making real-time adjustments to maintain it within a predefined optimal range. In manual mode, users can directly control the switching of capacitor banks, which is useful for testing, maintenance, or specific operational requirements.

An LCD display interface is integrated to provide real-time visualization of system parameters, enabling users to easily monitor voltage, current, power factor, and system status.

Furthermore, the system is enhanced with Internet of Things (IoT) capability through the integration of an ESP8266 WiFi module. This allows real-time data transmission to a cloud platform or mobile application, enabling remote monitoring, data logging, and control of the system from any location. Such connectivity supports the development of smart energy management systems and aligns with modern trends in automation and smart grid technologies.

Overall, the proposed Arduino-based power factor correction system provides an efficient, economical, and scalable solution for improving power quality. It reduces reactive power demand, minimizes transmission losses, improves voltage stability, and enhances the overall efficiency of electrical systems. The combination of real-time monitoring, automated control, user-friendly interface, and IoT integration makes this system highly suitable for both industrial and residential applications, contributing to sustainable and intelligent energy management practices.

2. LITERATURE SURVEY

Power factor correction has been an important research area in electrical engineering due to its direct impact on energy efficiency and system performance. Many earlier works focused on improving power factor using conventional methods such as fixed capacitor banks and synchronous condensers. Although these methods are simple, they lack flexibility and cannot adapt to varying load conditions, leading to inefficient compensation in dynamic systems.

With the advancement of power electronics, researchers introduced thyristor-based switching techniques such as TRIAC and Silicon Controlled Rectifier (SCR) for dynamic power factor correction. These methods provide faster switching and better control over reactive power compensation. However, they increase system complexity, cost, and require careful design to handle switching issues, especially with inductive loads.

In recent years, microcontroller-based systems have gained popularity for power factor correction. Several studies have implemented systems using microcontrollers like Arduino to monitor electrical parameters and control capacitor banks accordingly. These systems offer better flexibility, real-time monitoring, and ease of implementation compared to traditional methods. The use of sensors such as PZEM modules enables accurate measurement of voltage, current, power, and power factor, improving system reliability.

Further improvements have been made by integrating automatic control strategies, where the system continuously monitors the power factor and adjusts compensation without human intervention. Some research also highlights manual control options for testing and operational flexibility, making the system more adaptable to different scenarios.

Recently, the integration of Internet of Things (IoT) technology has enhanced power factor correction systems by enabling remote monitoring and control. WiFi-based modules such as ESP8266 are widely used to transmit real-time data to cloud platforms, allowing users to analyze system performance and control devices from anywhere. This approach supports smart energy management and aligns with modern smart grid concepts.

Overall, previous studies show a transition from conventional capacitor-based methods to intelligent, automated, and IoT-enabled systems. However, there is still a need for simple, low-cost, and efficient solutions that combine real-time monitoring, automatic correction, and user control. The proposed system addresses this gap by using an Arduino-based design with relay switching, dual operating modes, and IoT functionality, providing a practical and scalable solution for power factor correction.

3.1 PROBLEM IDENTIFICATION

In modern electrical systems, a significant challenge is the presence of a low power factor caused by inductive loads such as motors, transformers, and industrial equipment. These loads draw reactive power from the supply, which does not perform useful work but increases the total current in the system. As a result, electrical networks experience higher transmission losses, voltage drops, reduced system capacity, and overheating of equipment. Additionally, consumers with poor power factor often face increased electricity charges and penalties from utility providers, making it both a technical and economic concern.

Conventional power factor correction methods, such as fixed capacitor banks, are not effective under varying load conditions because they cannot adapt dynamically. This leads to either under-compensation or over-compensation, both of which negatively affect system performance. Advanced solutions using power electronic devices like thyristors and TRIACs offer better control but introduce higher complexity, cost, and maintenance requirements, making them less suitable for small-scale or cost-sensitive applications.

Furthermore, many existing systems lack real-time monitoring and user-friendly control mechanisms. Without proper visibility of electrical parameters, it becomes difficult to analyze system performance and take corrective actions. The absence of remote monitoring capabilities also limits the ability to manage systems efficiently in modern, connected environments.

Therefore, there is a need for a simple, cost-effective, and intelligent solution that can continuously monitor electrical parameters, automatically correct power factor under varying load conditions, and provide user control along with remote monitoring features. Addressing these issues forms the basis of the proposed Arduino-based power factor correction system.

3.2 SCOPE OF THE PROJECT

This project focuses on developing a simple and efficient system for improving power factor in electrical installations using an Arduino-based control approach. The scope includes real-time monitoring of important electrical parameters such as voltage, current, power, and power factor using a sensor module, and applying corrective action through capacitor banks. The system is designed to work for both small-scale industrial setups and domestic applications where power factor issues commonly occur due to inductive loads. The project also covers the implementation of both automatic and manual modes of operation. In automatic mode, the system continuously analyzes the power factor and adjusts the capacitor banks accordingly, while in manual mode, users can control the system based on their specific requirements. This flexibility makes the system suitable for testing, maintenance, and customized usage. Another important aspect of the project scope is the integration of IoT technology. By using a WiFi module, the system enables remote monitoring and control through a mobile or web-based platform. This allows users to track system performance in real time and take necessary actions from any location, supporting the concept of smart energy management.

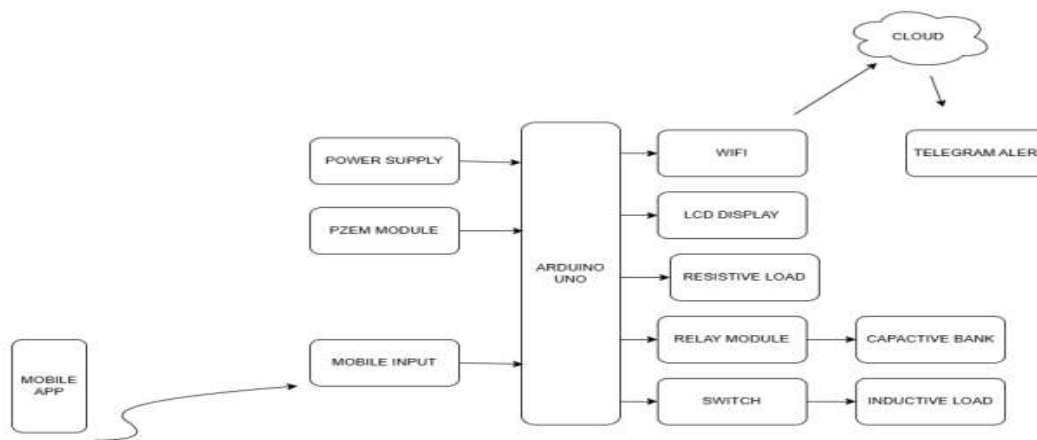
Additionally, the project emphasizes a cost-effective and easy-to-implement design by using relay-based switching instead of complex power electronic devices. The system can be further expanded in the future for three-phase applications, larger industrial loads, and integration with smart grid technologies. Overall, the project aims to provide a practical solution that improves energy efficiency, reduces power losses, and enhances the overall performance of electrical systems.

4. METHODOLOGY & MODELLING

The proposed system is designed to improve the power factor of electrical loads by continuously monitoring system conditions and applying correction when needed. The working process begins with measuring electrical parameters such as voltage, current, power, and power factor using a PZEM sensor module. This sensor sends real-time data to the Arduino microcontroller, which acts as the main control unit of the system. The Arduino reads and processes this data to understand how the load is behaving at any given moment.

After receiving the data, the controller checks the value of the power factor. If the power factor is low, which usually indicates an inductive load, the system decides how much correction is required. Based on this condition, the Arduino sends signals to a relay module connected to capacitor banks. These capacitors are then switched ON to supply reactive power, which helps in improving the power factor. If the power factor becomes higher than required, the system can switch OFF some capacitors to maintain balance. This step-by-step switching ensures smooth operation and avoids sudden changes in the system. The system works in two modes: automatic and manual. In automatic mode, the entire process happens on its own. The Arduino continuously monitors the system and makes decisions without any user involvement, keeping the power factor close to unity. In manual mode, the user has control over the relay switches and can turn the capacitor

banks ON or OFF based on their needs. This feature is useful for testing, maintenance, or specific operating conditions.



To make the system easy to use, an LCD display is included to show real-time values like voltage, current, and power factor. This helps users understand the system performance directly. In addition, an ESP8266 WiFi module is used to provide IoT functionality. Through this, users can monitor system data and control the operation remotely using a mobile or web application. This adds convenience and supports modern smart monitoring systems. From a modelling point of view, the system can be understood as a simple closed-loop control system. The load acts as the input, the sensor measures the system condition, the Arduino processes the information, and the relay with capacitor banks acts as the output that corrects the system. The main goal is to maintain the power factor as close as possible to unity by balancing reactive power in the system.

Since the system uses relays, the correction is done in steps rather than continuously. To ensure stable performance, certain limits are set so that the relays do not switch too frequently. Small delays are also included in the control logic to prevent unnecessary switching and to increase the life of components. Overall, the methodology provides a simple, practical, and cost-effective way to improve power factor while maintaining reliability and ease of use.

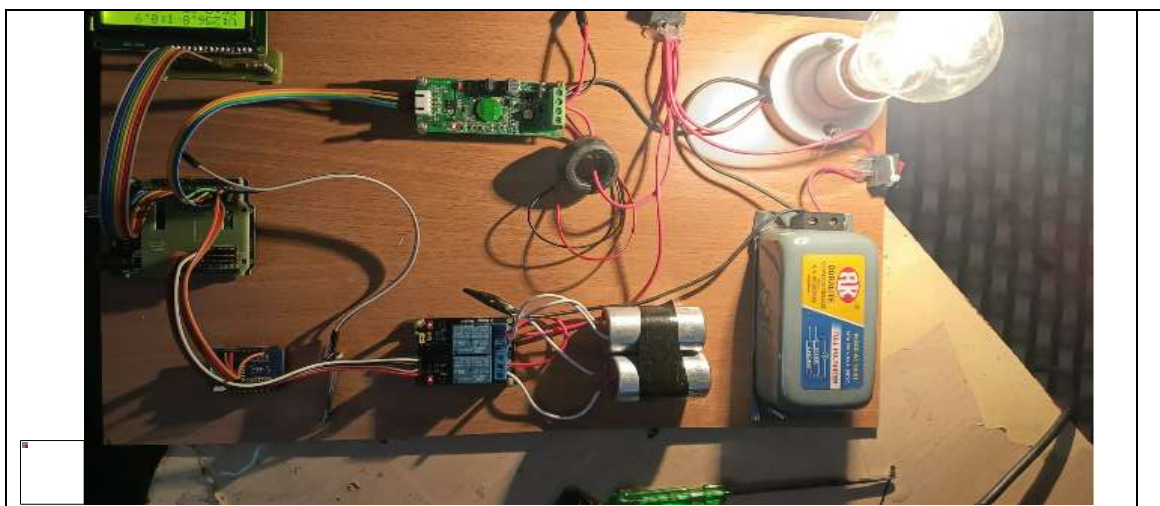
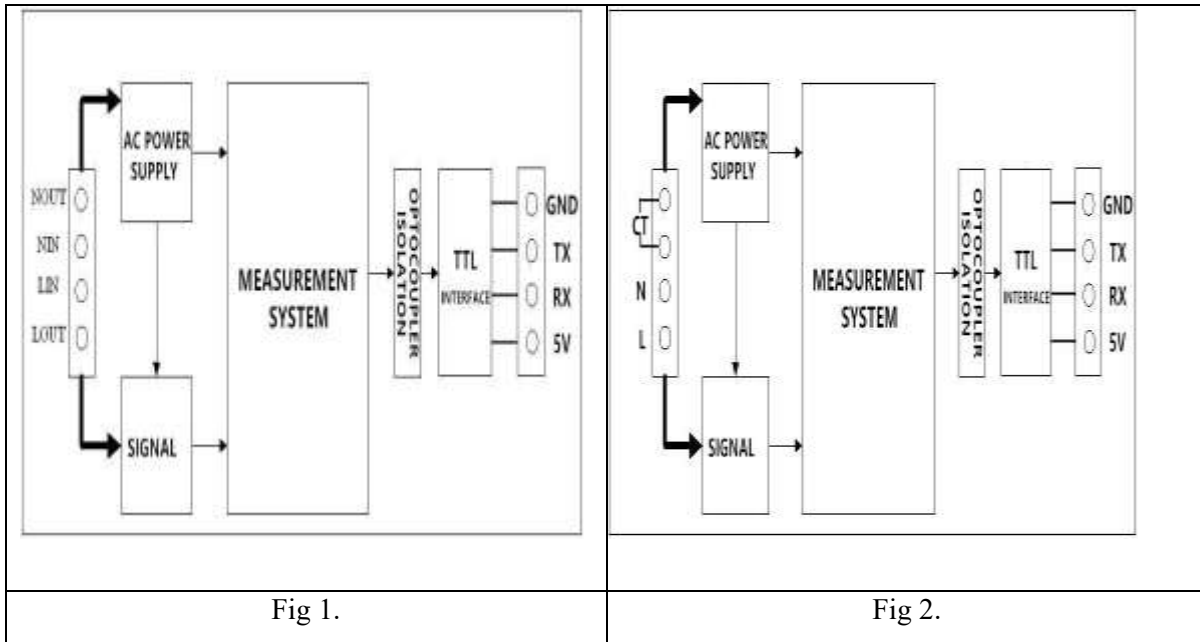


FIG 3



FIG 4

5. Result

The performance of the proposed power factor correction system is analyzed by comparing electrical parameters before and after compensation using capacitor banks.

S.NO	VOLTAGE	CURRENT	POWER	P.F(Before)	P.F(After)	Status
1	220	1.20	264	0.65	0.95	Improved
2	225	1.10	247	0.70	0.96	Improved
3	230	1.30	299	0.68	0.97	Improved
4	220	1.15	253	0.72	0.98	Improved
5	238	1.25	285	0.66	0.96	Improved

Observation

- The power factor is significantly improved and maintained close to unity after correction.
- Current drawn from the supply is effectively reduced for the same load conditions.
- The system responds properly under different operating conditions, ensuring stable performance.

6. Conclusion

The proposed Arduino-based power factor correction system provides an effective and practical solution for improving power quality in electrical systems. By continuously monitoring electrical parameters using a PZEM sensor, the system is able to accurately detect low power factor conditions and apply appropriate correction through capacitor banks. The use of a relay module ensures a simple, reliable, and cost-efficient switching mechanism.

The implementation of both automatic and manual modes adds flexibility to the system, allowing it to operate independently as well as under user control when required. The integration of an LCD display makes real-time monitoring easy, while the inclusion of the ESP8266 module enables remote access and control, aligning the system with modern IoT-based applications.

Overall, the system successfully reduces power losses, improves energy efficiency, and enhances the overall performance of electrical installations. Its low cost, ease of implementation, and scalability make it suitable for both domestic and industrial applications. This project demonstrates a smart and efficient approach to power factor correction, contributing to better energy management and sustainable usage of electrical resources.

REFERENCES

- [1]. A. Kumar and S. Singh, “Design and Implementation of Automatic Power Factor Correction Using Microcontroller,” *International Journal of Engineering Research & Technology (IJERT)*, vol. 6, no. 5, pp. 45–49, 2017.
 - [2]. R. Patel and M. Shah, “Power Factor Correction Using Arduino-Based System,” *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 7, no. 3, pp. 1123–1128, 2018.
 - [3]. PZEM-004T Energy Meter Module Datasheet, Peacefair Electronic Co., Ltd., China, 2019.
 - [4]. Arduino, “Arduino Uno Rev3 Datasheet,” [Online]. Available: <https://www.arduino.cc>
 - [5]. Espressif Systems, “ESP8266EX Datasheet,” 2020.
 - [6]. B. L. Theraja and A. K. Theraja, *A Textbook of Electrical Technology*, vol. 2, S. Chand Publications, New Delhi, 2014.
 - [7]. M. H. Rashid, *Power Electronics: Circuits, Devices and Applications*, 3rd ed., Pearson Education, 2004.
 - [8]. S. Mehta and V. Shah, “IoT-Based Smart Energy Monitoring System,” *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 8, no. 6, pp. 5234–5239, 2019.
 - [9]. N. Mohan, T. Undeland, and W. Robbins, *Power Electronics: Converters, Applications and Design*, Wiley, 2003.
-