International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048
Volume 10, Issue 5, pp 668-672, May-2026
https://doi.org/10.47001/IRJIET/2026.105089

IoT Based Power Factor Monitoring & Control System

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***Abstract* - This paper presents an Internet of Things (IoT)-based power factor monitoring and control system for electrical loads. Modern industries and commercial systems mainly operate with inductive loads such as motors, transformers, compressors, and fluorescent lighting systems. These inductive loads reduce the power factor of the electrical system, resulting in increased current consumption, higher power losses, poor voltage regulation, and reduced efficiency. Continuous monitoring and correction of power factor are therefore essential for effective energy management and improved system performance. The proposed system uses ATmega328 microcontroller, PZEM004 sensor module, ESP WiFi module, relay circuit, and capacitor bank for automatic monitoring and correction of power factor. Voltage, current, power, and power factor values are continuously measured and processed by the controller. Whenever the power factor decreases below the predefined threshold level, relay circuits automatically switch ON the capacitor bank for correction. The measured parameters are displayed on LCD display and simultaneously uploaded to ThingSpeak cloud platform for remote monitoring through internet connectivity.**

Keywords: IoT, Power Factor Correction, Capacitor Bank, Energy Efficiency, Voltage Sensor, Current Sensor, Relay Circuit, Electrical Monitoring, ThingSpeak, ATmega328.

I. INTRODUCTION

Electrical energy is one of the most important requirements for industrial, commercial, and domestic applications. Most industrial electrical equipment such as induction motors, transformers, pumps, compressors, welding machines, and fluorescent lamps operate on inductive loads. Inductive loads consume reactive power along with active power, resulting in low power factor conditions in electrical systems.

Power factor is defined as the ratio of real power to apparent power in an electrical system. It represents the efficiency with which electrical power is utilized. A power factor close to unity indicates efficient utilization of electrical energy, whereas low power factor results in excessive current flow through conductors and electrical equipment.

Low power factor creates several technical and economic problems such as:

- Increased current consumption
- Higher copper losses
- Excessive heating of conductors
- Poor voltage regulation
- Reduced efficiency of electrical equipment
- Overloading of transformers and generators
- Increased electricity charges due to utility penalties

To overcome these problems, power factor correction methods are used in electrical systems. Capacitor banks are commonly used for compensating reactive power and improving power factor. Conventional power factor correction systems are mostly manual and require continuous supervision. Manual systems are less efficient under varying load conditions and may not provide accurate correction.

Recent advancements in embedded systems and Internet of Things technology have enabled the development of smart monitoring and automatic control systems. IoT technology allows real-time monitoring, cloud data storage, remote access, automation, and intelligent energy management. Integration of IoT with power factor correction systems provides improved reliability, efficiency, and monitoring capability.

The proposed IoT-Based Power Factor Monitoring and Control System continuously monitors voltage, current, power, and power factor using PZEM004 sensor module. The ATmega328 microcontroller processes the measured data and controls relay switching operations for capacitor bank connection.

Whenever the power factor drops below the predefined threshold level, the relay circuit automatically switches ON the capacitor bank for correction. Electrical parameters are displayed locally on 16×2 LCD display and uploaded to ThingSpeak cloud platform through ESP WiFi module for remote monitoring.

The proposed system offers several advantages including:

- Automatic power factor correction
- Real-time electrical parameter monitoring
- Remote access through IoT platform

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- Reduced power losses
- Improved system efficiency
- Enhanced equipment life
- Reduced electricity charges
- Smart energy managements

The developed system is suitable for industries, manufacturing plants, educational institutions, hospitals, commercial buildings, and smart grid applications where inductive loads are extensively used.

II. LITERATURE REVIEW

Several researchers have proposed automatic power factor correction systems using microcontrollers and smart monitoring technologies.

1. Singh et al. developed an automatic power factor correction system using relay-operated capacitor banks. The proposed system improved efficiency and reduced reactive power demand in industrial applications.
2. Patel and Shah implemented a wireless energy monitoring system using ESP8266 WiFi module. The system enabled remote monitoring of electrical parameters through IoT cloud platforms.
3. Kumar et al. designed a microcontroller-based automatic capacitor switching system for industrial power factor correction. Experimental results showed significant reduction in current consumption and power losses.
4. Sharma et al. proposed an IoT-based smart energy management system for industrial automation applications. The developed system provided cloud-based monitoring and remote supervision.
5. Rao and Prakash developed a cloud-connected electrical parameter monitoring system using embedded controllers and wireless communication modules.

III. PROPOSED SYSTEM

The proposed system mainly consists of:

- ATmega328 Microcontroller
- PZEM004 Voltage and Current Sensor
- ESP WiFi Module
- Relay Driver Circuit
- Capacitor Bank
- LCD Display
- Buzzer Indicator
- Thing Speak Cloud Platform

The PZEM004 module continuously measures voltage and current values from the electrical load and transfers data to ATmega328 controller. The controller calculates power factor and displays measured values on LCD display.

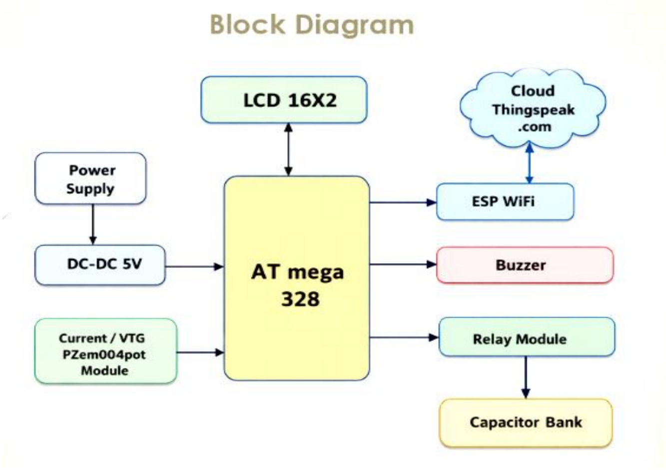

Figure 1: Block Diagram

When the power factor reduces below the desired value, the controller activates the relay module, which switches ON the capacitor bank for correction. The ESP WiFi module uploads electrical parameters to ThingSpeak cloud platform for online monitoring and analysis. The buzzer acts as an indication device during system operation.

The proposed system continuously measures voltage and current values using PZEM004 module. Measured data are processed by ATmega328 controller for calculating power factor. When power factor falls below the threshold value, the controller activates relay module for switching capacitor bank. Capacitor bank compensates reactive power and improves the power factor. Electrical parameters are displayed on LCD display and uploaded to ThingSpeak cloud platform through ESP WiFi module. The complete operation is automatic and requires minimal human intervention. The complete system improves efficiency, reduces power losses, and enables smart monitoring using IoT technology.

IV. MATERIALS AND METHODS

4.1 ATmega328 Microcontroller

ATmega328 acts as the main controller of the proposed system. It processes sensor data, calculates power factor, controls relay switching, and manages communication with IoT platform.

Features

1. Low power consumption
2. High processing speed
3. Multiple input/output pins
4. Serial communication support
5. Reliable operation

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4.2 PZEM004 Sensor Module

PZEM004 module measures:

- Voltage
- Current
- Power
- Energy
- Frequency
- Power Factor

The module provides accurate measurement of electrical parameters and communicates with the controller through serial communication.

4.3 ESP WiFi Module

ESP8266 WiFi module provides internet connectivity for remote monitoring.

Function

1. Uploading data to cloud platform
2. Wireless communication
3. Remote monitoring support

4.4 Relay Module

Relay modules are used for switching capacitor banks automatically.

Advantages

1. Electrical isolation
2. Automatic operation
3. Reliable switching

4.5 Capacitor Bank

Capacitor banks provide reactive power compensation for improving power factor.

Benefits

1. Reduction in reactive power demand
2. Improved power factor
3. Reduced current consumption
4. Improved efficiency

4.6 LCD Display

The 16×2 LCD display shows:

- Voltage
- Current
- Power factor
- Power
- System status

V. RESULTS AND DISCUSSIONS

The developed system was tested under various inductive load conditions. Experimental observations confirmed successful monitoring and automatic correction of power factor.

5.1 Monitoring Performance

Voltage, current, and power factor values were accurately measured by the PZEM004 sensor module. Real-time values were displayed on LCD and uploaded to cloud platform successfully.

Observed Features:

1. Accurate sensing
2. Continuous monitoring
3. Stable communication
4. Remote accessibility

5.2 Power Factor Correction

Before correction, inductive loads operated at lagging power factor values between 0.65 and 0.78.

After capacitor bank switching:

1. Power factor improved to 0.95–0.99
2. Current consumption reduced
3. Power losses decreased
4. System efficiency improved

5.3 IoT Monitoring

ThingSpeak platform successfully displayed graphical representation of electrical parameters.

Achieved Functions

1. Real-time cloud monitoring
2. Data storage
3. Wireless access
4. Remote supervision

5.4 Comparative Analysis

Table 1: Comparative Analysis

Parameter	Before Correction	After Correction
Power Factor	0.68	0.97
Current	High	Reduced
Power Loss	High	Reduced
Efficiency	Low	Improved
Voltage Regulation	Poor	Improved

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5.5 Advantages of Proposed System

1. Automatic operation
2. Reduced power losses
3. Improved energy efficiency
4. Remote monitoring capability
5. Reduced electricity penalties
6. Smart energy management
7. Improved equipment performance
8. Easy installation and maintenance

5.6 Future Perspective

Future improvements of the proposed system may include:

- Artificial intelligence-based energy management
- Machine learning algorithms for adaptive correction
- Mobile application integration
- Smart grid connectivity
- Solar energy integration
- SCADA system implementation
- Multi-stage intelligent capacitor control
- Predictive maintenance systems

The future scope of IoT-based power factor correction systems is highly promising for industrial automation and smart energy management applications.

VI. CONCLUSION

The proposed IoT-Based Power Factor Monitoring and Control System successfully demonstrated automatic monitoring and correction of power factor using embedded and IoT technologies. The developed system continuously monitored voltage, current, power, and power factor using PZEM004 sensor module and processed the measured data through ATmega328 microcontroller.

Whenever the power factor reduced below the predefined threshold value, the controller automatically switched capacitor banks using relay circuits for correction. The corrected parameters were displayed on LCD display and uploaded to ThingSpeak cloud platform through ESP WiFi module for remote monitoring.

The implementation of automatic power factor correction significantly reduced current consumption, minimized power losses, improved voltage regulation, and enhanced energy efficiency. Integration of IoT technology enabled cloud-based monitoring, remote accessibility, and smart electrical parameter analysis.

The proposed system provides a reliable, economical, and efficient solution for industrial and commercial applications where inductive loads are widely used. The developed system contributes to energy conservation, improved equipment life, and effective power management.

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Citation of this Article:

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