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✉ ijareeie@gmail.com

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IOT-Based Power Factor Controller

Aman Jangid, Harish Payal, Kanishk Khandal, Karan Mourya, Naveen Ghosliya

Dept. of Electrical Engineering, SKIT Jaipur, India

Avadhesh Kumar Sharma

Assistant Professor, Dept. of Electrical Engineering, SKIT Jaipur, India

ABSTRACT: This paper presents the simple and low-cost design of an IOT based power factor correction (PFC) system for single-phase domestic loads. The proposed design uses relays to switch the capacitor banks in order to correct the power factor of inductive loads. An Arduino board controls the switching of relays based capacitor re-actor bank depending on power factor measured. The Arduino is programmed to non-stop monitor and calculate the power factor of the connecting load by sensing the signal from CT, PT and Zero Cross Detectors (ZCDs), and keep the power factor of the load above the reference value (0.95) by appropriately energizing the capacitors in parallel to the connecting load through relays switching so as to correct power factor close to unity. The value of power factor before and after improvement is displayed on LCD. The hardware prototype of the proposed APFC design is also developed to validate its operation. The satisfactory and acceptable results of the APFC system test have con-firmed that the suggested design yields a reliable output and can be further used in any single-phase practical application to ensure the power factor close to unity. This setup improves power factor up to 0.99.

I. INTRODUCTION

In modern electrical power systems, maintaining high energy efficiency and power quality is a critical requirement, particularly in industrial and commercial settings where inductive loads such as motors, transformers, and fluorescent lighting are prevalent. These inductive elements introduce reactive power into the system, resulting in a lagging power factor, which not only reduces the efficiency of power usage but also leads to increased transmission losses and higher electricity bills due to penalties imposed by utility providers. Power Factor Correction (PFC) is the process of improving the power factor by compensating for the reactive power using capacitive elements. Traditionally, this has been implemented using fixed or automatic capacitor banks manually configured or controlled via embedded systems. However, these systems often lack the ability to adapt dynamically to rapidly changing loads and do not provide remote monitoring or control capabilities. With the emergence of the Internet of Things (IoT), there is an opportunity to enhance conventional PFC techniques by integrating real-time data acquisition, remote accessibility, and intelligent decision-making. IoT-enabled power factor controllers can continuously monitor electrical parameters such as voltage, current, and power factor, and automatically switch capacitor banks based on real-time requirements. Moreover, these systems can transmit data to a cloud dashboard, enabling remote monitoring and diagnostics from anywhere with internet access. This paper presents the design and development of an IoT-based Power Factor Controller using the ESP32 microcontroller and PZEM-004T sensor module. The proposed system is capable of real-time monitoring, automated capacitor switching, and web-based visualization, making it a smart and cost-effective solution for improving power quality in small to medium-scale applications.

II. SYSTEM ARCHITECTURE

The proposed system consists of an ESP32 microcontroller, a PZEM-004T energy monitoring sensor, relay modules for capacitor switching, and an IoT dashboard. Voltage and current are measured and analyzed to determine the power factor. If the value falls below a set threshold, relays engage capacitors to correct it. The ESP32 handles sensor communication, control logic, and Wi-Fi-based data transmission.

III. HARDWARE IMPLEMENTATION

Key components include:

- ESP-WROOM-32 (ESP32) microcontroller
- PZEM-004T sensor for voltage, current, and PF
- 5V 2-channel and 4-channel relay modules
- Capacitor banks (2 x 5 μ F)



- 16A switch and socket for high load connections
- Arduino IDE for firmware development

Wiring ensures safe switching and accurate sensing, with isolated relay channels and regulated power supply.

IV. SOFTWARE SYSTEM

Using Arduino IDE, the ESP32 is programmed to:

- Continuously acquire data from the PZEM sensor
- Analyze power factor
- Trigger relays to switch capacitors based on PF thresholds
- Host a web interface for remote monitoring and manual control

V. CONCLUSION AND FUTURE SCOPE

This project presented the design, development, and implementation of an IoT-based power factor controller for improving the efficiency of electrical systems in small- scale environments. The controller automatically compensates for reactive power by switching capacitor banks based on real-time measurements obtained from a multifunction energy meter (PZEM-004T). The core of the system is an ESP32 microcontroller that processes data and controls capacitor switching while also uploading the data to the Arduino cloud platform for remote monitoring and analysis.

The project successfully combined the principles of power factor correction with the capabilities of modern IoT technologies. It has demonstrated that effective power quality control can be achieved using affordable hardware, intelligent programming, and cloud connectivity.

Key Achievements

- Designed a low-cost and compact IoT-based PFC system using off-the-shelf components.
- Achieved real-time power factor measurement and automatic correction using relay-controlled capacitor banks.
- Implemented cloud-based monitoring using ThingSpeak, enabling data logging and visualization of voltage, current, power, and PF trends.
- Validated the system under various load conditions, confirming PF improvement from ~ 0.72 (inductive load) to ~ 0.96 after capacitor engagement.
- Ensured safe and reliable operation, with hardware isolation, threshold-based logic, and minimal latency.
- Learning Outcomes
- Throughout this project, several core areas of engineering knowledge and practical skills were reinforced, including:
 - Embedded systems design using ESP32 and sensor integration.
 - Electrical measurement principles including power factor, real, apparent, and reactive power.
 - Relay control logic and hardware safety in AC systems.
 - Cloud communication using HTTP protocols and IoT APIs.
 - Real-time monitoring and diagnostics through IoT dashboards.
- Broader Impact and Use Cases
- This project offers a scalable and adaptable solution to the challenge of power factor management in:
 - Residential homes with heavy appliances
 - Small commercial establishments
 - Educational labs for practical learning on smart grids and IoT
 - Energy audit setups for testing load behavior
- The success of this design also lays a foundation for more advanced systems such as.
 - Three-phase correction systems
 - AI-based prediction and automation
 - Mobile app interfaces for PF control

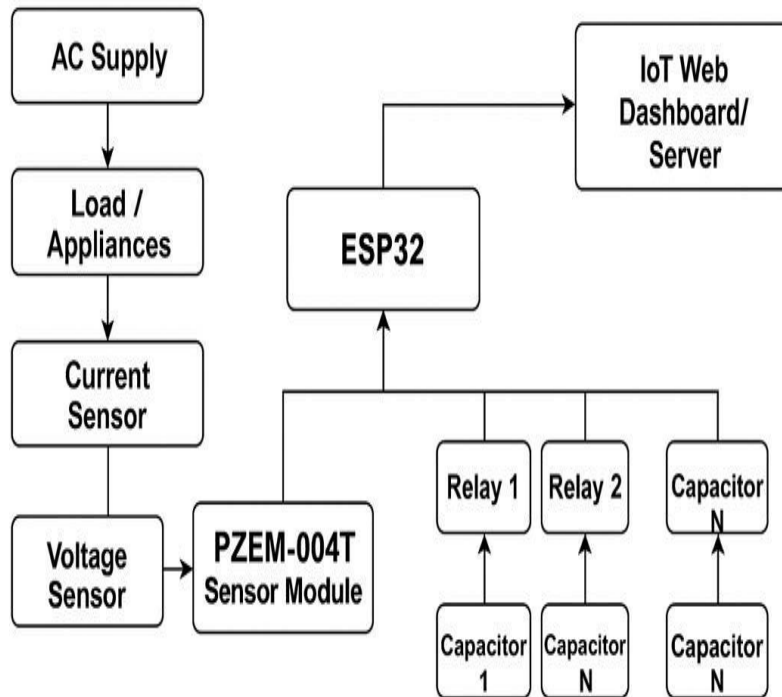


Fig. No. 1: Block Diagram of IOT-Based Power Factor Controller

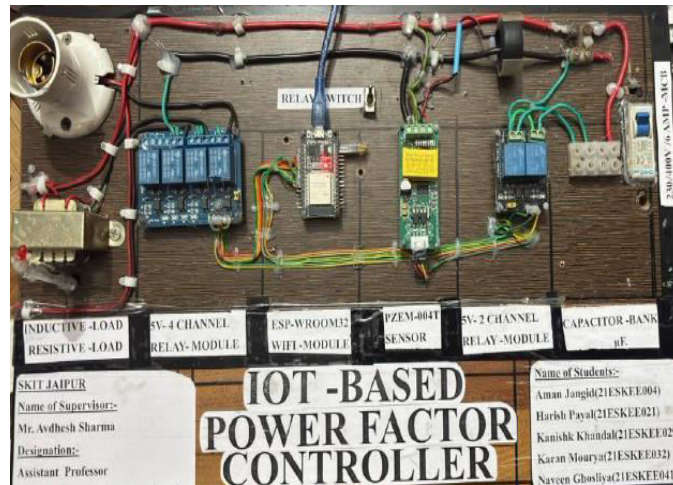


Fig. No. 1: Hardware Project

VI. RESULT

In conclusion, the IoT-Based Power Factor Controller serves as a significant step toward modernizing electrical energy management by integrating automation, intelligence, and connectivity. It proves that power factor correction, once a passive and manually managed process, can now be controlled dynamically and monitored globally all at an affordable cost.

This system paves the way for smarter, greener, and more efficient power systems, aligning with the broader vision of Industry 4.0 and smart energy infrastructure.



Load Condition	PF Before	Cap. Status	PF After
Appliance 1 only	0.98	None	0.98
Appliance 2 only	0.90	Cap. 1 ON	0.93
Appliance 2 + Cap. 1	0.93	Cap. 2 ON	0.98
Appliance 3	0.83	Cap. 1 ON	0.90
Appliance 3 + Cap. 1	0.90	Cap. 2 ON	0.97

Table No. 1: Test Results

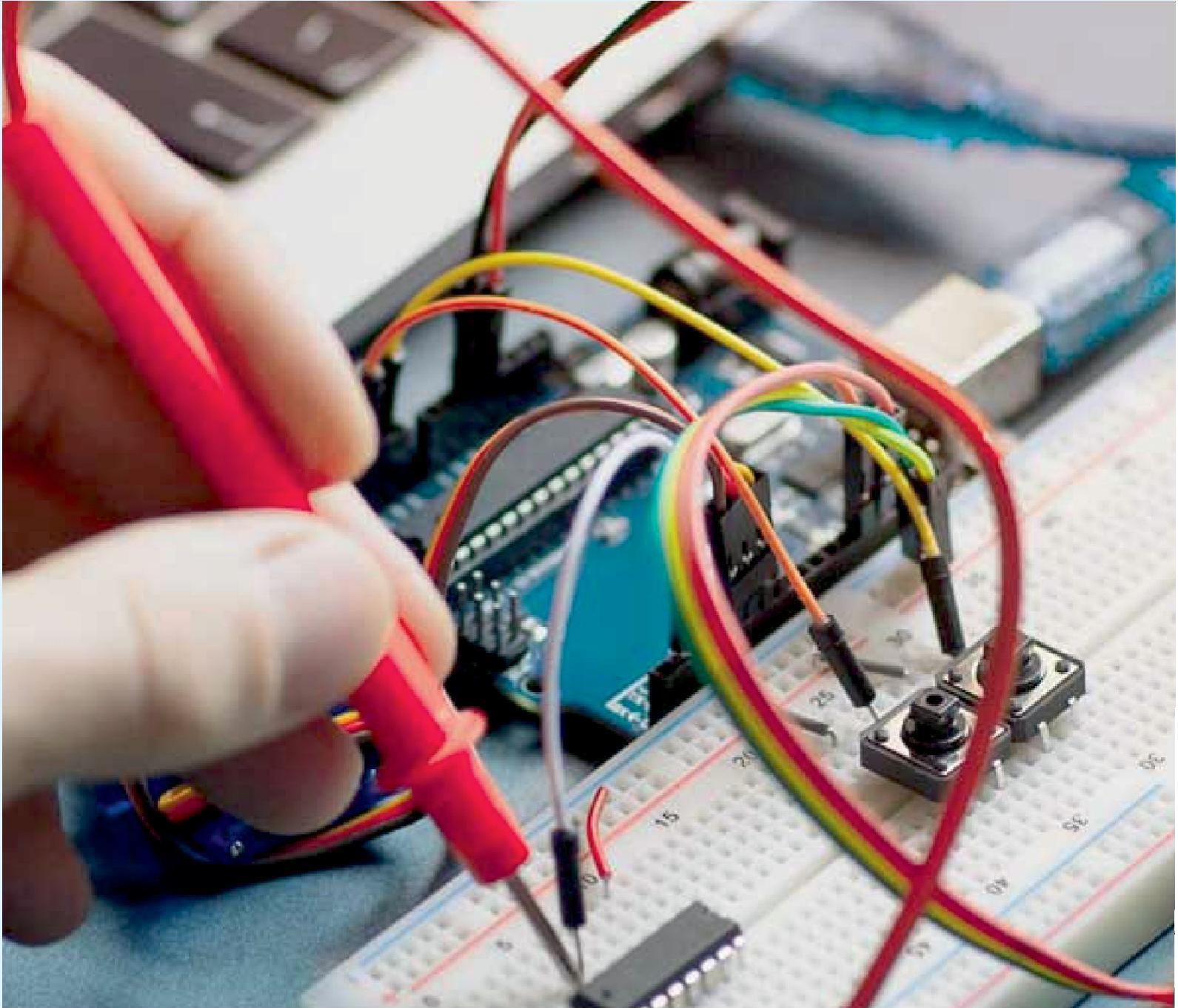
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