

ESP32-Based Smart Power Factor Correction and Load Balancing System

Mr. G. Manga Rao¹, Vannam Prasanna², Karra Bhavani³, Mannala Narendra⁴, Veeravalli Sankar Sai⁵, Vemula Sreenivasulu⁶

¹Associate Professor, Dept. of ECE, PBR VITS, Kavali, Andhra Pradesh, India.

^{2,3,4,5,6}Department of Electronics and Communication Engineering PBR VISVODAYA INSTITUTE OF TECHNOLOGY & (SCIENCE, KAVALI AUTONOMOUS) SPSR Nellore (Dt.), Andhra Pradesh – 524201

Abstract - This project represents the design and implementation of a the Power Factor Control (PFC) system using ESP-32 is designed to monitor and improve the power factor of electrical loads efficiently. The system utilizes a PZEM-004T sensor module to measure voltage, current, active power, and power factor, which are processed by the ESP-32. The measured values are displayed on an LCD screen for real-time monitoring. When the power factor falls below a present threshold, the automatically operates relays to switch corrective components, such as capacitors, into the circuit to bring the power factor closer to unity.

Key Words: Power Factor Correction (PFC) ,ESP-32 Microcontroller ,PZEM-004T Sensor ,Capacitor Bank Switching ,Relay Control ,Real-Time Monitoring ,Electrical Load Management

1. INTRODUCTION

Modern electrical systems, efficient power management is crucial to reduce energy losses, improve power quality, and ensure stable operation of electrical loads. One major challenge in power distribution is poor power factor, which leads to increased current flow, higher transmission losses, and reduced system efficiency. Another issue is uneven load distribution, which can overload certain phases or circuits, causing overheating, voltage instability, and inefficient utilization of available power sources. This project, “ESP32–Smart Power Factor Correction and Load Balancing,” aims to design and implement an intelligent system that automatically corrects the power factor and balances electrical loads using real-time monitoring and control. The ESP32 microcontroller, with its built-in Wi-Fi and Bluetooth capabilities, serves as the central processing unit, enabling both local computation and remote data visualization through IoT connectivity.

2. LITERATURE SURVEY

Kumar and Patel (2020) developed a microcontroller-based automatic power factor correction system using relay-controlled capacitor banks. The system measured voltage and current values and switched capacitors accordingly to maintain power factor close to unity. While the system improved power factor, it did not include remote monitoring features and had limited scalability. Rao and Singh (2018) proposed a system for real-time energy monitoring using embedded systems. Their work emphasized efficient data collection and display of electrical parameters. However, the system focused mainly on monitoring and did not implement automatic correction or intelligent load management. Lee and Kim (2020) introduced an improved sensing technique for electrical measurements using advanced signal processing methods. Their research enhanced the accuracy of current and voltage measurements, which is essential for calculating power factor. Despite improved accuracy, the system did not include IoT integration or automation features.

3. EXISTING SYSTEM

Traditional power factor correction methods include manual switching of capacitor banks, where operators monitor the power factor using meters and manually connect or disconnect capacitors, and fixed capacitor methods, where capacitors are permanently connected to improve power factor. Electromechanical automatic controllers use relays to switch capacitors based on measurements. Despite the development of various power factor correction systems, existing methods still have several limitations that affect their efficiency and performance. Most traditional systems rely on fixed capacitor banks or manual switching techniques, which are not suitable for dynamic load conditions. These systems cannot adjust automatically when the load changes, leading to poor power factor and increased energy losses.

4. PROPOSED SYSTEM

The proposed system is designed to develop an intelligent solution for improving power factor and balancing electrical loads using the ESP32 microcontroller. The system integrates sensing, processing, control, and communication units to achieve real-time monitoring and automatic correction. By combining hardware components with IoT technology, the system ensures efficient energy management and reliable operation. The ESP32 microcontroller acts as the central control unit of the system. It collects data from voltage and current sensors, processes the information, and controls the operation of relay modules and capacitor banks. The ESP32 is chosen due to its built-in Wi-Fi capability, high processing speed, and suitability for IoT-based applications. The system continuously measures electrical parameters such as voltage and current using appropriate sensors. Based on these values, the power factor is calculated in real time. If the power factor falls below a predefined threshold, the ESP32 automatically activates the required capacitor banks through relay switching. This compensates for reactive power and improves the power factor towards unity.

5. RESULTS



Fig 1: Real time power factor Monitoring

The fig1 represents real time power factor monitoring. This system works by continuously monitoring and controlling electrical parameters using the ESP32 and PZEM-004T. When the power supply is given, the connected loads such as the bulb and motor start operating, which may cause a reduction in power factor due to inductive effects. The PZEM sensor measures important parameters like voltage, current, power, and power factor and sends this data to the ESP32. The controller then processes the data and checks whether the power factor is below the desired level. If the power factor is low, the ESP32 automatically activates relay modules to connect capacitors into the circuit. These capacitors compensate

for reactive power and improve the power factor closer to unity.



Fig 2: Output for power factor correction

The LCD display shows the real-time electrical parameters of the system, indicating its proper operation. The voltage is displayed as 244V, which is within an acceptable range for standard supply conditions. The current is shown as 0.3A, suggesting that the connected load is relatively low. The power value, approximately 162W, represents the amount of electrical power being consumed by the load. Additionally, the power factor is indicated as 0.98, which is very close to unity, meaning the system is operating efficiently with minimal power losses. The value "P: 75" may represent the active power level, load percentage, or a specific control stage depending on the system design. Overall, the output confirms that the power factor correction system is functioning effectively and maintaining high efficiency.

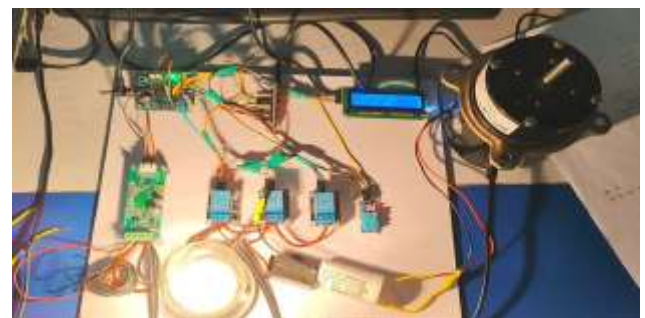


Fig 3: Load switching process Using ESP32

The load switching process using an ESP32 is carried out by continuously monitoring electrical parameters and controlling connected loads accordingly. In this system, the ESP32 reads real-time values such as voltage, current, and power factor from the sensing module (like PZEM). Based on these readings, it

analyzes whether the power factor is below the desired threshold. If the power factor decreases, the ESP32 sends control signals to the relay module, which in turn switches ON the required capacitors or loads to compensate for the reactive power. Similarly, when the power factor improves or reaches the desired level, the ESP32 deactivates the unnecessary relays, thereby switching OFF the extra capacitors or loads. This automatic switching helps in maintaining system efficiency and prevents power losses. The LCD display simultaneously shows the real-time status of voltage, current, power factor, and switching actions, ensuring proper monitoring and control of the system. The process begins with the initialization of the ESP32 microcontroller and all connected components, including the PZEM-004T sensor, LCD display, relays, and buzzer. Once the system is initialized, the PZEM sensor continuously measures electrical parameters such as voltage, current, and power factor.

6. CONCLUSION

The ESP32-Based Smart Power Factor Correction and Load Balancing System successfully demonstrates an efficient and intelligent approach to modern power management. The system is capable of continuously monitoring electrical parameters such as voltage and current, and automatically correcting the power factor by switching capacitor banks when required. This helps in reducing reactive power losses and improving overall energy efficiency. In addition to power factor correction, the system effectively balances the load across different phases, ensuring stable operation and preventing overloading. The integration of the ESP32 microcontroller enables real-time processing and control, while its built-in Wi-Fi capability allows data to be transmitted to an IoT platform for remote monitoring. The system reduces the need for manual intervention and minimizes human errors through automation. It also helps in reducing electricity costs by maintaining a high power factor and avoiding penalties imposed by power utilities. The compact design and cost-effective components make the system suitable for practical implementation in various applications. Overall, this project provides a reliable and scalable solution for energy management in modern electrical systems. It highlights the importance of combining embedded systems and IoT technologies to achieve efficient, smart, and sustainable power utilization.

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