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POWER FACTOR MONITORING AND CONTROLLING USING IOT

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ABSTRACT

This project focuses on improving the efficiency of AC electrical systems by monitoring and controlling the power factor using IoT technology with an ESP32 module. Power factor is the ratio of useful or true power (in kW) to apparent power (in kVA) consumed by electrical loads; especially inductive loads were current lags voltage. A low power factor indicates poor efficiency, causing higher power consumption, increased energy loss, and higher electricity costs. The system employs current and voltage sensors to accurately sense the electrical parameters and calculates power factor in real time. The ESP32 module displays these values on an LCD and sends the data to a cloud server for remote monitoring. When the power factor drops below a desired threshold, the system automatically triggers relay-based switching units to connect shunt capacitors, which provide leading reactive power to counteract the lagging reactive power of inductive loads. This correction reduces I^2R losses in transformers and distribution equipment, frees up extra kVA capacity from the existing supply, reduces greenhouse gas emissions due to efficient power use, and lowers electricity bills. The ESP32 microcontroller, with its dual-core architecture and built-in Wi-Fi and Bluetooth, handles real-time processing, communication, and control functions effectively. The project also includes a regulated 5V DC power supply for stable operation of sensors and control circuits. This IoT-based automatic power factor correction system enables efficient and cost-effective energy management for industrial and commercial AC loads without manual intervention. It enhances system efficiency by increasing power factor toward unity through dynamic capacitor switching, ultimately improving energy savings and reducing environmental impact.

KEYWORDS: Power Factor Correction, Inductive Load, Shunt Capacitor, Esp32 Iot Module, Current And Voltage Sensors, Relay Switching Unit

INTRODUCTION

Electric power is vital in almost all electrical systems, in industry, machines, households, power transmission and distribution, and institutional power systems. In electrical systems, there is extensive use of AC power, which contains real, apparent, and reactive power. Loads are primarily of inductive type, which provides lagging power to the system. So, there is a matter of efficiency, utilization, and electric losses. This efficiency depends on the power factor value, which has to be close to the unity power factor value to get higher efficiency. Less power factor means less efficiency and electric losses. Due to the use of various type of loads, the power factor is affected in different ways. Lagging load increases the reactance power, giving a larger angle between voltage and current phase difference. This result in a less power factor value of less than 1. If we need maximum efficiency of electric machines or power, we must maintain the power factor value close to the unity power factor. The project outlines an IoT-based power factor monitoring and correction system designed for AC inductive loads, such as those in vehicles or industrial settings, to improve efficiency by maintaining power factor close to unity (1.0). It uses an ESP32 IoT module as the central controller to sense voltage via a ZMPT107 transformer and current via a ZMCT103C transformer, calculating power factor as the cosine of the phase angle between waveforms and displaying values on an LCD while transmitting data to a cloud server like Blynk for remote monitoring.

MATERIALS AND METHODS:

LITERATURE SURVEY

[1] Snehal Mane et al. (2020) "Microcontroller-Based Automatic Power Factor Correction System for Power Quality Improvement". This study highlights the significance of power quality in industrial and utility applications. Power factor is identified as a key parameter affecting system efficiency and energy losses. Increased reactive power demand leads to a reduction in power factor, thereby decreasing overall system performance. The authors propose a digitally controlled Automatic Power Factor Correction (APFC) system using a microcontroller that automatically switches capacitor banks when the power factor falls below a predefined threshold (0.92). The proposed approach effectively reduces losses and enhances power quality. [2] Md. Sajidur Rahman et al. (2022) "Automatic Power Factor Measurement and Improvement Using Capacitor Bank" This paper presents an automatic power factor measurement and correction system using current transformers (CTs) and potential transformers (PTs). Zero-crossing detection circuits are employed to determine the phase difference between voltage and current. The resulting signal is processed through logic circuitry to control relay-operated capacitor banks. The system dynamically compensates reactive power based on load conditions, improving the overall power factor.[3] Kudarat Kumar Joshi et al. (2020) "Precise Improvement of Power Factor with Hybrid System Using APFC and STATCOM" The authors address the increasing complexity of modern power systems caused by rising inductive loads and variable demand. These factors significantly degrade power factor and increase transmission losses. A hybrid solution combining Automatic Power Factor Correction (APFC) and STATCOM is proposed to provide precise reactive power compensation. The approach improves system efficiency and reduces power losses under varying load conditions. [4] Chaman Lal Dewangan et al. (2019) "Automatic Power Factor Controller in Low Voltage Residential Distribution System with High Solar Power Generation" This research focuses on reactive power compensation in low-voltage residential distribution networks with high solar penetration. Capacitor banks installed near load points reduce losses in distribution networks and transformers while improving voltage profiles. A PIC microcontroller-based APFC system is proposed to automatically control capacitor switching according to power factor variations. [5] Mayuri B. Gawande et al. (2024) "Power Factor Correction Using PLC" This paper discusses power factor degradation caused by inductive industrial loads, particularly high-power three-phase motors. While fixed capacitors can improve power factor, varying load conditions require adaptive control. The authors propose a Programmable Logic Controller (PLC)-based power factor correction system that dynamically adjusts capacitor switching to maintain an optimal power factor. [6] V. Govindaraj et al. (2024) "Automated Power Factor Correction and Predictive Energy Monitoring Using Machine Learning" This work introduces an advanced APFC system integrated with machine learning for predictive energy monitoring. Power factor is defined as the ratio of real power (kW) to apparent

Objectives

1. To design and develop an automated system capable of continuously monitoring the power factor in real-time for electrical loads.
2. To implement IoT technology (using ESP32) for wireless transmission of power factor data to enable remote monitoring and control.
3. To accurately measure voltage and current using current transformers and voltage transformers for precise power factor calculation.
4. To automate the correction process by switching appropriate shunt capacitor banks via relay control, improving the power factor towards unity.
5. To reduce power losses and improve energy efficiency by maintaining an optimal power factor, thereby minimizing electricity costs and penalties.
6. To provide a local display unit (LCD) for real-

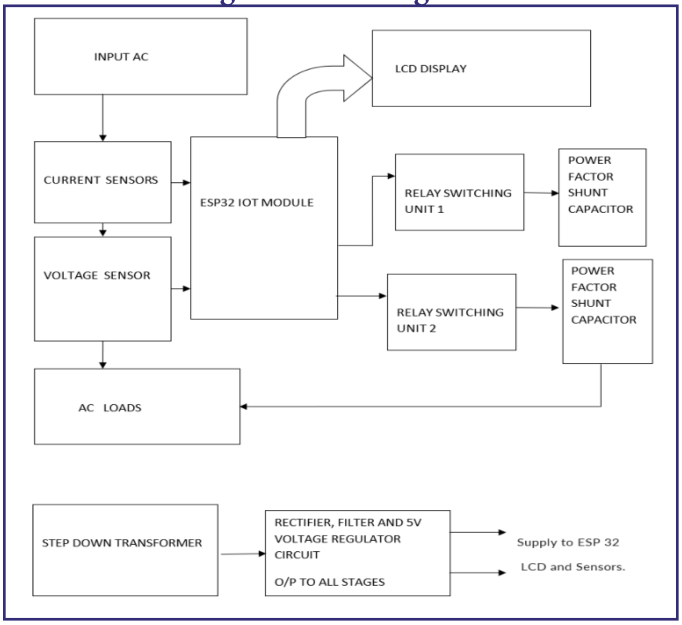
time visualization of electrical parameters and system status.

7. To enhance system reliability and accuracy through proper power supply regulation, sensor calibration, and robust control algorithms.
8. To demonstrate the applicability of the system for industrial and commercial settings with varying inductive loads.

METHODOLOGY

System Architecture

Fig. 1: Block Diagram



1. Real-Time Sensing of Electrical Parameters: The system employs current transformers (CT) and voltage transformers (PT or VT) to measure load current and supply voltage. These devices convert electrical signals to safe, measurable levels and provide accurate data on waveform characteristics. The microcontroller (ESP32 or Arduino) reads these sensor outputs to determine the instantaneous voltage and current values.
2. Power Factor Calculation: Power factor (PF) is the cosine of the phase angle between voltage and current waveforms. The microcontroller analyzes the waveform phase difference to calculate PF continuously. Real-time computation allows for immediate detection of low power factor conditions, indicating inefficient energy usage typically caused by inductive loads.
3. Decision Making and Threshold Comparison: The system compares the measured PF with a predefined reference threshold (e.g., 0.85 or 0.95). If the PF is below the threshold, indicating poor power quality, the system triggers corrective actions. If the PF is acceptable, the system continues monitoring without switching capacitors.
4. Capacitor Bank Switching for Correction: Correction is achieved by switching one or more capacitors in parallel with the load. Relays or solid-state switches (e.g., IGBTs) controlled by the microcontroller connect/disconnect capacitor banks. Each capacitor bank corresponds to a discrete reactive power compensation step, allowing incremental correction. The system sequentially switches capacitors on or off to raise the PF towards unity, minimizing reactive power and losses.
5. Display and Remote Monitoring via IoT: The system includes an LCD or similar display for local visualization of voltage, current, power factor, power. Using its built-in Wi-Fi, the ESP32 module uploads data to cloud platforms (e.g., Blynk), enabling remote monitoring and control. Remote control through the IoT interface enables users to manually switch capacitor banks and adjust system settings from anywhere, providing flexible power factor correction.

DESCRIPTION OF COMPONENTS

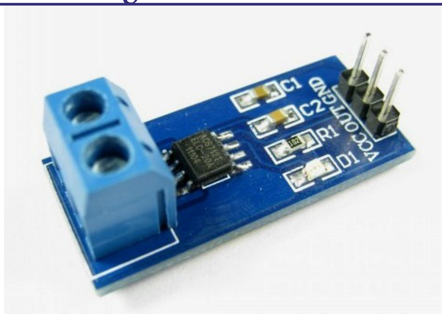
1. ESP32 (Espressif32)

Fig. 2: ESP32

The ESP32 is a low-cost, energy-efficient microcontroller family with integrated Wi-Fi and Bluetooth capabilities, designed primarily for IoT applications. It features various processors including dual-core and single-core Tensilica Xtensa LX6, LX7 CPUs, or a single-core RISC-V, combined with several peripherals and low power management modules.

2. ACS 712 Current Sensor

Fig. 3: ACS 712



The ACS712 Current Sensors offered on the internet are designed to be easily used with micro controllers like the Arduino. These sensors are based on the Allegro ACS712ELC chip. These current sensors are offered with full scale values of 5A, 20A and 30A. The basic functional operation of each of these devices is identical

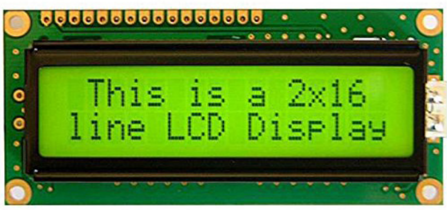
3. ZMPT107 | AC Voltage Sensor

Fig. 4: ZMPT107

This AC Voltage Sensor is the low-cost solution to solve all the above problems. If you want to measure AC voltage and have size limitations, this is best low cost and high precision Voltage Transducer for PCB Mounting. This module makes it easy to measure AC voltage up to 1000 volts without any noise. Its size is slightly smaller than ZMPC101B.

4. LCD 16*2

Fig. 5: LCD



We come across LCD displays everywhere around us. Computers, calculators, television sets, mobile phones, digital watches use some kind of display to display the time. An LCD is an electronic display module which uses liquid crystal to produce a visible image. The 16×2 LCD display is a very basic module commonly used in DIYs and circuits. The 16×2 translates o a display 16 characters per line in 2 such lines. In this LCD each character is displayed in a 5×7 pixel matrix.

5. Electromagnetic Relay

Fig. 6: Relay

The relay consists of the electromagnetic coil as shown in the figure. Whenever the electromagnetic coil gets the supply the coil energies because Of the electromagnetic induction. As the coil energies it at because Of common Contact, common contact will be closed with respect to NO contact.

6. Capacitors

Fig. 7: Capacitor

Capacitor banks improve power factor in AC systems by providing leading reactive power that compensates for the lagging reactive power caused by inductive loads like motors and transformers. Inductive loads cause the current to lag behind the voltage, resulting in a poor power factor. Capacitors, when connected in parallel with such loads, generate a leading current that offsets this lagging current, thereby reducing the phase difference between current and voltage and improving the overall power factor toward unity.

7. Chock Coil

Fig. 8: Chock Coil

A choke coil is an inductor designed to block high-frequency alternating current (AC) while allowing direct current (DC) and lower-frequency AC to pass through with little resistance. It works on the principle of self-induction, where the coil creates a magnetic field that opposes changes in current, effectively "choking" high-frequency signals. This makes it useful in filtering AC signals and for voltage regulation in AC circuits without wasting energy as heat, unlike a resistor.

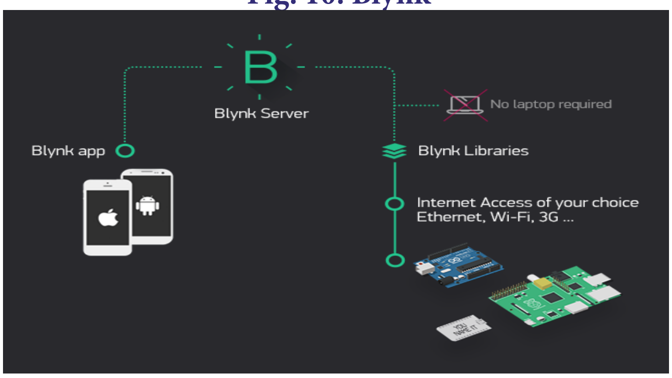
8. Load

Fig. 9: Bulb

An incandescent light bulb, a traditional type of electric lamp used for general lighting in homes and other places. An incandescent bulb has a thin tungsten filament sealed inside a glass bulb that is either evacuated or filled with inert gas such as argon or nitrogen. When current flows through the filament, it heats up to a high temperature and glows, producing light along with a lot of heat.

9. Blynk

Fig. 10: Blynk



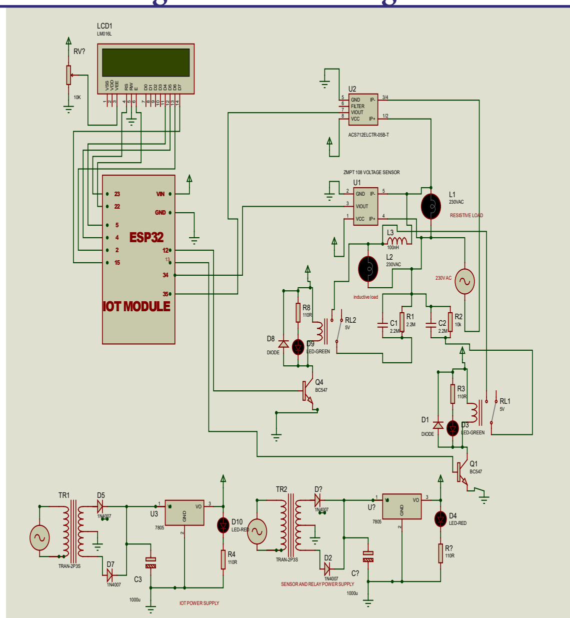
Blynk is a low-code IoT (Internet of Things) platform that helps developers and businesses quickly build, deploy, and manage connected products by providing tools for mobile apps, web consoles, cloud infrastructure, and device management, all with drag-and-drop interfaces and minimal coding, allowing you to control hardware remotely and scale IoT solutions from prototypes to millions of devices.

Circit Diagram

Power factor correction (PFC) is a technique used to reduce the lagging power factor in inductive loads by connecting a high-value capacitor across the phase and neutral close to the load. When voltage and current are in phase, the power factor is unity and electrical energy is efficiently converted into useful work. A reduction in power factor increases current demand and system losses; for instance, a drop from unity to 0.9 increases current by about 15%, while a power factor of 0.7 increases power requirement by nearly 40%.

Inductive loads such as motors, refrigerators, and inverters cause current to lag behind voltage, resulting in a lagging power factor. This can be compensated by capacitors that provide leading reactive power. In this system, voltage and current are monitored using potential transformer and ACS712 sensors interfaced with an ESP32 IoT module. The ESP32 calculates the power factor and displays it on an LCD. If the power factor falls below 0.7, a relay connects a 2.2 μF capacitor across the load to improve it, with parameters monitored via the Blynk cloud platform.

Fig. 11: Circuit Diagram



IMPLEMENTATION AND DESIGN

FLOW CHART:

The given flowchart explains the operational sequence of an ESP32-based power factor monitoring and correction system with IoT (Blynk). The working is described step by step as follows:

1. Start: process begins when power is supplied to the system.
2. Setup / Initialization: In this stage, the ESP32 initializes all required modules such as serial communication, Wi-Fi connection, voltage and current sensors, LCD display, and relay modules. This ensures that all hardware and communication interfaces are ready for operation.
3. Main Loop Execution: After initialization, the program enters the continuous loop where the Blynk platform and timer functions are executed repeatedly. This allows real-time monitoring and periodic data updates.
4. Timer Event: At predefined time intervals, a timer event is triggered. During this event:
   - Voltage and current values are read from the sensors.
   - Electrical parameters such as active power, reactive power, apparent power, and power factor are calculated.
   - The calculated values are updated on the LCD display.
   - Data is printed to the serial monitor for debugging and logging.
   - The same data is sent to the Blynk cloud using virtual pins for remote monitoring.
5. Sensor Readings: The voltage and current sensors continuously measure electrical parameters from the load and feed the data to the controller.
6. Power Calculation: Using the sensed values, the system computes real power, reactive power, apparent power, and power factor.
7. Display Update: The LCD displays real-time voltage, current, power, and power factor values for local monitoring.
8. Serial Print: All measured and calculated data are logged to the serial monitor for analysis and troubleshooting.
9. Blynk Communication: The ESP32 transmits data to the Blynk cloud server, allowing the user to view parameters and control relays remotely via a mobile application.
10. End / Repeat Cycle: The cycle completes and repeats continuously, ensuring real-time monitoring and control.

Fig. 12: Flowchart of the System

RESULTS

The developed IoT-based power factor monitoring and controlling system successfully measures the voltage and current of an AC inductive load, calculates the power factor in real time, and automatically switches a shunt capacitor to improve it when required. Using the ACS712 current sensor and a potential-transformer voltage sensor interfaced to the Node MCU/ESP controller, the prototype reliably identifies conditions where the power factor drops below about 0.7 and then energizes the relay to connect a 2.2 μF correction capacitor across the load, after which the measured power factor returns to the desired range of 0.8–1.0 as shown on the LCD and in the cloud dashboard. Experimental runs confirm that, once the capacitor bank is engaged, the load draws less current for the same power, validating that the system reduces reactive power and is suitable for application on small industrial or commercial inductive loads while providing convenient remote monitoring through Blynk.

Fig. 13: Prototype

DISCUSSION

Discussion section should focus on the interpretation of the results with proper justification. The Results and Discussion sections may be combined into one section.

CONCLUSIONS: (OPTIONAL)

The implemented IoT-based power factor correction (PFC) prototype demonstrates reliable performance for real-time monitoring and correction of power factor in inductive AC loads, making it well suited as a robust academic and laboratory system rather than a metering-grade industrial solution. Using an ESP32 controller with ZMPT107 voltage sensing and ACS712 current sensing, the system can continuously acquire voltage and current waveforms, estimate the power factor from their phase difference, and automatically switch shunt capacitor banks via relays to improve the power factor toward unity, thereby reducing reactive power demand and line current. The ZMPT107 provides isolated, linear voltage measurement in the 50–60 Hz range with class 0.2 accuracy, while the ACS712 offers low-loss, bidirectional current measurement up to ±30 A, although noise and temperature drift require software filtering and calibration to achieve stable readings. Power factor computation is conceptually accurate, but practical precision is limited by sensor phase shifts and ADC constraints, so the system attains acceptable performance for prototypes but not utility billing applications. Relay-based capacitor switching successfully enhances power factor and cuts losses, though mechanical relays introduce slower response, finite lifetime, and possible inrush stress if switching is too frequent. Overall, the ESP32 provides ample processing capacity for measurement, LCD display, and Blynk-based IoT cloud updates, with local correction continuing even when Wi-Fi connectivity is poor, making the system efficient, economical, and effective for educational, domestic, and small-scale industrial demonstrations

TABLES AND FIGURES:

Table 1: Result Table

S.no	Load Type	PF when 0 CB On	PF when 1 CB On	PF when 2 CB on
1	Resistive load	0.84	0.84	0.84
2	Inductive load	0.46	0.58	0.82

Fig. 14: Resistive load

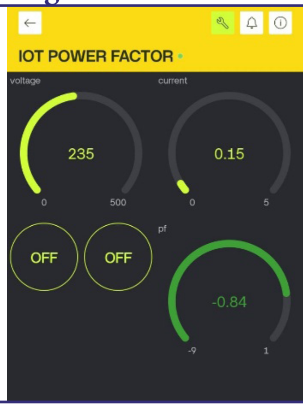


Fig. 15: Inductive lode

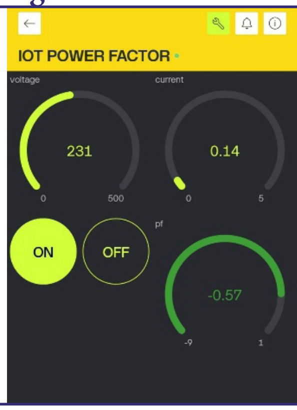
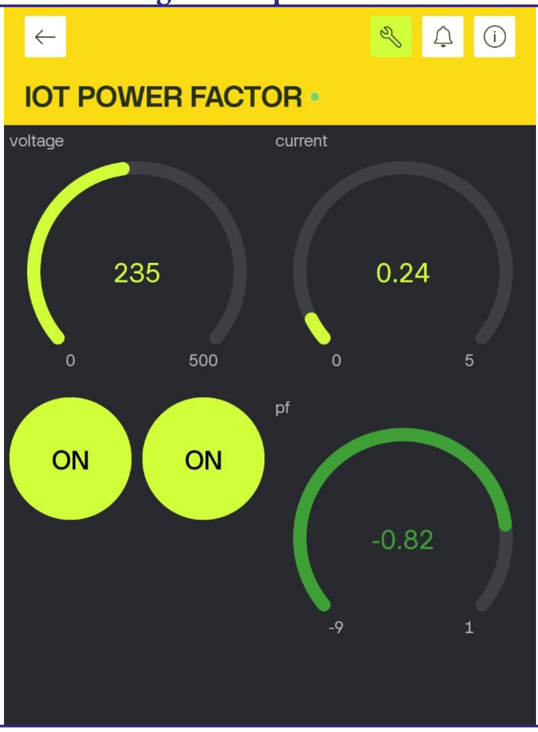


Fig. 16: Improved PF



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