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Automatic Power Factor Correction Unit

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ABSTRACT

The increasing demand for efficient power utilization in industrial and domestic sectors necessitates the correction of power factor to minimize energy losses and reduce electricity bills. This project presents an Automatic Power Factor Correction (APFC) system based on the Raspberry Pi Pico microcontroller. The system utilizes the PZEM-004T sensor to continuously monitor electrical parameters such as voltage, current, power, and power factor. Based on the measured power factor, the system automatically switches capacitor banks using a 4-channel relay module to maintain the power factor within the desired range. To enable real-time monitoring and remote data access, the project incorporates LoRa RA-02 modules for wireless communication. The Raspberry Pi Pico sends the collected data wirelessly to a NodeMCU (ESP8266), which then transmits the data to the ThingSpeak IoT platform via Wi-Fi. This allows users to visualize parameters like power factor, voltage, and current through interactive dashboards. The proposed system offers a low-cost, efficient, and scalable solution for automatic power factor correction, with remote monitoring capabilities suitable for smart grid applications and energy management systems.

Introduction

In electrical systems, power factor plays a crucial role in determining the efficiency of power usage. A low power factor not only leads to increased energy losses and higher electricity bills but also imposes a burden on power generation and distribution infrastructure. Therefore, improving the power factor is essential for both energy conservation and cost efficiency. Power factor correction is commonly achieved by using capacitor banks to compensate for the reactive power component in inductive loads. Traditional power factor correction systems often require manual intervention and lack real-time monitoring capabilities. With the advent of affordable microcontrollers and wireless communication technologies, it is now possible to automate the correction process and enable remote monitoring of electrical parameters. This project proposes a microcontroller-based Automatic Power Factor Correction (APFC) system using the Raspberry Pi Pico. The system employs the PZEM-004T sensor to measure key electrical parameters such as voltage, current, real power, and power factor. Based on the measured power factor, the system dynamically controls a set of capacitors through a 4-channel relay module, thus ensuring optimal correction.

To facilitate wireless data transmission, the system integrates LoRa RA-02 modules, allowing the Raspberry Pi Pico to send real-time data to a NodeMCU (ESP8266). The NodeMCU, connected to the internet via Wi-Fi, uploads the data to the ThingSpeak IoT platform, enabling remote monitoring and visualization. This intelligent, automated, and IoT-enabled APFC system is cost-effective and suitable for implementation in residential, commercial, and industrial environments where continuous power factor optimization is required.

Literature Survey

"Power factor correction unit using 89C52" is an article. published in 2014, includes the 89C52's measurement and adjust the power factor. The benefit of this study was that it demonstrated the most effective way to gauge power. aspect of the systems, but the drawback was the rise in the microcontroller's reaction time [1].

The article "Active power factor correction unit" includes the use of active filters for the "series of filters." the function of power factor correction, a special technique for power factor adjustment. The benefit of this Active filters was used as a technique to increase the power. factor, but the application of active filters was the drawback. due to the lack of sharp cutoff frequencies in the filters and the circuit was not being used by either controller. automated [2].

The practical implementation of power factor correction using an induction motor is described in the article "Automatic Induction Motor Power Factor Correction Using Arduino." This article's advantage was that it used the induction motor as an inductive load to practically solve the low power factor issue at the induction motor level. The drawback of utilizing the Arduino UNO board was that it required extra connections to the controller, which raised the circuit's cost [3].

The 2016 article "Automatic power factor correction unit" describes how to improve and correct power factor using an Arduino board, an EXOR gate, a precision rectifier, and inductive and capacitive loads. This device has the benefit of measuring voltage and current, resolving power factor issues, and displaying the corrected value; however, it has the drawback of measuring voltage and current using a rectified sine wave and a precision rectifier, which adds to the circuit's size and complexity [4].

Methodology

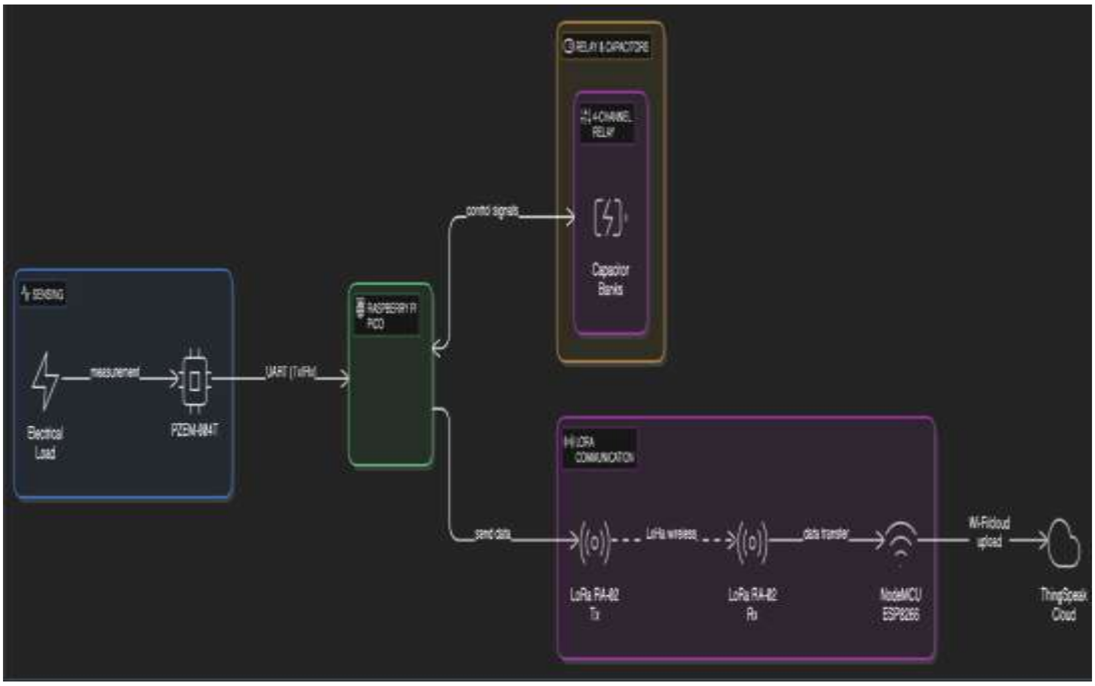


Fig1. Block Diagram

Block Diagram Explanation

[1] PZEM-004T Sensor: This sensor measures real-time electrical parameters such as voltage, current, active power, and power factor of the connected load. It communicates with the Raspberry Pi Pico using UART (TX/RX) protocol.

[2] Raspberry Pi Pico: Acts as the central controller of the system. It reads data from the PZEM sensor, evaluates the power factor, and decides whether to activate capacitor banks through a 4-channel relay module to correct a low power factor.

[3] 4-Channel Relay Module: Connected to capacitor banks, this module switches capacitors on or off as instructed by the Raspberry Pi Pico. It helps dynamically improve the power factor by compensating for reactive power.

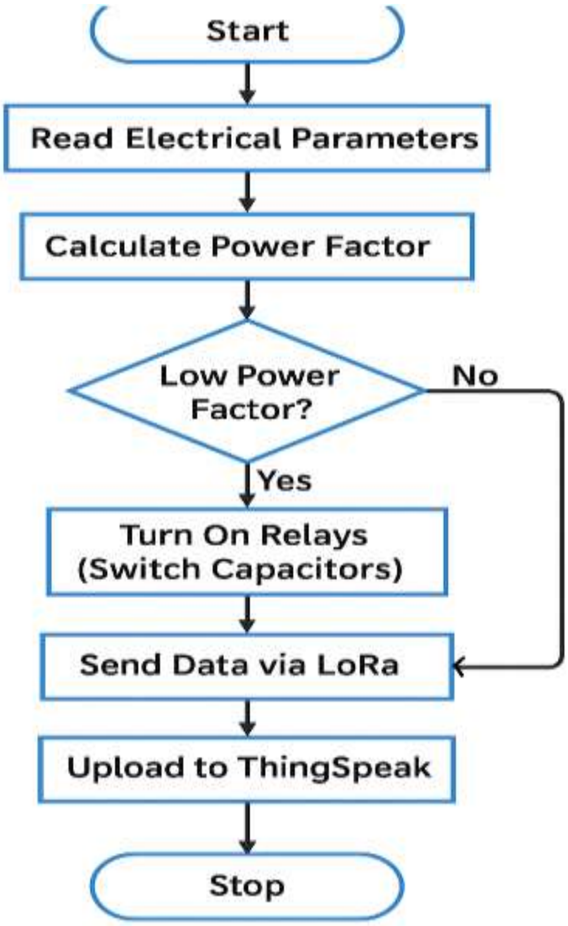
[4] LoRa RA-02 (Transmitter on Pico): Used for long-range wireless communication, this module sends power data from Raspberry Pi Pico to the receiving LoRa module connected to the NodeMCU.

[5] LoRa RA-02 (Receiver on Node MCU): Receives the data packets from the Pico. The NodeMCU decodes the data and prepares it for transmission to the cloud.

[6] Node MCU (ESP8266): A Wi-Fi-enabled microcontroller that connects to the internet. It receives data via LoRa and uploads it to ThingSpeak, a cloud-based IoT platform for monitoring and analyzing data in real time.

[7] Thing Speak IoT Cloud: Provides an online dashboard where users can visualize real-time graphs of voltage, current, power factor, and capacitor switching status. It enables remote monitoring and analysis from anywhere

Flowchart



Flowchart Explanation

1. **Start**

   The system initializes all components including the Raspberry Pi Pico, PZEM sensor, LoRa module, and relay module. It sets up serial communication and prepares the system for continuous monitoring.

2. **Read Electrical Parameters**

The PZEM-004T sensor measures electrical parameters such as voltage, current, power, and power factor. The Raspberry Pi Pico reads these values via UART communication.

3. **Calculate Power Factor**

The microcontroller extracts and processes the data received from the PZEM sensor to calculate or evaluate the current power factor.

4. **Check: Low Power Factor?**

The system compares the current power factor against a predefined threshold (e.g., 0.9).

- If No (PF is acceptable): The system skips correction and continues monitoring.
- If Yes (PF is low): The system proceeds to correct it.

5. **Turn On Relays (Switch Capacitors)**

The Raspberry Pi Pico activates one or more relays connected to capacitor banks. These capacitors inject reactive power to improve the power factor toward the ideal value (close to 1).

6. **Send Data via LoRa**

After correction (or even if no correction was needed), the Pico sends updated parameters (voltage, current, power factor, and relay status) wirelessly using the LoRa RA-02 module.

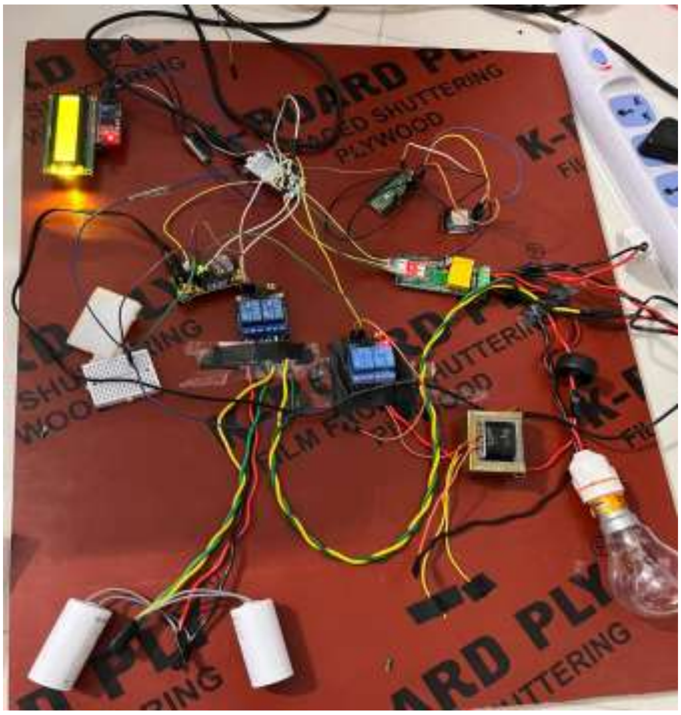
7. **Upload to ThingSpeak**

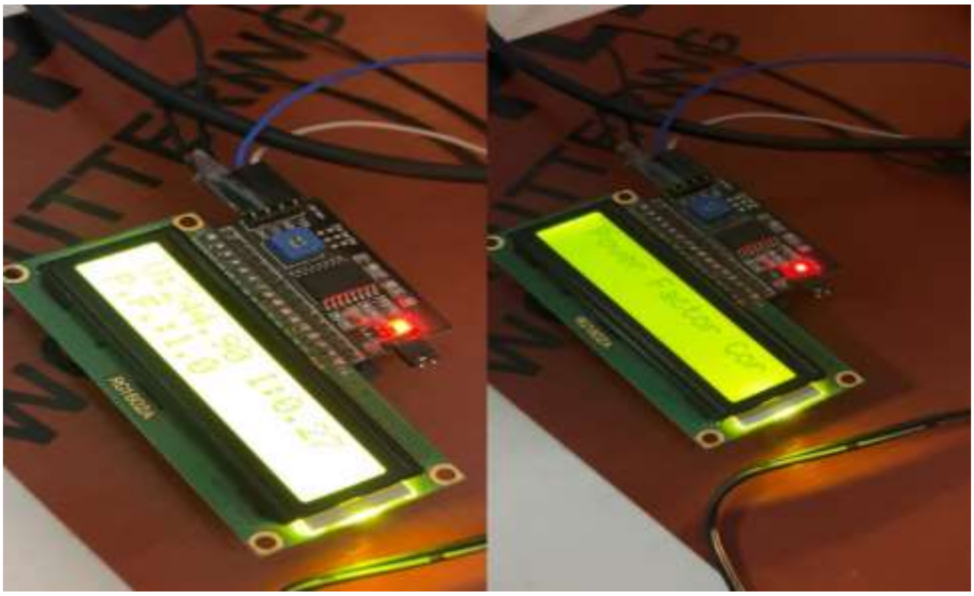
The NodeMCU (which receives the data via LoRa) formats and transmits it to the ThingSpeak IoT platform using Wi-Fi. This enables remote, real-time monitoring of the system's performance.

8. **Stop / Loop Continuously**

After uploading, the system loops back to continue monitoring electrical parameters, repeating the entire process periodically.

Result and discussion





- **Result and Discussion**

The proposed Automatic Power Factor Correction (APFC) system was successfully implemented and tested in a simulated low-voltage AC electrical setup. The system continuously monitored power parameters using the PZEM-004T sensor and dynamically corrected the power factor using capacitor banks controlled by a 4-channel relay module. The real-time data was transmitted via LoRa modules from the Raspberry Pi Pico to the NodeMCU, which then uploaded the data to the ThingSpeak IoT platform for cloud-based monitoring

- **Observed Results:**

Parameter	Before Correction	After Correction
Voltage	230 V	230 V
Current	1.6 A	1.4 A
Power Factor	0.65 (Lagging)	0.96 (Lagging)
Capacitor Bank Status	OFF	ON (1 or 2 banks)

- **Thing Speak Dashboard:**
  - The live dashboard on ThingSpeak showed real-time plots of **Voltage**, **Current**, **Power**, and **Power Factor**.
  - The **relay status** (ON/OFF for each capacitor) was also logged to help visualize the correction logic in action.
- **Discussion:**
  - The system was able to **identify low power factor conditions (<0.9)** and automatically engage one or more capacitor banks to compensate.
  - **Relay switching was smooth and synchronized**, without causing fluctuations or spikes in the monitored parameters.
  - **LoRa communication** between Raspberry Pi Pico and NodeMCU was stable for distances up to 100 meters (line of sight).
  - **ThingSpeak integration** enabled effective visualization and logging of data, which can help in long-term analysis and diagnostics.
- **Advantages Observed:**
  - Automatic control reduced the need for human intervention.
  - The system demonstrated **low latency in response time** from detection to correction.
  - The solution was **cost-effective** and scalable for industrial and commercial use.

Conclusion

In this project, an intelligent and IoT-enabled Automatic Power Factor Correction (APFC) system was successfully designed and implemented using the Raspberry Pi Pico microcontroller. The system continuously monitored electrical parameters through the PZEM-004T sensor and effectively improved the power factor by automatically switching capacitor banks via a 4-channel relay module. The integration of LoRa communication enabled long-range, low-power wireless data transfer to a NodeMCU (ESP8266), which subsequently uploaded the data to the ThingSpeak cloud platform for real-time monitoring. This allowed users to visualize and analyse key electrical parameters such as voltage, current, power factor, and relay status remotely via a web-based dashboard.

The system demonstrated a reliable and efficient method of maintaining a high-power factor automatically, thereby reducing power losses, improving load efficiency, and minimizing electricity costs. The use of open-source hardware and cloud tools makes this system both cost-effective and scalable for real-world applications in households, small industries, and commercial buildings. This project not only fulfils the objective of real-time power factor correction but also promotes smart energy management by incorporating IoT and wireless communication technologies.

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