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IoT Based Energy Monitoring System

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Abstract – *This paper presents an IoT-Based Energy Monitoring and Control System using ESP32 and PZEM-004T sensor for real-time electrical parameter monitoring. The system measures voltage, current, power, and energy consumption and displays the data on an LCD display as well as on the ThingSpeak cloud platform through Wi-Fi connectivity. A relay module is integrated for remote load control using a mobile application. The proposed system enables real-time monitoring, cloud data storage, graphical analysis, and remote access for efficient energy management. The project helps reduce electricity wastage and supports smart home and smart campus applications.*

This paper presents an IoT-Based Energy Monitoring and Control System using ESP32 and PZEM-004T sensor for real-time electrical parameter monitoring. The system measures voltage, current, power, and energy consumption and displays the data on an LCD display as well as on the ThingSpeak cloud platform through Wi-Fi connectivity. A relay module is integrated for remote load control using a mobile application. The proposed system enables real-time monitoring, cloud data storage, graphical analysis, and remote access for efficient energy management. The project helps reduce electricity wastage and supports smart home and smart campus applications.

The system also provides continuous monitoring of electrical loads and helps users analyze power consumption patterns effectively. The integration of IoT technology improves automation, reliability, and user convenience. The proposed solution is low-cost, user-friendly, and suitable for residential, industrial, and educational energy management applications.

INTRODUCTION

Nowadays, electricity consumption is increasing rapidly due to the growing use of electrical and electronic devices in homes, industries, colleges, and commercial buildings. Efficient energy monitoring and management have become very important to reduce electricity wastage and improve energy utilization. Traditional energy meters only provide basic readings and do not support real-time monitoring, remote access, or automatic control of electrical appliances. Therefore, there is a need for a smart and automated energy monitoring system.

The Internet of Things (IoT) technology provides an effective solution for smart energy management by enabling real-time monitoring and remote access through the internet. This project presents an IoT-Based Energy Monitoring and Control System using ESP32 and PZEM-004T sensor. The system continuously measures electrical parameters such as voltage, current, power, and energy consumption and displays the readings on an LCD display as well as on the ThingSpeak cloud platform.The ESP32 microcontroller is used as the main processing unit because of its built-in Wi-Fi capability and IoT support. The measured data is uploaded to the cloud platform for real-time monitoring and graphical analysis. A relay module is also integrated into the system for remote ON/OFF control of electrical loads through a mobile application. The proposed system helps improve energy efficiency, supports smart automation, and provides a low-cost and user-friendly solution for smart homes, industries, and smart campus applications.

LITERATURE REVIEW

Traditional energy monitoring systems provide only basic electricity readings and do not support real-time monitoring or remote access. With the development of IoT technology, smart energy monitoring systems have become more efficient and automated. Many researchers have developed IoT-based systems using microcontrollers such as Arduino, ESP8266, and ESP32 for monitoring electrical parameters remotely.

Cloud platforms like ThingSpeak are widely used for real-time data storage and graphical analysis, while sensors such as PZEM-004T are used for accurate measurement of voltage, current, power, and energy consumption. Relay modules are also used for remote control of electrical appliances. The proposed project combines ESP32, PZEM sensor, LCD display, relay module, and ThingSpeak platform to provide a low-cost, real-time, and smart energy monitoring solution.

This system helps improve energy efficiency and reduces electricity wastage through continuous monitoring and smart control. The integration of IoT technology enables users to access real-time electrical data remotely using mobile phones or computers. The proposed solution is simple, cost-effective, and suitable for smart home and smart campus applications.

METHOLOGY

The proposed IoT-Based Energy Monitoring System is developed using ESP32, PZEM-004T sensor, LCD display, relay module, and ThingSpeak cloud platform. The PZEM sensor continuously measures electrical parameters such as voltage, current, power, and energy consumption from the connected load. The measured data is sent to the ESP32 microcontroller through UART communication using TX and RX pins.

The ESP32 processes the received data and displays the real-time readings on the LCD display for local monitoring. The ESP32 also connects to Wi-Fi and uploads the measured data to the ThingSpeak cloud platform for remote monitoring and graphical analysis. A relay module is integrated into the system to control the electrical load remotely through a mobile application.

The complete system enables real-time monitoring, cloud data storage, remote access, and smart energy management using IoT technology.

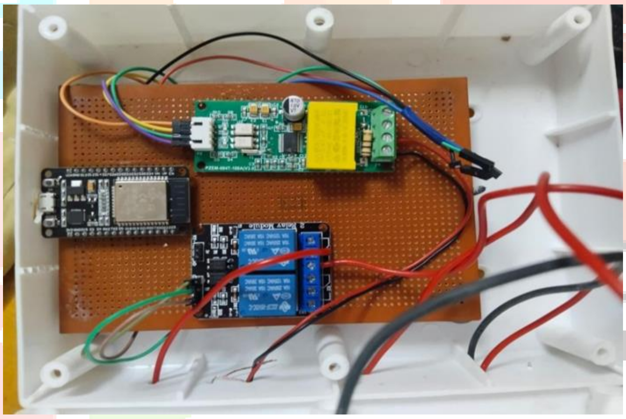

Fig. 1- Project Interfac

Hardware Setup

The implementation first consisted of carefully assembling all components onto a prototype platform and wiring them, with much attention to electrical safety and reliable data communication.

Component Mounting and Power Wiring. This will be assembled around the ESP32 development board, which acts as the control center. Key peripheral modules include the PZEM-004T energy meter, the PIR sensor, and the Relay module. These have been positioned for maximum safety, the high-voltage AC parts have been kept away from the low-voltage logic circuitry.

Power Rail: The common 5V rail is created using a single 5V DC Power Adapter. This rail powers the ESP32 via its VIN pin, the PZEM-004T VCC, PIR VCC, and the relay coil. All component Ground (GND) connections are tied to the ESP32's ground in order to establish a single, common reference point for all digital and power signals. This is crucial for accurate communication.

Firmware Development Environment: The software controlling the system was implemented using the Arduino IDE, an open-source environment used for embedded C++ programming. This platform was chosen due to its extensive library support for the ESP32 and ease of integration with cloud APIs.

Core Libraries and Dependencies:

The system relies on several essential libraries to manage its multi-layered operations:
WiFi.h: Manages the connection between the ESP32 and the local wireless network.
PZEM004Tv30.h: A manufacturer-provided library that allows for robust retrieval of electrical metrics via UART.
PubSubClient.h: Enables the MQTT (Message Queuing Telemetry Transport) protocol for lightweight, low-latency data transmission to the cloud.
LiquidCrystal_I2C.h: Facilitates communication with the LCD display using only two pins (SDA/SCL).
System Logic and Algorithm: The program follows a cyclic execution model designed for real-time sensing and response control. This is divided into two primary stages:
Setup and Initialization

During the setup() phase, the system performs a one-time configuration:
GPIO Configuration: Pins IO12 (Relay) and IO4 (PIR) are initialized as output and input, respectively.
Serial Communication: UART ports are opened to communicate with the PZEM-004T energy meter.
Network Handshake: The ESP32 establishes a secure, persistent connection to the Wi-Fi network and the chosen cloud dashboard (ThingSpeak or Blynk).

The Infinite Loop (Main Cycle) Once initialized, the loop() function executes the core logic continuously:
Data Acquisition: The system polls the PZEM-004T for voltage, current, power, and energy metrics.
Occupancy Processing: The PIR sensor is scanned for a HIGH signal.
Automated Control Decision:
If motion is detected, the ESP32 immediately triggers the relay to the ON state, powering the load.
If no motion is detected, the system initiates a countdown (timeout period). If the sensor remains LOW for the duration (e.g., 60 seconds), the relay is deactivated to shed the load.
Cloud Transmission: The processed data is packaged and sent to the remote dashboard at defined 1-second sampling intervals.
Communication Protocol Analysis: MQTT vs. HTTP While the system supports both, the implementation prioritizes MQTT for higher efficiency.
Lightweight Architecture: MQTT uses a "Publish/Subscribe" model, which reduces the data overhead compared to the "Request/Response" model of HTTP.
Minimal Bandwidth: This ensures that the high-frequency 1-second data logging does not saturate the network bandwidth.

COMPONENTS

1. ESP32 Microcontroller
ESP32 is the main controller of the project used for processing and controlling all operations. It receives data from the PZEM sensor, displays readings on the LCD, and uploads the data to ThingSpeak using built-in Wi-Fi. It also controls the relay module for load operation.

2. PZEM-004T Energy Meter Module
PZEM-004T is used to measure electrical parameters such as voltage, current, power, energy, frequency, and power factor. It continuously monitors the connected load and sends the measured data to the ESP32 through UART communication.

3. CT Sensor (Current Transformer)
The CT sensor is used to measure the current flowing through the electrical load. It works by detecting the magnetic field produced by the current-carrying wire and provides safe current measurement without direct electrical contact.

4. LCD Display
The LCD display is used to show real-time electrical readings such as voltage, current, power, and energy locally. It is connected to the ESP32 using I2C communication through SDA and SCL pins.

5. Relay Module
The relay module is used to control the electrical load ON/OFF remotely. It acts as an electrically operated switch that allows the low-voltage ESP32 to safely control high-voltage AC appliances.

6. ThingSpeak Cloud Platform
ThingSpeak is an IoT cloud platform used for real-time online monitoring and data storage. It receives electrical data from ESP32 through Wi-Fi and displays live readings and graphs for remote monitoring.

7. Power Supply / Adapter
The adapter converts AC supply into regulated DC voltage required for ESP32 and other modules. It provides stable power supply for proper operation of the complete system.

8. Jumper Wires and Breadboard
Jumper wires and breadboard are used for making electrical connections between different components of the project. They help in easy circuit prototyping and testing without soldering.

9. Load (Bulb/Fan)
The electrical load such as a bulb or fan is connected to the system for monitoring and control. The project measures the energy consumption of the connected load and controls it through the relay module.

WORKING

The PZEM-004T sensor continuously measures electrical parameters such as voltage, current, power, and energy consumption from the connected electrical load. The measured data is sent to the ESP32 microcontroller through UART communication using TX and RX pins. The ESP32 processes the received data and displays the real-time readings on the LCD display for local monitoring.
The ESP32 also connects to Wi-Fi and uploads the measured data to the ThingSpeak cloud platform for remote monitoring and graphical visualization. The relay module is integrated into the system to control the electrical load remotely through a mobile application. This complete system provides real-time monitoring, cloud data storage, remote access, and smart energy management using IoT technology.

FUTURE SCOPE

The proposed IoT-Based Energy Monitoring and Control System can be further improved by integrating advanced technologies and smart automation features. In the future, the system can be connected with mobile applications for better user interaction and real-time notifications. Artificial Intelligence and Machine Learning techniques can also be implemented for energy usage prediction and automatic energy optimization.
The project can be extended for smart grid and industrial energy management applications. Additional safety features such as overload protection, SMS alerts, and automatic fault detection can be integrated to improve system reliability and security. The system can also be expanded to monitor and control multiple electrical appliances simultaneously for large-scale smart home and smart campus applications.

CONCLUSION

The proposed IoT-Based Energy Monitoring and Control System successfully monitors electrical parameters such as voltage, current, power, and energy consumption in real time using the PZEM-004T sensor and ESP32 microcontroller. The system displays the measured data on the LCD display and uploads it to the ThingSpeak cloud platform through Wi-Fi for remote monitoring and graphical analysis.
The integration of the relay module enables remote control of electrical loads, making the system more efficient and smart. The project helps reduce electricity wastage, improves energy management, and provides a low-cost and user-friendly IoT solution for smart homes, industries, and smart campus applications.

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