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Smart Energy Meter

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ABSTRACT

The rapid advancement in embedded systems and Internet of Things (IoT) technologies has created unprecedented opportunities for intelligent energy management and real-time power consumption monitoring. This project presents the design and implementation of a Smart Energy Meter with IoT-Based Real-Time Monitoring system, which addresses the critical need for accurate, accessible, and intelligent power consumption tracking in residential and commercial environments.

At the heart of the system lies the ESP32 microcontroller, which serves as both the processing unit and the IoT gateway. The PZEM-004T V3.0 AC monitoring module provides high-precision measurement of six critical electrical parameters simultaneously, including voltage, current, active power, energy consumption, power factor, and frequency. A Current Transformer (CT) coil enables non-invasive current measurement without interrupting the existing electrical circuit, ensuring safe and convenient installation.

The ESP32 collects real-time data from the PZEM-004T module and transmits it wirelessly to a cloud-based IoT platform, enabling users to monitor their energy consumption from anywhere through a smartphone or web interface. The system provides instant alerts for abnormal conditions such as voltage fluctuations, excessive current draw, or poor power factor, helping users take corrective action and optimize their energy usage..

INTRODUCTION

In today's rapidly evolving world, efficient energy management has become a critical necessity due to the increasing demand for electricity and the depletion of natural resources. Traditional energy meters, which require manual reading and offer limited functionality, are no longer sufficient to meet modern energy monitoring and management needs. These conventional systems are often prone to human error, delayed billing, and lack of real-time information.

A Smart Energy Meter is an innovative solution that overcomes these limitations by incorporating advanced technologies

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such as embedded systems, wireless communication, and data analytics. It enables automatic measurement and transmission of energy consumption data, eliminating the need for manual intervention. With real-time monitoring capabilities, consumers can track their electricity usage more accurately and take proactive steps to optimize consumption.
Furthermore, smart energy meters play a significant role in the development of smart grids, where there is two-way communication between utility providers and consumers. This allows for better load distribution, quicker fault detection, and improved energy efficiency. The integration of smart meters with mobile or web applications enhances user convenience by providing instant access to consumption data, billing information, and alerts.
Overall, the Smart Energy Meter represents a major advancement in energy management systems

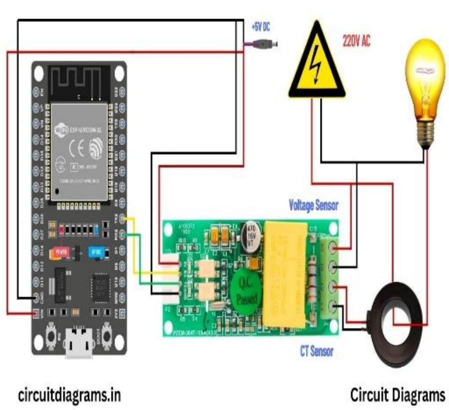
LITERATURE SURVEY

The field of smart energy metering has been the subject of extensive research and development over the past decade. Several studies and commercial projects have explored various approaches to intelligent power monitoring, ranging from simple single-parameter current sensors to sophisticated multi-parameter power quality analyzers integrated with advanced analytics platforms. This literature survey examines key works relevant to the design and implementation of this Smart Energy Meter project.

Early IoT-based energy monitoring systems typically used simple current transformers with microcontrollers like the Arduino Uno to measure only current consumption, inferring approximate power consumption by assuming a constant voltage and unity power factor. While these systems demonstrated the feasibility of IoT-connected energy monitoring, they suffered from significant accuracy limitations and failed to capture important power quality parameters.

More sophisticated systems began incorporating dedicated power measurement ICs such as the ADE7758 or CS5490, which provide high-accuracy multi-parameter measurement capabilities. These systems achieved measurement accuracies within 0.5% across multiple parameters but required complex analog front-end circuitry and careful PCB design for optimal performance. The PZEM-004T represents a significant simplification, integrating all measurement functions in a single module while maintaining industrial-grade accuracy.

Architecture Diagram



PROPOSED SYSTEM

The proposed Smart Energy Meter system is designed to provide an efficient and user-friendly solution for real-time electricity monitoring by integrating Internet of Things (IoT) technology with a mobile application interface. The system eliminates the need for manual meter reading and allows users to access their energy consumption data remotely.

The system consists of voltage and current sensors connected to a microcontroller such as ESP32. These sensors continuously measure electrical parameters like voltage and current from the connected load. The microcontroller processes these values to calculate power and total energy consumption in kilowatt-hours (kWh).

A dedicated mobile application acts as the central control and monitoring unit of the system. The microcontroller transmits the processed data to the cloud server via Wi-Fi, and the mobile app retrieves this data in real-time. This enables users to monitor their electricity usage anytime and from anywhere.

The mobile application provides an interactive dashboard that displays:

Real-time voltage, current, and power
Total energy consumption
Estimated electricity bill
Historical usage data

In addition to monitoring, the system can also support control features. Users can remotely switch electrical appliances ON or OFF through the mobile app, helping to reduce unnecessary energy consumption.

The system also includes safety and alert mechanisms. If the energy consumption exceeds a predefined limit or if an overload condition occurs, the system sends notifications to the user through the mobile application.

Overall, the proposed system offers a smart, cost-effective, and scalable energy management solution by combining sensor-based monitoring with mobile app control, making it suitable for modern homes and industrial applications.

IMPLEMENTATION

The implementation of the Smart Energy Meter system is carried out by integrating sensing, processing, communication, and user interface modules to achieve real-time monitoring and control of electrical energy consumption.

The system is powered by a regulated power supply which provides the required voltage to all components. The electrical parameters are measured using a voltage sensor and a current sensor. The voltage sensor continuously monitors the supply voltage, while the current sensor measures the load current flowing through the circuit.

These analog signals are fed into the microcontroller unit, such as ESP32, which converts them into digital values using its built-in Analog-to-Digital Converter (ADC). The microcontroller then processes these values to calculate instantaneous power using the relation:

$$P = V \times I$$

Further, the system integrates power over time to compute total energy consumption in kilowatt-hours (kWh). This data is continuously updated and stored temporarily in the microcontroller.

The ESP32, equipped with an inbuilt Wi-Fi module, establishes a connection with a cloud server. The processed data is transmitted periodically to the cloud using IoT protocols such as HTTP or MQTT. The cloud platform acts as a central database, storing and managing energy consumption data.

A dedicated mobile application is developed to provide a user-friendly interface. The application retrieves real-time data from the cloud and displays it in graphical and numerical formats. The user can monitor parameters such as:

Voltage

Current

Power consumption

Total energy usage

Estimated electricity cost

The mobile application also allows remote interaction with the system. By integrating a relay module with the ESP32, users can control connected appliances through the app. This enables switching devices ON/OFF remotely, thereby improving energy efficiency.

To enhance system safety, an overload detection mechanism is implemented. If the measured current or power exceeds a predefined threshold, the microcontroller triggers an alert and sends a notification to the mobile application. This helps prevent damage to appliances and reduces the risk of electrical hazards.

Additionally, the system maintains a feedback loop by storing historical data in the cloud. This data can be analyzed to understand consumption patterns and optimize energy usage.
Overall, the implementation ensures a seamless integration of hardware and software components, resulting in a reliable, scalable, and intelligent energy monitoring system.

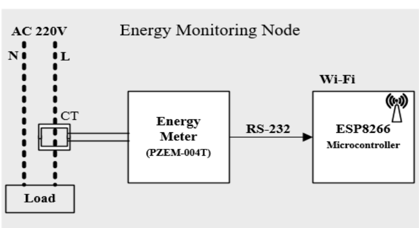


Fig: 1: Block Diagram

Energy Monitoring Nodes In order to monitor energy usages, we utilize the PZEM-004T; it made by Peacefair Electronics. Its operation is based on the principle of current transformer. It uses a precision AC current transformer coil as a sensing part that has the output of 100A/100mA. The PZEM-004T provides RMS voltage, RMS current and calculates active power and total energy usage over time or accumulative power consumption. The PZEM-004T uses SD3004 energy measurement SoC chip from SDIC microelectronics. It has very good measurement accuracy. Fig. 2 illustrates simple diagram of the developed IoT energy monitoring node. Figure 2. Diagram of IoT electric energy monitoring module. In order to send measured data from the PZEM-004T to the network or the internet, we employed the ESP8266 Wemos D1 mini to communicate with the PZEM-004T via RS-232. Fig. 3 illustrates the prototype of energy monitoring node in which the PZEM-004T is connected with the Wemos D1 mini via RS-232 port. The firmware for Wemos D1 mini was developed using the Arduino software environments. The main function of the Wemos D1 mini is used to collect energy data from the PZEM-004T and send recived data to the server wirelessly, through Wi-Fi. The data will be sent to the server approximatly every 20 seconds. The JSON format is a lightweight data-interchange format and easy to understand. Therefore, JSON format is used for transmitting structured data over network connection via MQTT

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HARDWARE IMPLEMENTATION

The hardware implementation of the Smart Energy Meter system is based on an ESP32 microcontroller integrated with an energy measurement module, relay unit, and a load. The ESP32 acts as the central processing unit, mounted on a breadboard for easy connections and prototyping. An energy monitoring module is connected to the AC mains supply to measure important electrical parameters such as voltage, current, power, and energy consumption. This module continuously sends real-time data to the ESP32 through serial communication. A relay module is interfaced with the ESP32 to control the connected appliance, which in this setup is represented by a bulb acting as a load. The relay allows safe switching of high-voltage devices using low-voltage signals from the microcontroller. The ESP32 is powered via a USB connection, while the sensing module is powered from the AC supply with proper isolation for safety. The system also includes a mobile application interface that displays real-time energy data and allows the user to remotely control the appliance. Overall, the hardware setup is compact, efficient, and capable of real-time monitoring and control, making it suitable for smart energy management applications.

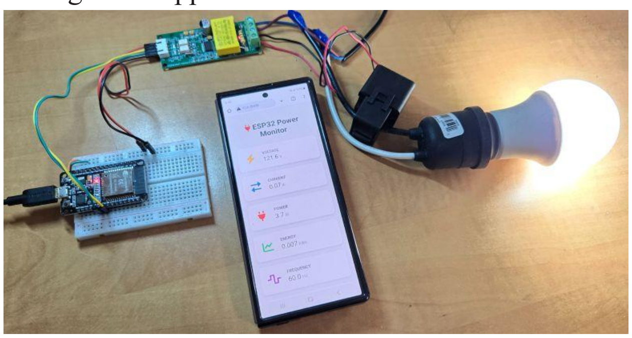
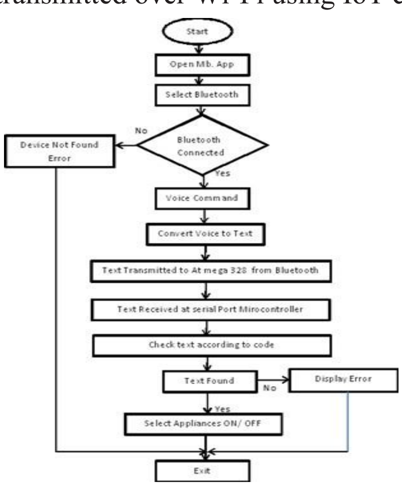


Fig. 2: Hardware Implementation

SOFTWARE IMPLEMENTATION

The software implementation of the Smart Energy Meter system is developed using the Arduino IDE for programming the ESP32 microcontroller and a mobile application platform such as Blynk for user interaction. The ESP32 is programmed using embedded C/C++ to read data from the energy monitoring module through serial communication. The software processes the incoming data to obtain parameters such as voltage, current, power, and energy consumption. These values are then formatted and transmitted over Wi-Fi using IoT communication protocols like HTTP or MQTT.

3: Flowchart



CONCLUSION

The Smart Energy Meter system successfully demonstrates an efficient and modern approach to monitoring and managing electrical energy consumption. By integrating an ESP32 microcontroller with an energy measurement module, the system is capable of accurately measuring parameters such as voltage, current, power, and energy in real time. The incorporation of Wi-Fi connectivity enables seamless data transmission to a mobile application, allowing users to monitor their energy usage remotely from anywhere.

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