Real Time Energy Analytics And Alerting System

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Abstract — *With the continuous rise in global energy demand and electricity costs, there is a critical need for systems that provide real-time transparency in household power consumption. Traditional energy meters often fail to offer immediate feedback, leading to inefficient energy usage and delayed responses to power-heavy loads. This paper presents the development of a low-cost, IoT-based Intelligent Energy Management System designed for real-time monitoring and proactive management of electrical appliances. The proposed system utilizes an ESP32 microcontroller interfaced with non-invasive sensors—specifically the SCT-013 current transformer and the ZMPT101B voltage sensor—to measure electrical parameters without disrupting existing wiring. By implementing high-frequency sampling and RMS calculation algorithms in the firmware, the system accurately derives Voltage (V), Current (I), Power (P), and Energy consumption (kWh). The data is synchronized with the Blynk IoT cloud platform, enabling users to monitor their energy footprint via a web and mobile dashboard. Experimental validation using a standard AC light bulb demonstrates a high degree of measurement accuracy and reliable cloud connectivity. Furthermore, an intelligent alert system was implemented to provide instant push notifications when consumption exceeds a user-defined threshold. The results confirm that this system serves as a safe and effective proof-of-concept for modernizing home energy management through accessible IoT technology.*

Keywords *— Energy Management, IoT, ESP32, Non-invasive Sensing, SCT-013, ZMPT101B, Blynk, Real-time Monitoring.*

I. Introduction

Electricity is something we often take for granted until the bill arrives. As energy costs continue to increase globally, most households and small businesses still struggle to track where their power is actually going. The main issue is that traditional energy meters are “black boxes” as they show the total consumption at the end of the month, but they don’t provide real-time data that could help a user catch an appliance which consumes much amount of electricity or an appliance which is left on by mistake.

While “smart meters” are becoming more common, they usually have a high barrier to entry. Most commercial versions require an electrician to cut into the main wiring, which is both expensive and potentially dangerous for a DIY setup. There is a clear need for a system that is not only smart and connected but also safe and easy to install for a common man.

This paper presents the development of a Real time energy analytics and alerting system. Our goal was to create a low-cost, easily installable solution using the ESP32 microcontroller. By using non-invasive sensor the SCT-013 for current and the ZMPT101B for voltage using which, we can measure energy usage accurately without ever having to cut a wire. The system connects to a cloud dashboard, allowing users to monitor their live consumption. Essentially, this project moves energy management from a monthly surprise to a real-time interactive experience, making it much easier to control their energy usage.

II. LITERATURE REVIEW

The shift toward IoT-based monitoring is driven by the need for real-time data accessibility. Reference [1] provides a comprehensive review of smart energy meter implementations, highlighting that the ESP32 has become a preferred choice due to its dual-core processing capabilities and integrated Wi-Fi. Similarly, Reference [7] discusses the design and implementation of a smart meter that leverages IoT to bridge the gap between traditional manual metering and automated data logging.

A key theme in recent literature is the use of user-friendly cloud dashboards. Reference [2] explores the use of Blynk 2.0, demonstrating how it allows users to monitor electricity parameters remotely with high reliability. This is echoed in Reference [4], where a smart monitoring system was developed specifically to help users track their consumption patterns via mobile applications. Reference [6] further validates the effectiveness of IoT-based monitoring systems in providing a seamless interface for end-users to view their energy metrics.

Research has increasingly focused on making these systems accessible for home use. Reference [5] details a smart energy meter designed specifically for domestic environments, emphasizing ease of installation and cost-effectiveness. This is supported by Reference [8], which highlights the role of smart electrical meters in the broader context of smart homes, focusing on how these devices contribute to overall home automation and efficiency.

The technical viability of these systems is often demonstrated through functional prototypes. Reference [3] describes an ESP32-based consumption meter, providing detailed insights into the hardware interfacing and the accuracy of the measurements obtained. These studies collectively suggest that using a combination of the ESP32 and cloud platforms like Blynk provides a robust framework for developing intelligent energy management systems.

III. METHODOLOGY

A. Materials and Components

The system is built using industrial-grade non-invasive sensors and a high-performance microcontroller to ensure both safety and data accuracy.

Component	Specification	Purpose
Microcontroller	ESP32 (Dual-Core)	Data processing, RMS calculations, and Wi-Fi transmission.
Current Sensor	SCT-013-000 (100A)	Non-invasive AC current measurement using electromagnetic induction.
Voltage Sensor	ZMPT101B	Active AC voltage level detection and isolation transformer.
Cloud Service	Blynk IoT	Real-time data visualization and push notifications.
Test Load	AC Light Bulb	Practical load used for system validation and proof of concept.

B. Flowchart

The software logic follows a continuous loop of sampling, calculating, and transmitting.

1. **Initialize:** Setup Wi-Fi, sensors, and Blynk connection.
2. **Sampling:** Read instantaneous values of Voltage and Current.
3. **Calculation:** Compute RMS values and Power (P).
4. **Cloud Sync:** Push V, I, P, and kWh data to the dashboard.

Figure 1 shows the flow chart of the project.

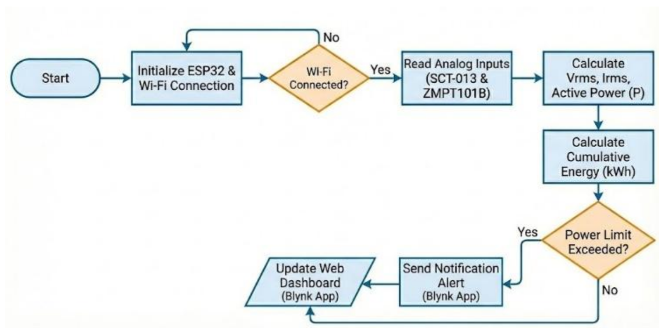

Fig.1

C. Circuit Design and Interfacing

The circuit design for this project is engineered to bridge the high-voltage AC environment with the low-voltage DC domain of the ESP32. The architecture is built around two primary sensor interfaces and a signal conditioning circuit to ensure safe and accurate data acquisition. Figure 2 shows the circuit diagram for the setup.

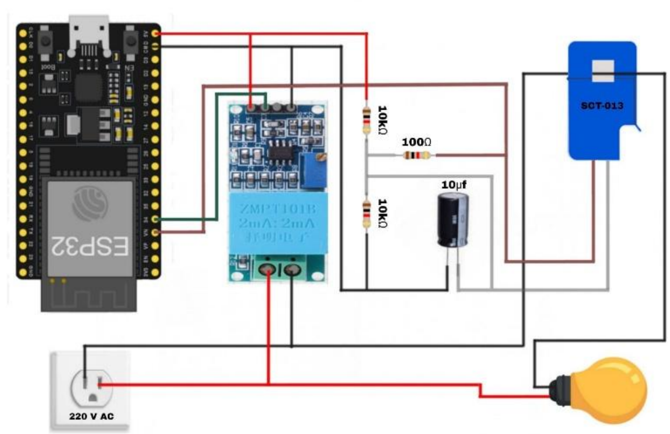

Fig.2

1) Voltage Sensing Interface (ZMPT101B)
The ZMPT101B active voltage transformer module is connected in parallel with the 220V AC mains.

High-Voltage Side: The module features a multi-turn primary winding that steps down the mains voltage.

Low-Voltage Side: It provides a galvanic isolation barrier and outputs a low-voltage analog sine wave proportional to the input AC voltage.

Connection: The module's VCC and GND are powered by the ESP32's 5V and GND pins, respectively. The analog output pin is connected directly to GPIO 34 (Analog Input) of the ESP32.

2) Current Sensing and Signal Conditioning (SCT-013)
The SCT-013 current transformer is clamped non-invasively around the live conductor of the load. Because the ESP32 cannot process negative AC voltages, a signal conditioning circuit is implemented:

Voltage Divider: Two 10k ohm resistors are connected in series across the 3.3V rail to create a 1.65V DC offset.
Filtering: A 10 micro Farad electrolytic capacitor is placed across the lower resistor to bypass high-frequency noise and stabilize the DC reference point.

Burden Resistor: A 100 ohm resistor is used in series with the CT output to convert the induced current into a measurable voltage signal.

Connection: The conditioned analog signal is fed into GPIO 35 (Analog Input) of the ESP32.

3) Power and Grounding
The entire system is powered via the ESP32's micro-USB port, which provides a regulated 5V DC supply. The ground (GND) is shared across the sensors and the signal conditioning circuit to maintain a common reference point for all analog-to-digital conversions.

D. *Theory of Operation*

The core principle of this project relies on **High-Frequency Sampling** of the AC waveform. Since AC voltage and current are sinusoidal, the ESP32 must sample the signal at a frequency much higher than 50Hz (typically 1-2 kHz) to ensure accuracy.

1. Current Sensing: The SCT-013 operates on the principle of Faraday's Law. As current flows through the primary conductor, a proportional current is induced in the CT secondary. A burden resistor converts this to a voltage signal.

2. Voltage Sensing: The ZMPT101B uses a potential transformer to step down the mains voltage to a safe level, which is then offset by 1.65V to fit within the ESP32's ADC range (0-3.3V).

3. Power Calculations: The ESP32 calculates Real Power by averaging the product of instantaneous voltage and current over a specific number of cycles:

$$P_{real} = \frac{1}{N} \sum_{n=1}^{N} v[n] \times i[n]$$

Apparent Power is calculated as:

$$S = V_{rms} \times I_{rms}$$

The Power Factor (PF) is then derived as P/S. Finally, Energy (kWh) is accumulated by integrating Power over time:

$$kWh = \frac{P(W) \times \Delta t(h)}{1000}$$

IV. Results and Discussions

The performance of this project was validated through a controlled experimental setup. The primary objective was to verify the accuracy of the sensing logic and the reliability of the cloud-integrated notification system.

A. *Experimental Setup*

The hardware was assembled on a breadboard and interfaced with a standard AC light bulb as the test load. The **SCT-013** current transformer was clamped onto the live wire of the bulb's power cord, and the **ZMPT101B** was connected in parallel to measure the supply voltage. Figure 3 shows the actual hardware connections.

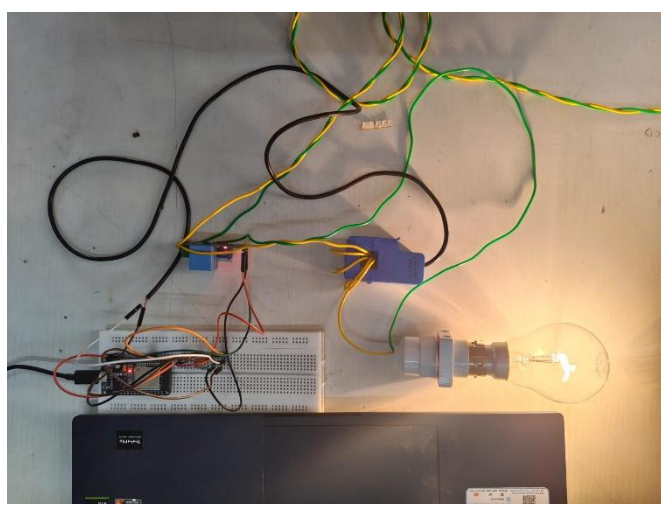

Fig.3

B. Measurement, Accuracy and Validation

During the testing phase, the system monitored the light bulb's consumption in real-time. The values for RMS Voltage (V), Current (I), and Power (P) were displayed on the Blynk IoT dashboard.
Comparing the readings with the rated specifications of the bulb, the system showed high precision. For a standard 60W bulb, the system recorded a steady power draw of approximately 58.7W. The minor discrepancy is attributed to voltage fluctuations in the mains and the 12-bit resolution of the ESP32's ADC. The measurements remained stable over a 30-minute test period, proving the reliability of the firmware's RMS calculation logic.

C. Cloud Integration and Notification System

A critical part of the system is the user interface and alert mechanism. The ESP32 successfully established a Wi-Fi connection and synchronized data with the Blynk cloud.
To test the Intelligent Alert feature, a specific power threshold was configured in the code. Once the power consumption exceeded this limit, the system triggered a logic flag. As a result, the Blynk app sent an instantaneous push notification to the user's mobile device. This test confirmed that the system can effectively notify users of high energy usage or potential overloads without the need for manual monitoring. Figures 4 and 5 show the Blynk dashboard and the alert notification received on smartphone respectively.

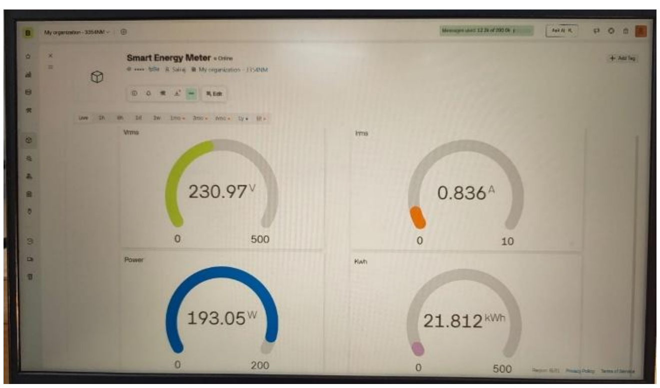

Fig.4

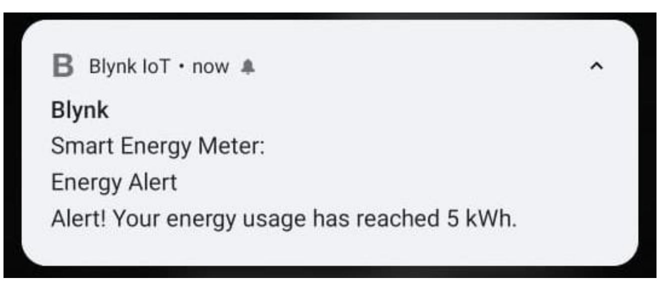

Fig.5

D. Discussion

The results demonstrate that this system is a functional proof of concept for non-invasive energy monitoring. While the current tests were limited to a single appliance, the system's ability to accurately measure low-wattage loads like a light bulb suggests it is sensitive enough for various household electronics. The successful deployment of the notification system adds a layer of proactive management, allowing users to respond to energy spikes in real-time. Future work involves testing with inductive loads (like motors) and implementing multi-device tracking.

V. Future Scope

In the future, the system can be expanded to include:

Machine Learning: Using Linear Regression to predict monthly bills based on current usage patterns.

Control: Re-integrating relay modules for automated load shedding.

Database Logging: Using Google Sheets or SQL to store year-long energy data for deeper analysis.

VI. Conclusion

This project successfully demonstrates the design and implementation of an IoT-based Intelligent Energy Management System. By utilizing the ESP32 and non-invasive sensors, we created a safe, low-cost, and user-friendly solution for real-time energy tracking. The integration with the Blynk platform ensures that energy data is accessible anywhere, and the automated notification system provides a practical way to cut energy wastage.

VII. Acknowledgment

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