International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

IOT – BASED SMART ENERGY METER MONITORING SYSTEM

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ABSTRACT :

The IoT-Based Smart Energy Meter Monitoring System overcomes the limitations of traditional analogue electricity meters by providing real-time visibility into voltage, current, power, energy consumption, and cost. The system integrates voltage and current sensors with an ESP32 microcontroller, enabling precise data acquisition and wireless transmission to a cloud platform such as Blynk for remote monitoring through mobile or web dashboards. Automated load control via relay switching, along with real-time alerts for abnormal consumption, supports efficient energy management and minimizes wastage.

Processed parameters—including RMS values, apparent power, energy (kWh), power factor, and tariff-based cost—are displayed locally on an I2C-enabled LCD and synchronized to the cloud for trend analysis. Experimental validation confirms reliable performance with accurate measurements and instant response to remote commands. The proposed IoT-based solution offers a low-cost, portable, and scalable approach suitable for homes, industries, and hostels, significantly improving user awareness and operational efficiency. While dependent on internet connectivity and calibration accuracy, the system provides a strong foundation for future enhancements such as overload detection, multi-device dashboards, and advanced analytics.

Keywords, Smart Energy Meter, ESP32, Sensors, Real-Time Monitoring, Energy Usage, Cloud Dashboard, Remote Control.

1. INTRODUCTION

Electricity consumption worldwide has surged due to the proliferation of electrical appliances, smart gadgets, and home automation systems, driven by urbanization and technological advancements. In India, where the project originates, residential and industrial sectors account for over 70% of total power usage, with peak demands straining grids and leading to frequent outages. Traditional analogue meters fail to capture this dynamic, offering only end-of-month cumulative readings that obscure daily or hourly patterns, resulting in undetected inefficiencies.

Conventional power meters, typically electromechanical or basic digital types, require manual inspections and provide no real-time data on voltage fluctuations, current draw, instantaneous power, or cumulative energy. This opacity allows energy wastage—such as standby losses from idle devices or overloads—to go unnoticed, inflating bills and contributing to broader environmental impacts like higher carbon emissions from fossil fuel-dependent generation. Without granular insights, users cannot optimize usage, exacerbating issues in resource-constrained settings like Indian households and small industries.

Smart energy systems, powered by IoT, deliver live telemetry of electrical parameters, enabling remote access and control via apps or dashboards to pinpoint high-consumption periods and automate responses, such as dimming lights or scheduling appliances. This shift promotes efficiency by alerting users to anomalies, forecasting bills based on tariffs (e.g., tiered pricing in Karnataka), and integrating with renewable sources for balanced load management. Ultimately, such systems foster sustainable habits, reducing wastage by up to 20-30% in monitored setups while supporting grid stability through demand-side management.

This introduction underscores the project's focus on bridging the gap between rising demand and outdated metering, offering a practical IoT solution tailored for accessible implementation in educational and domestic contexts. By leveraging affordable components like ESP32, the system not only monitors but also empowers proactive energy stewardship, aligning with global sustainability goals and local needs in Bengaluru's power ecosystem.

2. IOT-BASED SMART ENERGY MONITORING SYSTEM.

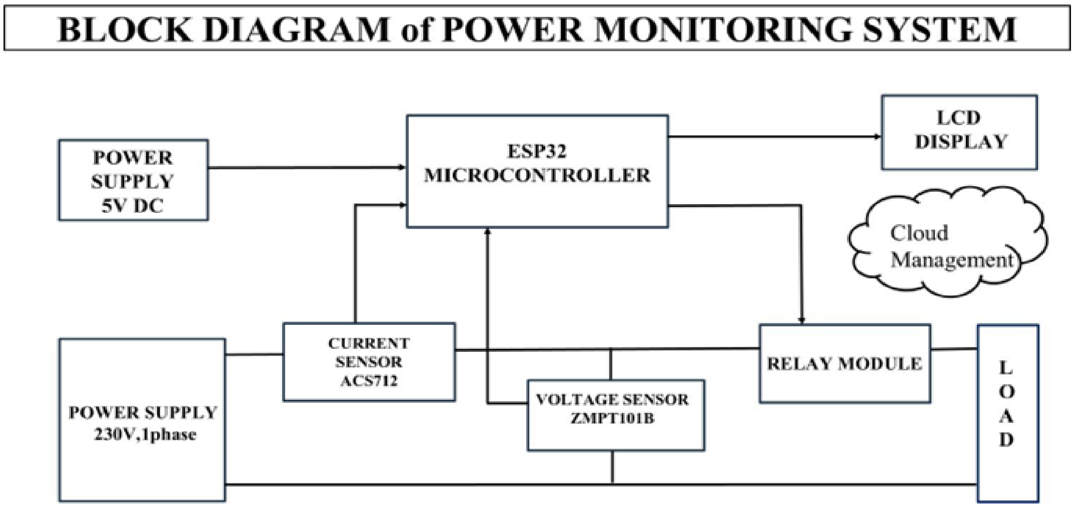

Fig 1. Block diagram of smart energy meter

The proposed IoT-based smart energy meter monitoring system features a clear architecture for sensing, processing, and cloud integration. It tracks and analyses electrical consumption in real time. Multiple sensors, including a voltage sensor (ZMPT101B) and a current sensor (ACS712/ACS758), connect to the ESP32/ESP8266 microcontroller to measure voltage, current, instantaneous power, and total energy use. These sensors sample data every 1 to 3 seconds to ensure accurate monitoring. The microcontroller runs calibration algorithms to check readings and calculates power factor, energy consumption, and estimated costs based on set tariff values.

Processed data is sent securely to the cloud via Wi-Fi using the MQTT/HTTP protocol. The Blynk platform stores time-stamped logs for long-term analysis. Cloud-based dashboards offer graphical summaries, consumption trends, and daily or weekly usage stats. This helps users assess load behaviour and spot unusual power patterns. The mobile app provides real-time gauges, notifications, and support for viewing multiple meters at once.

The system also includes an automated alert feature to keep users informed and safe. Notifications are activated when the load exceeds a set threshold or when abnormal power spikes happen. Alerts are sent through app notifications and email. A relay module in the system lets authorized users remotely switch connected loads ON or OFF via the Blynk app, ensuring smart power control and preventing overloads. All configuration changes, including tariff updates and threshold adjustments, are authenticated and securely logged.

Additional features include graphical displays of historical consumption, automated daily energy reports, and support for OTA firmware updates to maintain long-term performance. Local data buffering ensures continuous logging during temporary network failures, syncing with the cloud once connectivity is restored. The modular hardware design allows for easy maintenance, sensor replacement, and system expansion. Overall, the system provides accurate, real-time smart energy monitoring with minimal manual effort, promoting efficient energy use, reducing waste, and raising user awareness in residential and commercial spaces.

3. RESULTS AND DISCUSSION

The IoT-based Smart Energy Meter was tested under two operating scenarios—normal usage and power theft—to evaluate its performance in real-time monitoring and load validation. Under normal conditions, with a 9 W LED bulb connected as the only load, the system displayed stable readings of approximately 230 V, 0.04 A, and 9 W on both the LCD display and the mobile dashboard. The calculated energy and cost increased gradually with time, confirming that the system measures and updates the parameters at regular intervals. The relay remained ON, indicating that the load was legally connected, and the communication between the ESP32 and the cloud platform was consistent without delays.

When the power theft condition was introduced by connecting an unauthorized additional load, the performance of the system changed significantly. The total power consumption increased suddenly to around 40 W, with the current rising to 0.17 A, while the voltage remained close to 230 V. This unexpected spike was immediately detected by the microcontroller and reflected on both the LCD and mobile dashboard. The energy and cost values increased rapidly compared to normal operation, clearly indicating abnormal consumption. Based on this condition, the system automatically switched the relay to OFF, disconnecting the power supply to avoid further electricity misuse.

From the experimental performance, it is evident that the proposed system not only records real-time electrical parameters accurately but also distinguishes unauthorized usage without manual inspection. The response time of the cloud dashboard, LCD display, and relay was quick and reliable in both scenarios, proving that the system is suitable for smart home energy monitoring, cost optimization, and power theft prevention.

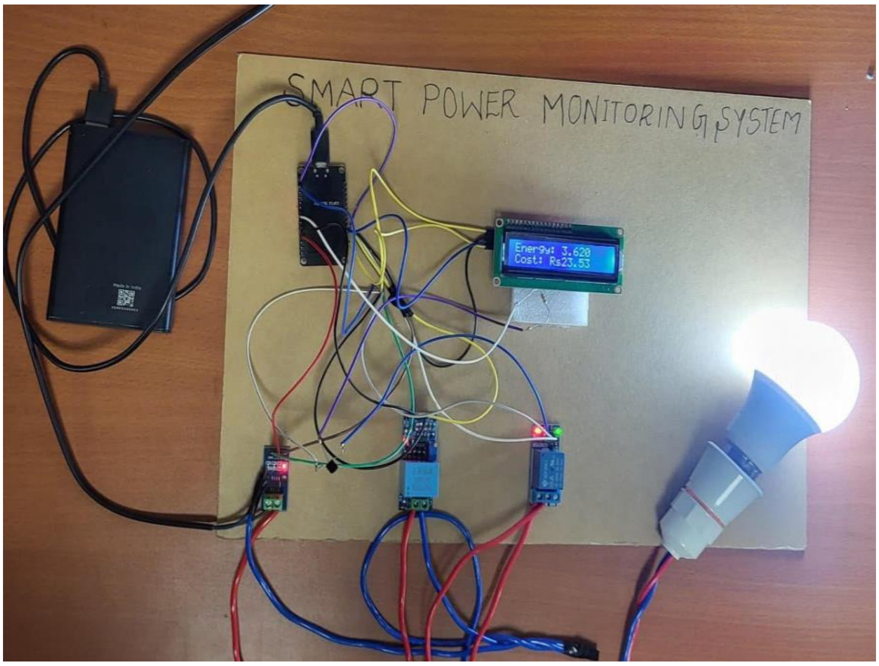

Fig 2. IOT – BASED SMART ENERGY METER MONITORING SYSTEM

In addition to displaying live electrical parameters, the system also demonstrated strong performance in terms of data consistency and user interaction. During testing, the Blynk mobile application continuously plotted voltage, current, power, and energy graphs without noticeable delay, proving that the ESP32 Wi-Fi module can handle cloud transmission efficiently. The LCD served as an offline backup visualization system, ensuring that even in the absence of internet connectivity, the user could still view the measured parameters locally. The synchronization between the LCD updates and the cloud dashboard reflected that both interfaces were receiving accurate and simultaneous data. This dual-display structure increases the reliability of the system for both domestic users and small commercial installations.

Parameter	Case 1 (Normal Condition – 9 W Load)	***Case 2 (Theft Condition – 40 W Load)***
Voltage (V)	230 V	230 V
Current (A)	0.04 A	***0.17 A (sudden rise detected)***
Power (W)	9 W	***40 W (unexpected power usage)***
Total Units (kWh)*	0.009 kWh	***0.040 kWh (irregular high usage)***
Cost (₹)**	₹0.05	***₹0.24 (rapid cost increase)***

Table 1. Results

4. CONCLUSION

The Based Smart Power Monitoring System proved to be an effective solution for tracking and managing household and industrial energy consumption. The system accurately measures voltage, current, power, and total energy used, and displays the readings instantly on both an LCD screen and an IoT mobile dashboard. With the addition of a relay module, the user can remotely switch appliances ON and OFF, making the project useful for smart home automation and reducing unnecessary energy usage. The project is reliable, economical, and user-friendly, helping consumers become more aware of their power consumption and encouraging efficient energy usage. Overall, the system successfully meets its objective of providing real-time power monitoring and remote load control through IoT technology.

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