

Review of Smart Energy Meter Implementations Using ESP32 Microcontroller and IoT Platforms

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Abstract: The goal of the Smart Energy Meter with Load project is to continuously measure and track electrical energy usage. It makes use of an ESP32 microcontroller in conjunction with the ZMPT101B voltage sensor and SCT-013 current sensor. The ESP32 processes the voltage and current data that these sensors gather from the load to determine power and energy consumption. Additionally, if consumption surpasses a predetermined threshold, the device can instantly disconnect the load and monitor load circumstances. Users can remotely check the readings on a web dashboard or mobile application thanks to its Internet of Things functionality. This project facilitates correct billing, monitoring, and effective energy management.

Keywords: Smart Energy Meter, ESP32, ZMPT101B, SCT-013, IoT, Voltage and Current Sensing, Power and Energy Monitoring, Load Control, Real-Time Data, Smart Grid, Automation

I. INTRODUCTION

The goal of the Smart Energy Meter with Load project is to update the conventional approach to electrical energy consumption measurement and tracking. Energy consumption is manually assessed in traditional systems, which frequently leads to mistakes, delays, and a lack of real-time data. These shortcomings are addressed by the suggested system, which offers an intelligent, automated, and digital solution. Using sensors such the ZMPT101B voltage sensor and SCT-013 current sensor, which are connected to an ESP32 microprocessor, it continuously detects voltage, current, power, and energy. With the help of its integrated Wi-Fi module, the ESP32 evaluates sensor data and determines power parameters, enabling remote monitoring of the readings via a mobile application or web dashboard.

In addition to measuring consumption, this device protects against overloads by instantly removing the load when the power level reaches a predetermined threshold. The collected data is perfect for smart grid and Internet of Things applications since it can be saved or uploaded to the cloud for long-term analysis. The initiative assists customers in tracking their monthly and daily energy consumption, detecting waste, and effectively managing electricity. It supports the idea of intelligent energy management and sustainable power usage by offering a dependable, affordable, and energy-efficient solution for homes, workplaces, and enterprises.

II. LITERATURE SURVEY

1. Muthusamy and associate (2025) In order to monitor and regulate electrical factors in industrial settings, the authors suggested an Internet of Things-based approach. Their technology continuously monitors power factor, voltage, and current. Preventive maintenance, efficiency, and power quality are all enhanced by this. In energy management, it facilitates prompt decision-making and remote oversight.

2. N and associate (2025) An Internet of Things-based real-time energy monitoring system for oil extraction equipment is presented in this work. In order to decrease power waste and increase machine efficiency, the system gathers data on energy usage. For heavy machinery, it facilitates predictive maintenance and defect identification. Their solution exemplifies how the Internet of Things may optimize industrial energy use.



3. Aishwarya and associates (2023) The authors created an affordable Internet of Things device to track how much electricity is being used in small company booths. Through mobile interfaces, it gives the owners access to real-time usage statistics. In small-scale systems, this encourages cost control and energy awareness. The system is intended for non-industrial users and is reasonably priced.
4. B and associates (2025) A smart metering system with price and power forecasting capabilities was presented in this study. It sends real-time warnings about pricing changes and use trends via the Internet of Things. Predictive data can be used to help users modify their consumption. It improves intelligent decision-making and energy conservation in houses.
5. Valsan and associates (2024) The study concentrated on employing RSA encryption to secure data transmission from smart meters. Confidentiality in intelligent energy trading systems is guaranteed by its IoT solution. Data on energy use is shielded from abuse and online threats. In smart grids, this gives smart meter communications an extra layer of security.
6. Hlabeli and associates (2024) They used integer programming techniques to propose a home energy management system. Appliance consumption is scheduled by the system to reduce electricity expenses. It manages loads more effectively by utilizing IoT sensors and data. This enhances consumer convenience and optimizes home energy use.
7. Yaichi and associates (2024) The ESP-NOW communication protocol served as the foundation for the smart street lighting system proposed in this work. IoT nodes use time-based and environmental inputs to coordinate lighting. It drastically lowers the amount of energy wasted by public lighting systems. Scalable energy savings in urban infrastructure are demonstrated.
8. Sasikala and associates (2024) For energy control, the authors put in place a home automation system based on BLE. Despite not being a meter, it enables scheduling and remote appliance control. By using intelligent load management, it helps to improve energy efficiency. This solution uses low-power wireless IoT to improve home automation.
9. Valsan and associates (2024) For safe smart meter data transfer, the authors created an IoT framework that is RSA-encrypted. By protecting the privacy and integrity of data, this method facilitates sustainable energy trade. It tackles the main issues with communication security in smart grids. IoT-based energy systems are safer and more trustworthy thanks to this strategy.
10. Kumar and associates (2023) In order to use water and energy efficiently, this study presented an IoT-based smart irrigation system. In the agricultural sector of Coimbatore, sensors track soil moisture and automate water supply. Despite being primarily concerned with watering, its automation helps save electricity. The system shows how IoT can maximize smart farming resource utilization.

Table 1: Smart Energy Meter with Load using ESP32

Paper Project /	System Architecture	Cost	Ease of Implementation	Performance	User Experience	Limitations
Muthusamy et al. (2025)	IoT-based industrial monitoring with real-time electrical tracking	Moderate	Medium (needs industrial setup)	High accuracy, efficient control	Improves industrial supervision	Needs industrial integration; limited scalability
N et al. (2025)	IoT energy monitoring for oil extraction machinery	High	Complex (for industrial machines)	Efficient tracking, predictive insights	Real-time automation and monitoring	Not suitable for non-industrial use
Aisuwarya et al. (2023)	Low-cost IoT for small business electricity tracking	Low	High (simple and affordable)	Good performance for small setups	Real-time feedback; easy to use	Limited to small-scale applications
B et al.	Smart metering	Moderate	Medium	High –	Interactive,	Needs stable



(2025)	with prediction and alert system			supports forecasting and alerts	user-focused	internet; may require updates
Valsan et al. (2024)	RSA-encrypted IoT for smart meter data transmission	Moderate–High (~\$80)	Medium	Reliable and secure data transmission	Trusted data handling experience	Complex encryption adds system overhead
Hlabeli et al. (2024)	Home energy management with optimization algorithms disaster recovery	Moderate (~\$70)	Medium	Optimized appliance scheduling	Energy usage control improved	Needs user configuration and planning
Yaichi et al. (2024)	ESP-NOW based smart street lighting system	Moderate (~\$60)	Medium	Efficient lighting control	Autonomous operation in public areas	Depends on environment and outdoor setup
Sasikala et al. (2024)	BLE-based IoT home automation system	Low (<\$40)	High (easy to set up)	Efficient for local smart control	Simple user interface for appliance use	Short communication range; no analytics
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III. PROPOSED METHODOLOGY

The Smart Energy Meter with Load Control was designed and implemented using a methodical approach that combines communication technology, sensor modules, and embedded hardware to provide an intelligent and effective energy management solution. Figure 1 shows block diagram of proposed methodology

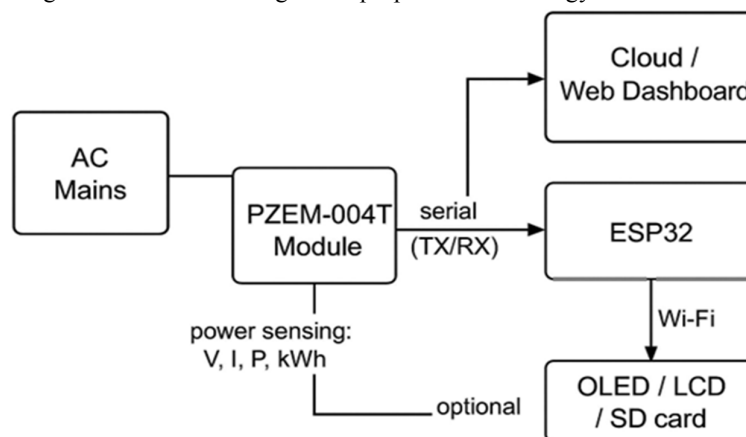


Fig. Smart Energy Meter with load



The AC mains supply, which provides the electrical power for the system to be monitored, is linked to it. For power sensing, the PZEM-004T energy monitoring module is utilized. Important metrics like voltage (V), current (I), power (P), and energy usage (kWh) are measured. Accurate and real-time data gathering is ensured by the module's serial interface (TX/RX) with the microcontroller. The system's processing and control center is the ESP32. It processes the data it receives from the PZEM-004T and determines power usage in real time. In addition to processing, it makes Wi-Fi connectivity possible so that data can be sent to the cloud. It may also regulate load switching (ON/OFF) by using preset threshold settings.

The ESP32 can be interfaced with an SD card or an OLED/LCD for local monitoring. This enables users to keep previous data for analysis or examine readings directly on a screen.

Wi-Fi is used to send the processed data to a web dashboard or cloud platform. This makes remote access possible, allowing the user to manage loads via an interactive interface, monitor energy use in real time, and receive alarms. When consumption surpasses predetermined thresholds, loads can be automatically or manually disconnected via a relay driver circuit that is coupled to the ESP32. This helps save energy and guarantees protection against overload.

IV. CONCLUSION

The Smart Energy Meter with Load project effectively illustrates a cutting-edge, effective technique for tracking and managing energy usage. The system can compute and show electrical parameters in real time by utilizing the ESP32 in conjunction with voltage and current sensors. Additionally, it allows users to remotely monitor energy consumption, which guarantees improved management and less power waste. A step toward more intelligent and environmentally friendly power monitoring systems is represented by this initiative.

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