International Journal of Engineering Research and Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 22, Issue 4 (April 2026), PP 61-65

Smart Energy Meter Adaptive Load Control Monitoring System

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ABSTRACT:
The Smart Energy Meter Adaptive Load Control Monitoring System is an advanced solution designed to monitor, analyse, and control electrical energy consumption in real time. This system utilizes an ESP32 microcontroller integrated with voltage and current sensors (ZMPT101B and ZMCT103C) to measure electrical parameters accurately. The collected data is displayed on a 16×4 LCD and simultaneously stored in an SD card module for future analysis. The system also incorporates an RTC DS3231 module to maintain precise time records for energy usage logging. Additionally, the system enables adaptive load control using relays connected to electrical loads (lamps), allowing automatic switching based on predefined conditions such as load demand or time scheduling. The data can be visualized through a laptop dashboard, enabling users to monitor energy usage remotely. This project contributes to energy conservation, efficient load management, and supports smart grid development.

OBJECTIVE:
The main objective of this project is to design and develop a smart energy meter system capable of monitoring and controlling electrical energy consumption in real time using an ESP32 microcontroller. The system aims to accurately measure voltage and current using appropriate sensors and display the measured parameters on a 16×4 LCD for user awareness. It also focuses on implementing adaptive load control through relays to optimize energy usage and reduce wastage. Additionally, the project intends to store energy consumption data along with time information using an RTC and SD card module for future analysis. Another objective is to provide a user-friendly monitoring interface through a laptop dashboard. Overall, the system is developed to enhance energy efficiency, promote smart energy management, and support future integration with IoT-based applications.

KEYWORDS:
IOT, Real-Time Energy Measurement, Power Consumption Analysis, Cloud-Based Monitoring, Automated Energy Integration, Load Management System.

Date of Submission: 20-03-2026 Date of acceptance: 03-04-2026

I INTRODUCTION

The project “Smart Energy Meter with Adaptive Load Control and Monitoring System” utilizes an ESP32 microcontroller to provide efficient, real-time control over household or industrial power consumption. It incorporates ZMPT101B voltage and ZMCT103C current sensors to accurately measure electrical parameters, ensuring precise monitoring of the connected loads. The measured voltage and current values are displayed on a 16×2 LCD, making the power and energy consumption data easy to visualize locally. For remote monitoring, the system transmits data to a cloud platform via Wi-Fi, allowing users to oversee usage through web or mobile applications from anywhere. The system features three relays connected to individual loads, which can be intelligently controlled using adaptive algorithms based on energy thresholds or overload scenarios, thus preventing system overload and saving energy. By integrating IoT technology, the project offers a robust solution for smart energy management, promoting optimized consumption, increased automation, and improved safety in electrical systems.

This project focuses on developing a smart energy meter capable of real-time monitoring and adaptive load control. By using IoT-enabled components like ESP32, the system not only measures voltage and current but also processes and displays data in a user-friendly manner. The inclusion of data storage and real-time clock enhances the system's capability for energy auditing and historical analysis.

The adaptive load control feature helps reduce energy wastage by automatically managing connected loads, making the system suitable for residential, industrial, and commercial applications.

In recent years, the rapid growth in population and industrialization has significantly increased the demand for electrical energy. Efficient utilization and proper monitoring of energy consumption have become essential to avoid energy wastage and ensure sustainable development. Conventional energy meters are limited to measuring total energy usage and do not provide real-time insights or control over electrical loads. This creates a gap in effective energy management, especially in residential, commercial, and industrial sectors.

To address these challenges, smart energy meter systems have emerged as an innovative solution. These systems combine sensing, processing, and communication technologies to provide detailed information about energy consumption patterns. The proposed Smart Energy Meter Adaptive Load Control Monitoring System is designed to monitor voltage and current continuously using sensors and process the data through an ESP32 microcontroller. The measured parameters are displayed on a 16×4 LCD, allowing users to easily understand their energy usage in real time.

A key feature of this system is adaptive load control, which enables automatic switching of electrical loads based on predefined conditions such as time, load demand, or energy limits. This helps in reducing unnecessary power consumption and improving overall system efficiency. The integration of relays allows the system to control multiple loads effectively, making it suitable for practical applications.

Furthermore, the system incorporates an RTC DS3231 module to maintain accurate time tracking and an SD card module to store energy consumption data for future reference and analysis. This data logging capability is highly useful for energy auditing, billing purposes, and performance evaluation. In addition, the system supports monitoring through a laptop dashboard, enhancing user interaction and accessibility.

Overall, this project represents a step towards smart energy management by combining embedded systems, IoT concepts, and automation. It not only improves energy efficiency but also provides a scalable platform that can be extended for advanced applications such as cloud-based monitoring, smart billing, and integration with renewable energy systems.

II LITERATURE SURVEY

[1] Title: A Review of Smart Energy Metering System Projects

Authors: Multiple authors

Publication: ResearchGate, August 2025

Summary: This review examines various smart energy metering projects, focusing on their implementation and impact on energy management.

[2] Title: Smart Energy Metering Systems: A Literature Review

Authors: Multiple authors

Publication: ResearchGate, August 2025

Summary: This literature review explores the development and challenges of smart energy metering systems, providing insights into their evolution and future trends.

[3] Title: IoT Enabled Smart Energy Meter for Efficient Power Management

Authors: M. Sharma, P. Verma

Publication: Journal of Electrical and Computer Engineering, 2024

Summary: The study proposes an IoT-based energy meter that measures voltage, current, and power consumption in real time. The data is transmitted to a mobile application to help users monitor and manage their electricity usage effectively.

[4] Title: Smart Metering System for Energy Monitoring Using Cloud Platform

Authors: S. Kumar, R. Singh

Publication: IEEE International Conference on Smart Energy Systems, 2023

Summary: This paper presents a smart metering system that monitors electricity consumption using cloud technology. The system collects energy data through sensors and sends it to a cloud server for remote monitoring and analysis.

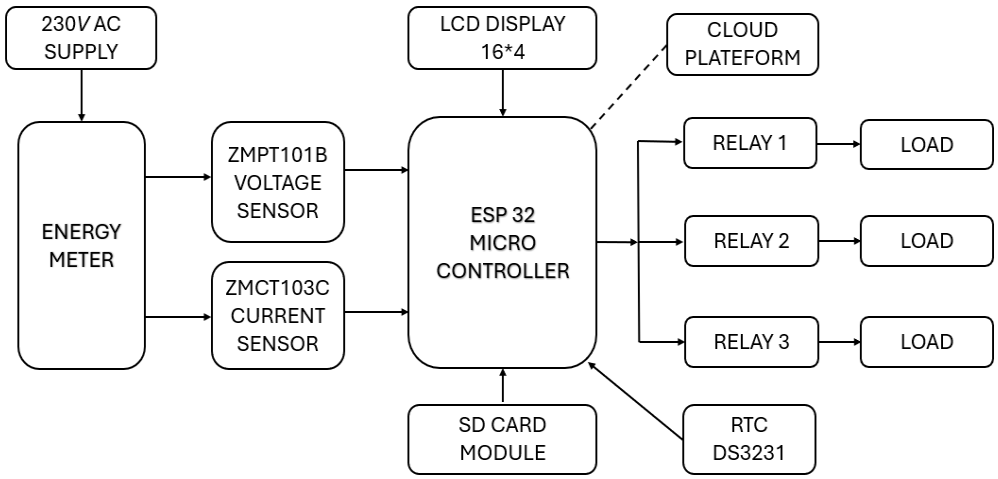
[5] Title: Design and Development of an IoT Smart Meter with Load Control

Author: O. Munoz

Publication: PMC, 2022

Summary: The paper details the design and validation of a smart meter integrated with load control functionalities, aimed at home energy management systems.

III BLOCK DIAGRAM



IV FLOWCHART

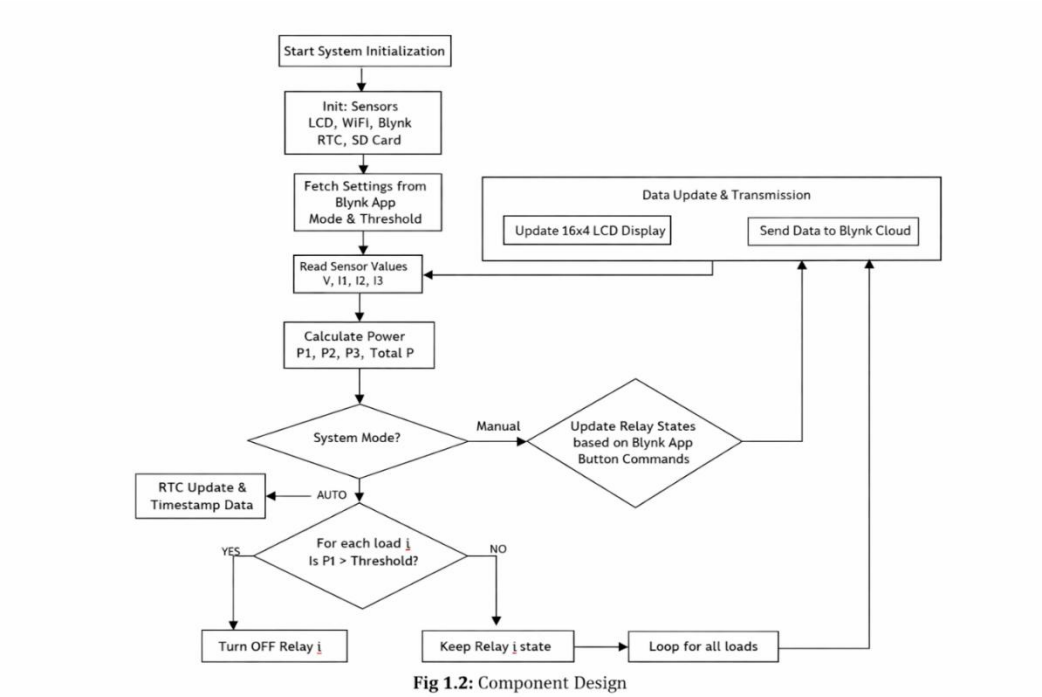


Fig 1.2: Component Design

V ELEVANCE OF THE WORK

The performance of the Smart Energy Meter Adaptive Load Control Monitoring System is evaluated based on accuracy, reliability, response time, and efficiency in energy management. The system successfully measures voltage and current using ZMPT101B and ZMCT103C sensors, providing reliable real-time data. The ESP32 microcontroller processes the sensor inputs efficiently and displays the results on a 16×4 LCD, ensuring user-friendly monitoring. The adaptive load control mechanism is tested by connecting multiple loads (lamps) through relays. The system effectively controls the loads based on predefined conditions such as time or energy consumption, demonstrating its ability to reduce energy wastage. The integration of the RTC DS3231 ensures accurate time-based logging, while the SD card module stores data consistently without loss, enabling future analysis. The dashboard interface on the laptop allows visualization of energy consumption data, improving accessibility and user awareness. The system shows stable performance with minimal delay in data processing and control actions. Overall, the proposed system proves to be cost-effective, efficient, and suitable for real-time energy monitoring and management applications.

VI PROPOSED WORK

The proposed work focuses on the design and implementation of a Smart Energy Meter Adaptive Load Control Monitoring System that enables real-time monitoring, analysis, and control of electrical energy consumption. The system is built using an ESP32 microcontroller, which acts as the central processing unit to collect and process data from voltage and current sensors (ZMPT101B and ZMCT103C). These sensors continuously measure electrical parameters such as voltage and current, allowing accurate calculation of energy consumption.

The measured data is displayed on a 16×4 LCD for immediate user reference and is also transmitted to a laptop-based dashboard for advanced visualization and monitoring. To ensure proper record-keeping, the system integrates an RTC DS3231 module for precise time tracking and an SD card module for storing energy consumption data with timestamps, enabling future analysis and energy auditing. A key feature of the proposed system is adaptive load control, which is achieved using relay modules connected to electrical loads (lamps). The system automatically controls these loads based on predefined conditions such as energy limits, time schedules, or demand levels. This helps in reducing unnecessary power consumption and improving overall energy efficiency. The proposed work aims to provide a cost-effective, scalable, and user-friendly solution for smart energy management. It can be applied in residential, commercial, and industrial environments and can be further enhanced with IoT integration, cloud storage, and smart billing features in the future.

VII METHODOLOGY

The methodology of the Smart Energy Meter Adaptive Load Control Monitoring System involves a systematic approach for data acquisition, processing, control, and storage of energy consumption. Initially, the system is designed by integrating the ESP32 microcontroller with voltage and current sensing units. The ZMPT101B voltage sensor measures the supply voltage, while multiple ZMCT103C current sensors are used to measure the current flowing through different loads. The sensed analogy signals are converted into digital values using the ESP32's internal ADC and are processed to calculate electrical parameters such as voltage, current, and energy consumption. These calculated values are then displayed on a 16×4 LCD module, providing real-time information to the user. For data logging, the system incorporates an RTC DS3231 module to maintain accurate time and date. The measured parameters along with timestamps are stored in an SD card module, enabling historical data analysis and energy auditing. The system also includes an adaptive load control mechanism using relay modules. Based on predefined conditions such as time schedules or energy consumption thresholds, the ESP32 sends control signals to the relays to switch connected loads (lamps) ON or OFF. This helps in optimizing energy usage and reducing wastage. Additionally, the processed data is transmitted to a laptop dashboard for visualization and monitoring. The overall methodology ensures continuous monitoring, efficient control, reliable data storage, and improved energy management.

VIII. RESULT AND DISCUSSIONS

The developed Smart Energy Meter Adaptive Load Control Monitoring System was successfully implemented and tested under different operating conditions. The system accurately measured voltage and current using ZMPT101B and ZMCT103C sensors, and the calculated values were consistently displayed on the 16×4 LCD in real time. The readings were observed to be stable and reliable when compared with standard measurement devices, indicating good accuracy of the sensing and processing units. The data logging feature using the RTC DS3231 and SD card module functioned effectively, storing time-stamped energy consumption data without any significant loss. This enables detailed analysis of energy usage patterns over time. The integration of the laptop dashboard provided clear visualization of the measured parameters, improving user interaction and accessibility.

The adaptive load control mechanism was tested by connecting multiple loads (lamps) through relay modules. The system successfully controlled the loads based on predefined conditions such as time scheduling and energy limits. It was observed that unnecessary power consumption was reduced when the loads were automatically switched OFF during non-essential periods. The overall system demonstrated fast response time, low power consumption, and stable operation. The results confirm that the proposed system is effective for real-time energy monitoring and efficient load management. The discussion highlights that integrating monitoring, data logging, and control in a single system significantly improves energy efficiency and user awareness, making it suitable for practical applications in smart homes and small-scale industries.

IX CONCLUSION

The Smart Energy Meter Adaptive Load Control Monitoring System has been successfully designed and implemented as an efficient solution for real-time energy monitoring and management. The system integrates sensing, processing, control, and data storage functionalities into a single platform using the ESP32 microcontroller. Accurate measurement of electrical parameters such as voltage and current is achieved through ZMPT101B and ZMCT103C sensors, ensuring reliable performance. The inclusion of a 16×4 LCD display provides immediate visualization of energy consumption, while the integration of the RTC DS3231 and SD card module enables continuous data logging with precise timestamps. This feature is particularly useful for energy auditing, historical analysis, and future enhancements like smart billing systems. A significant contribution of this project is the implementation of adaptive load control using relay modules. The system effectively reduces energy wastage by automatically managing connected loads based on predefined conditions such as time schedules or energy thresholds. This improves overall energy efficiency and promotes responsible energy usage. Furthermore, the dashboard monitoring through a laptop enhances user accessibility and awareness, allowing users to track and analyse their energy consumption patterns in real time. The system operates with good stability, fast response, and cost-effectiveness, making it suitable for practical deployment in residential and small-scale industrial environments. In conclusion, the proposed system provides a reliable, scalable, and intelligent solution for modern energy management. It serves as a foundational step towards the development of smart grids and IoT-based energy systems, contributing to sustainable development and efficient utilization of electrical resources.

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