Iot Based Smart Energy Meter

K. Sushma[1], M. Sewag [2], P. Rakshith[3], K. Ashwitha[4], K. Ramyasri[5]
[1]*Assistant Professor, Dept of ECE, TKR College of Engineering and Technology*
[2,3,4,5]*Student, Dept of ECE, TKR College of Engineering and Technology*

Abstract—The increasing demand for electricity and the need for efficient energy management have led to the development of smart metering systems. Traditional energy meters lack real time monitoring, remote accessibility, and effective control mechanisms, resulting in inefficient usage and higher chances of electricity theft. To overcome these limitations, this project presents an IoT-Based Smart Prepaid Energy Meter using ESP32withIR-basedTamper Detection. The proposed system uses the ESP32 microcontroller as the core processing unit to monitor energy consumption through a pulse-based sensing mechanism. The system operates on a prepaid model, where the user maintains a balance that is deducted based on the energy consumed. Real-time data such as units consumed and remaining balance are displayed on an LCD and transmitted to a mobile application using IoT technology. The system also incorporates an IR sensor for tamper detection, which identifies unauthorized access and triggers alerts through a buzzer, LED indicators, and mobile notifications. Additionally, a relay module is used to automatically disconnect the load when the balance reaches zero, ensuring controlled energy usage.

I. INTRODUCTION

The rapid growth in population, urbanization, and industrial development has significantly increased the demand for electrical energy, creating challenges in efficient power management and distribution. Ensuring optimal utilization of electricity, minimizing losses, and maintaining system reliability have become essential in modern power systems. Traditional energy meters, commonly used in residential and commercial sectors, primarily measure electricity consumption in kilowatt-hours (kWh). However, they lack advanced features such as real-time monitoring, remote accessibility, and automated billing. Manual meter reading by utility personnel is time- consuming, labor-intensive, and prone to human errors, leading to inefficiencies in billing and energy management. Additionally, consumers are unable to track their energy usage in real time, which often results in poor energy management and unexpectedly high electricity bills. Another major challenge in conventional metering systems is electricity theft, which includes meter tampering and unauthorized connections. These activities lead to significant revenue losses for utility providers and affect the overall stability of power distribution systems. To overcome these limitations, the integration of Internet of Things (IoT) technology into energy management systems has emerged as an effective solution. IoT enables real-time data collection, monitoring, and communication between devices through the internet, enhancing transparency and efficiency. The proposed system, an IoT-based smart prepaid energy meter using the ESP32 microcontroller, addresses these issues by combining monitoring, control, and communication features. The ESP32, with its built-in Wi-Fi capability, allows seamless connectivity to cloud platforms and mobile applications. This enables users to monitor their energy consumption, recharge their balance, and control electrical appliances remotely. The system operates on a prepaid billing model, where users maintain a balance that is deducted based on their energy usage, promoting responsible consumption and eliminating unpaid bills. Energy consumption is measured using a pulse-based method, ensuring accurate and real-time calculation of units consumed. To enhance security, an infrared (IR) sensor is used for tamper detection, triggering alerts through a buzzer and notifications via the IoT platform. An LCD display provides real-time information such as energy usage and remaining balance. Overall, this system improves efficiency, transparency, and security in energy management.

II. EXISTING METHOD

Energy metering systems have evolved significantly over time, moving from basic electromechanical devices to advanced IoT- enabled smart meters.

Understanding the limitations of existing systems and comparing them with modern solutions is essential to justify the need for innovation. This chapter presents a detailed comparison between conventional energy metering systems and the proposed IoT-based smart prepaid energy meter. It highlights the drawbacks of traditional systems and explains how the proposed design overcomes these challenges using modern technologies. Existing System Traditional energy metering systems are widely used in residential, commercial, and industrial sectors. These systems are typically classified into: Electromechanical meter Digital (static) meters Electromechanical meters operate based on mechanical rotation of a disc, which is proportional to energy consumption. Digital meters, on the other hand, use electronic circuits to measure energy more accurately. Despite their widespread usage, these systems have several limitations. The most common method of operation involves manual meter reading, where utility personnel visit each consumer location periodically to record readings.

In addition, traditional systems follow a postpaid billing model, where users consume electricity first and pay later. This often leads to issues such as delayed payments, billing disputes, and accumulation of unpaid dues. Another major drawback is the lack of real-time monitoring. Users cannot track their electricity usage continuously, making it difficult to control consumption or identify wastage. This lack of awareness often results in inefficient energy usage. Furthermore, conventional meters do not provide adequate security features. They are vulnerable to tampering, unauthorized access, and electricity theft. Since these systems do not have built-in detection mechanisms, such activities often go unnoticed. Some advanced digital meters provide limited automation, but they are often expensive and do not include features such as IoT connectivity, prepaid billing, or remote control.

III. PROPOSED SYSTEM

The proposed system is an IoT-Based Smart Prepaid Energy Meter using ESP32 with IR- based Tamper Detection, designed to address the shortcomings of traditional systems. At the core of the system is the ESP32 microcontroller, which provides high processing capability along with built-in Wi-Fi connectivity. This enables seamless communication with IoT platforms such as mobile applications and cloud servers. The system continuously monitors energy consumption using a pulse-based sensing mechanism. Each pulse corresponds to a unit of energy, which is processed by the ESP32 to calculate total consumption. Unlike conventional systems, the proposed system operates on a prepaid billing model. Users maintain a balance in the system, and the cost of energy consumption is deducted automatically. This ensures better financial control and eliminates issues related to unpaid bills. A key feature of the system is tampering detection using an IR sensor. The sensor continuously monitors the meter for any unauthorized interference. If tampering is detected, the system activates alerts such as a buzzer and LED indicators, and also sends notifications to the user via the IoT platform. The system also includes a relay module to control electrical loads. When the balance reaches zero, the relay automatically disconnects the load, preventing further energy usage. An LCD display provides real-time information such as energy consumption, remaining balance, and system status. Additionally, users can control appliances remotely using a mobile application.

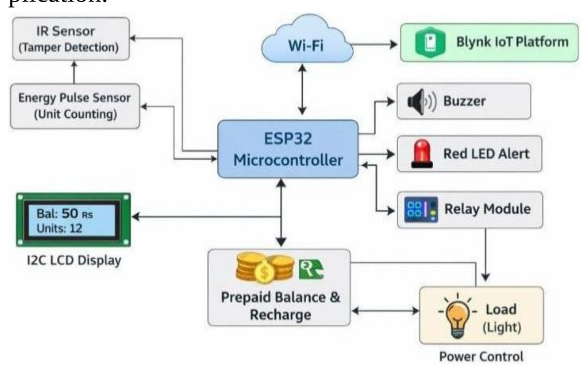

Fig:1 Methodology of proposed system

IV. RESULTS

The IoT-Based Smart Prepaid Energy Meter was tested under different operating conditions to evaluate its performance, accuracy, and reliability. The experimental results indicate that the system functions effectively in monitoring energy consumption, managing prepaid balance, and detecting tampering events. The pulse-based energy measurement mechanism operated accurately during testing. The system successfully detected pulses corresponding to energy usage and calculated the number of units consumed without error. The deduction of balance based on unit consumption was consistent and precise, ensuring reliable prepaid billing. The system also demonstrated a quick response to variations in load, with minimal delay in updating values on both the LCD and the Blynk application.

The automatic power cut-off feature performed as expected. When the prepaid balance reached zero, the system immediately disconnected the load through the relay, preventing further energy consumption. This ensures controlled usage and eliminates the possibility of unpaid electricity consumption. The recharge functionality through the IoT platform worked efficiently, with updated balance values reflected instantly in the system. The IR-based tamper detection mechanism showed reliable performance during testing. When a tampering condition was introduced, the system detected it promptly and activated the buzzer and red LED as warning indicators. Simultaneously, a notification was sent to the user via the IoT platform, confirming effective real-time alert capability. This feature enhances system security and helps in preventing electricity theft. The IoT communication using the Blynk platform was stable and responsive under normal network conditions. Users were able to monitor energy consumption, control connected loads, and receive notifications in real time without significant delays. Overall, the system demonstrated high accuracy, low response time, and effective coordination between hardware and software components. It successfully achieved its objective of providing a smart, automated, and secure energy management solution. Some minor limitations were observed, such as dependency on internet connectivity and the need for proper sensor calibration. However, these factors do not significantly affect the overall performance of the system. In summary, the proposed system proves to be a cost-effective, reliable, and efficient solution for modern energy management, offering improved transparency, reduced electricity theft, and enhanced user control.

V. CONCLUSION

The development of the IoT-Based Smart Prepaid Energy Meter using ESP32 with IR- based Tamper Detection presents an effective and modern solution to the challenges faced by conventional energy metering systems. Traditional meters, which rely on manual readings and postpaid billing, lack transparency, efficiency, and security. The proposed system successfully overcomes these limitations by integrating real-time monitoring, prepaid billing, remote accessibility, and tamper detection into a single platform. The system demonstrates accurate measurement of energy consumption through a pulse-based mechanism, ensuring reliable calculation of electricity usage. The prepaid billing model enhances financial control by allowing users to manage their energy expenses efficiently while eliminating issues related to delayed payments and billing errors. The automatic power cut-off feature further strengthens the system by preventing excessive or unpaid consumption. Overall, the proposed system offers a cost- effective, scalable, and user-friendly approach to modern energy management. It not only improves efficiency and transparency but also contributes to reducing electricity theft and energy wastage. With further enhancements such as integration with smart grids, renewable energy systems, and advanced data analytics, the system has the potential to play a significant role in the future of intelligent energy management and sustainable development.

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