International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 14 Issue 4 ǁ April 2026 ǁ PP. 62-68

Smart Energy Meter with Real-Time Monitoring and Load Control using ESP32, Blynk IoT and Telegram

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ABSTRACT
The increasing demand for electricity and the need for efficient energy management have led to the development of smart energy monitoring systems. Traditional energy meters provide limited information and require manual monitoring, which makes it difficult to track real-time energy consumption and cost. This paper presents a Smart Energy Meter with real-time monitoring and load control using ESP32, Blynk IoT, and Telegram. The proposed system measures electrical parameters such as voltage, current, power, and total energy using ACS712 current sensor and ZMPT101B voltage sensor. The ESP32 microcontroller processes the data and displays it on a 16×2 LCD while simultaneously sending real-time readings to the Blynk IoT dashboard for remote monitoring and control. The system also integrates a Telegram bot that provides load status, voltage, current, power, total energy, and cost information, where the cost is calculated at a rate of ₹6 per unit. A push button is used to reset energy and cost values, and relay modules are used to connect or disconnect loads remotely. The proposed system provides an efficient, low-cost, and user-friendly solution for smart energy monitoring and billing. It is suitable for residential and small industrial applications where real-time monitoring and energy management are required.
Keywords: *Smart Energy Meter, ESP32, Blynk IoT, Telegram Bot, ACS712, ZMPT101B, Energy Monitoring, IoT, Load Control.*

Date of Submission: 01-04-2026 Date of Acceptance: 10-04-2026

I. INTRODUCTION

The rapid growth in electricity consumption has increased the need for efficient energy monitoring and management systems. Traditional energy meters are widely used in residential and industrial applications, but they provide limited information and require manual monitoring of energy consumption and billing. In many cases, users are unable to track their real-time electricity usage, which leads to excessive power consumption and higher electricity bills. Therefore, a smart and automated energy monitoring system is required to improve efficiency, reduce power wastage, and provide real-time information to users.

With the advancement of Internet of Things (IoT) technology, smart energy meters have become more reliable and efficient. IoT-based systems allow users to monitor electrical parameters such as voltage, current, power, and energy consumption remotely through mobile applications and cloud platforms. These systems provide real-time monitoring, remote control, and automated billing, which makes energy management easier and more effective. The integration of wireless communication and cloud-based platforms enables users to access energy data anytime and from anywhere.

The proposed Smart Energy Meter is designed using the ESP32 microcontroller, which provides Wi-Fi connectivity and fast data processing capabilities. The system uses ACS712 current sensor and ZMPT101B voltage sensor to measure electrical parameters accurately. A 16×2 LCD with I2C module is used to display real-time readings locally, while relay modules are used to control electrical loads. The power supply is provided through a rectifier that converts AC mains into 5V DC required for the system components. A push button is included to reset energy and cost values, making the system more user-friendly.

The system is integrated with a Blynk IoT dashboard for real-time monitoring and remote load control. Users can view voltage, current, power, total energy, and cost directly on the dashboard and control the load using relay switches. In addition to this, a Telegram bot is integrated to provide instant notifications and energy reports, including load connected or disconnected status, voltage, current, power, total energy, and cost calculation at a rate of ₹6 per unit. This feature makes the system suitable for smart billing and remote monitoring applications.

The main objective of this project is to develop a low-cost, reliable, and efficient smart energy meter that provides real-time monitoring, remote control, and automated billing using IoT technology. The proposed system helps users monitor their energy consumption, reduce electricity wastage, and improve energy management in residential and small industrial environments.

II. LITERATURE REVIEW AND BACKGROUND

The development of smart energy meters has gained significant attention in recent years due to the increasing demand for efficient energy monitoring and management systems. Researchers and engineers have proposed various IoT-based energy monitoring systems to improve the accuracy, reliability, and accessibility of electrical energy data. Traditional energy meters mainly focus on measuring total energy consumption, but modern smart meters provide real-time monitoring, remote control, and automated billing features, which enhance the overall efficiency of energy management.

Several studies have focused on the implementation of smart energy meters using microcontrollers and wireless communication technologies. Many researchers have used Arduino and GSM modules to send energy consumption data through SMS alerts and remote monitoring systems. These systems provide basic monitoring and billing features, but they lack real-time cloud-based monitoring and user-friendly interfaces. GSM-based systems also increase the cost and complexity of the system, making them less suitable for low-cost applications.

Recent advancements in IoT technology have introduced cloud-based platforms such as Blynk, Thing Speak, and Firebase for real-time energy monitoring. IoT-based smart energy meters allow users to monitor voltage, current, power, and energy consumption through mobile applications and web dashboards. The integration of Wi-Fi-enabled microcontrollers such as ESP8266 and ESP32 has made it easier to develop low-cost and efficient smart monitoring systems. ESP32 provides better processing speed, built-in Wi-Fi, and low power consumption, which makes it suitable for real-time energy monitoring and control applications.

In many existing systems, current sensors such as ACS712 and voltage sensors such as ZMPT101B are commonly used to measure electrical parameters. These sensors provide accurate measurement of voltage and current, which helps in calculating power and energy consumption. Some research works also include relay modules for load control and LCD displays for local monitoring. However, many existing systems do not include an integrated cost calculation and notification system, which limits their practical use in real-time billing applications.

To improve the efficiency of smart energy monitoring, recent research has focused on integrating IoT dashboards and messaging platforms for instant alerts and notifications. Telegram bots and cloud dashboards provide a simple and effective way to monitor energy consumption and receive billing information. These systems allow users to track their electricity usage and cost in real time, reducing energy wastage and improving management.

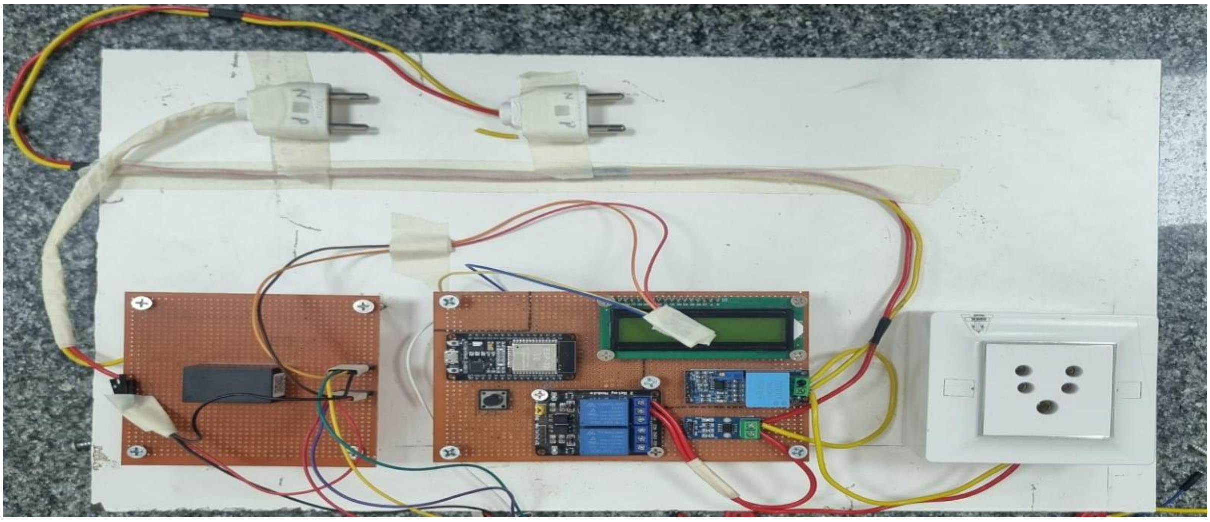

Fig. 1. Hardware implementation of Smart Energy Meter system.

Based on the literature review, it is observed that most existing systems focus on monitoring and data transmission but lack an integrated solution that combines real-time monitoring, load control, cost calculation, and instant notification in a single platform. The proposed Smart Energy Meter system addresses these limitations by using ESP32, ACS712, ZMPT101B, Blynk IoT dashboard, and Telegram bot to provide real-time monitoring, load control, cost calculation at ₹6 per unit, and instant alerts. This makes the proposed system more efficient, user-friendly, and suitable for practical applications in residential and small industrial environments.

III. PROPOSED SYSTEM AND METHODOLOGY

The proposed Smart Energy Meter system is designed to monitor electrical parameters in real time and provide remote access to energy consumption data through IoT platforms. The system integrates sensors, a microcontroller, display unit, relay modules, and communication platforms to create an efficient and low-cost energy monitoring solution. The main objective of the proposed system is to measure voltage, current, power, and total energy consumption and provide real-time monitoring, load control, and cost calculation using ESP32, Blynk IoT, and Telegram bot.

The overall structure of the system consists of an ESP32 microcontroller, ACS712 current sensor, ZMPT101B voltage sensor, 16×2 LCD with I2C module, relay module, push button, rectifier power supply, Blynk IoT dashboard, and Telegram bot. The ACS712 sensor measures the current flowing through the load, while the ZMPT101B sensor measures the supply voltage. The ESP32 processes the sensor data and calculates power and total energy consumption. The measured values are displayed on the LCD and simultaneously transmitted to the Blynk IoT platform and Telegram bot through Wi-Fi.

A. Block Diagram of Proposed System

The block diagram of the Smart Energy Meter system shows the overall flow of data and control. The rectifier converts AC supply into 5V DC to power the ESP32 and other components. The voltage and current sensors measure electrical parameters and send signals to the ESP32. The ESP32 processes the data and displays it on the LCD while also sending the information to the Blynk IoT dashboard and Telegram bot. The relay module is used to connect or disconnect the load remotely, and the push button is used to reset energy and cost values.

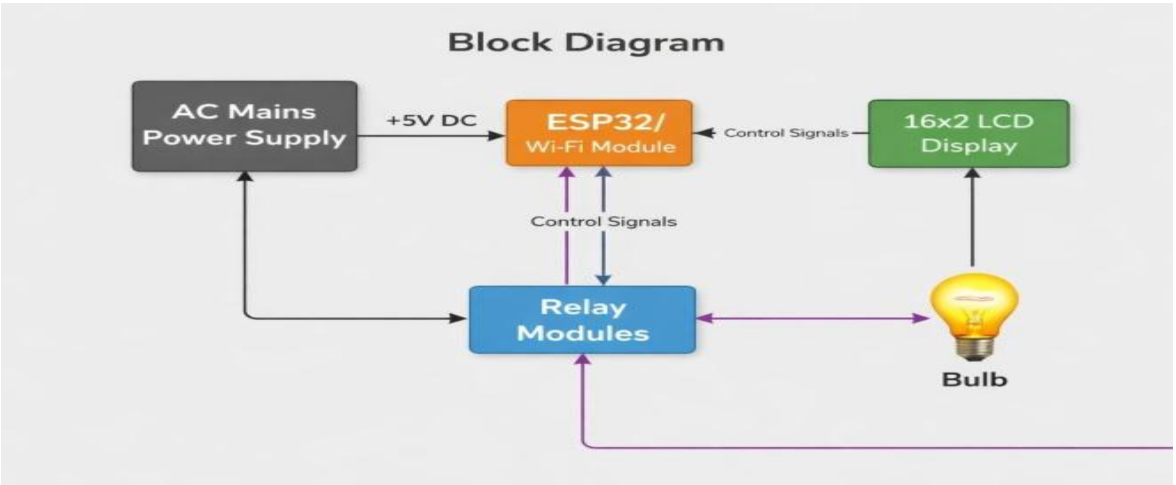

Fig. 2. Block diagram of Smart Energy Meter system.

B. Hardware Implementation

The hardware implementation of the proposed Smart Energy Meter system is designed using low-cost and easily available components. The ESP32 acts as the main controller and manages all operations of the system. The ACS712 current sensor and ZMPT101B voltage sensor are connected to the ESP32 to measure electrical parameters. The LCD display shows real-time voltage, current, power, and energy readings locally. The relay module is connected to control the load, and the push button is used for resetting energy and cost values. The rectifier circuit provides stable 5V DC power to all components.

The hardware setup is compact and easy to install in residential and small industrial environments. The system continuously monitors electrical parameters and sends real-time data to IoT platforms for remote monitoring and control.

C. Circuit Diagram

The circuit diagram of the Smart Energy Meter system shows the detailed connection of all components. The ACS712 current sensor is connected in series with the load to measure current, while the ZMPT101B voltage sensor is connected across the supply to measure voltage.

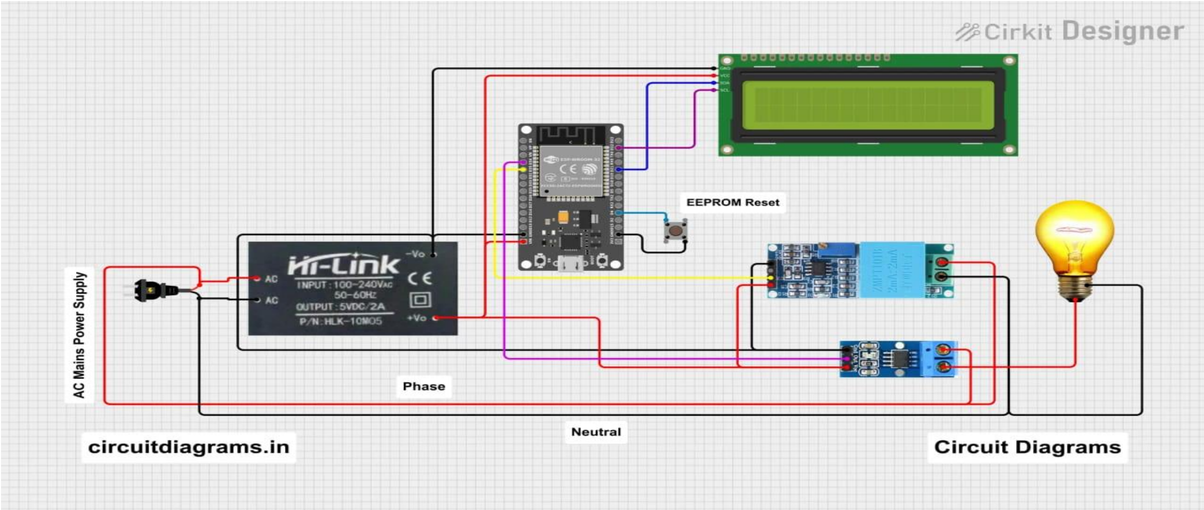

Fig. 3. Circuit diagram of Smart Energy Meter system.

The LCD is connected using the I2C module to reduce wiring complexity. The relay module is connected to ESP32 digital pins to control the load. The push button is connected to reset energy and cost values, and the rectifier provides 5V DC power supply to the system.

The circuit ensures proper measurement, safe operation, and efficient communication between components. The ESP32 processes all input signals and controls the output devices accordingly.

IV. IoT Monitoring and Control

The integration of Internet of Things (IoT) technology in the proposed Smart Energy Meter enables real-time monitoring, remote load control, and automated energy tracking through cloud-based platforms. The ESP32 microcontroller connects to a Wi-Fi network and continuously sends electrical parameter data to the Blynk IoT dashboard and Telegram bot. This allows users to monitor energy consumption and control electrical loads from anywhere using a smartphone or computer.

The Blynk IoT platform provides a user-friendly interface for monitoring voltage, current, power, total energy, and cost in real time. The ESP32 transmits sensor data to the cloud, and the dashboard displays it in graphical and numerical format. Users can remotely control the connected loads using relay switches available on the dashboard. This feature helps in efficient energy management and reduces unnecessary power consumption. A cost reset button is also provided on the dashboard, which allows users to reset energy and cost values for a new billing cycle. This feature is useful for monthly energy tracking and accurate billing.

In addition to Blynk monitoring, the system integrates a Telegram bot for instant notifications and energy updates. The Telegram bot provides real-time information such as load connected or disconnected status, voltage, current, power, total energy consumption, and calculated cost at a rate of ₹6 per unit. The cost value is highlighted in the Telegram message to make billing information clearly visible to the user. The Telegram bot acts as a remote dashboard and notification system, providing quick updates and alerts whenever there is a change in load status or energy consumption.

Fig. 4. Blynk IoT dashboard for real-time monitoring and load control with cost reset button

The combination of Blynk IoT dashboard and Telegram bot makes the system more efficient and reliable. While Blynk provides continuous monitoring and remote control, Telegram provides instant alerts and billing information. This dual-platform approach improves the overall functionality of the Smart Energy Meter and ensures that users receive real-time updates and control over their electrical system

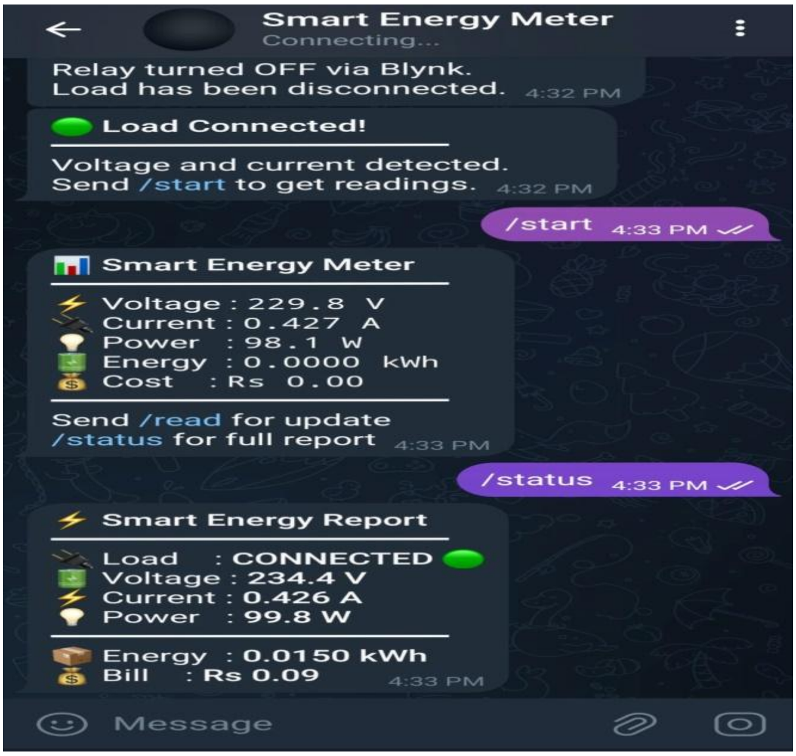

Fig. 5. Telegram bot dashboard showing load status, voltage, current, power, total energy, and cost information.

V. WORKING PRINCIPLE

The working principle of the proposed Smart Energy Meter is based on real-time measurement of electrical parameters and transmission of data to IoT platforms for monitoring and control. The system operates using an ESP32 microcontroller, which acts as the central processing unit and manages all sensors, display, relay modules, and communication with Blynk IoT and Telegram bot. The system is powered by a rectifier circuit that converts AC supply into stable 5V DC required for the ESP32, sensors, LCD, and relay modules.

Initially, the AC supply is provided to the system, and the rectifier converts it into 5V DC to power the components. The ZMPT101B voltage sensor is connected across the supply line to measure voltage, while the ACS712 current sensor is connected in series with the load to measure current flowing through the circuit. The ESP32 reads analog signals from both sensors and processes the data to calculate electrical parameters such as voltage, current, power, and total energy consumption. The calculated values are continuously updated and displayed on the 16×2 LCD with I2C module for local monitoring.

The ESP32 then connects to the Wi-Fi network and sends real-time data to the Blynk IoT dashboard. The dashboard displays voltage, current, power, total energy, and cost values, allowing users to monitor energy consumption remotely. The relay modules are controlled through the Blynk dashboard, enabling users to connect or disconnect electrical loads from anywhere. This remote control feature helps in reducing energy wastage and improving system efficiency.

Simultaneously, the ESP32 sends energy data to the Telegram bot, which provides instant notifications and billing information. The Telegram bot displays load connected or disconnected status, voltage, current, power, total energy, and cost calculated at ₹6 per unit. The cost value is highlighted to make billing information clearly visible to the user. This ensures that users receive real-time updates and can monitor their electricity usage effectively.

A push button is included in the system to reset energy and cost values. When the push button is pressed, the ESP32 resets the total energy and cost calculation and starts a new monitoring cycle. This feature is useful for monthly billing and system maintenance. The continuous monitoring and control process ensures reliable performance and efficient energy management in residential and small industrial applications.

VI. HARDWARE IMPLEMENTATION

The hardware implementation of the proposed Smart Energy Meter system is designed using low-cost and easily available components to ensure reliable and efficient performance. The system consists of ESP32 microcontroller, ACS712 current sensor, ZMPT101B voltage sensor, 16×2 LCD with I2C module, relay module, rectifier power supply, and push button. All components are properly connected to measure electrical parameters and transmit real-time data to IoT platforms for monitoring and control.

The ESP32 microcontroller acts as the main controller of the system and manages all operations, including data processing, sensor interfacing, Wi-Fi communication, and relay control. It receives analog input signals from the ACS712 current sensor and ZMPT101B voltage sensor and converts them into digital values for calculation of power and energy. The ESP32 then sends the processed data to the Blynk IoT dashboard and Telegram bot for remote monitoring and billing.

The ACS712 current sensor is used to measure the current flowing through the load. It is connected in series with the load and provides analog output proportional to the current. The ZMPT101B voltage sensor is used to measure the supply voltage and is connected across the AC supply line. Both sensors provide accurate electrical parameter measurement, which helps in calculating power and total energy consumption.

A 16×2 LCD with I2C module is used to display real-time electrical parameters such as voltage, current, power, and total energy. The I2C module reduces wiring complexity and allows easy communication with the ESP32. The relay module is used to control electrical loads remotely through the Blynk IoT dashboard and Telegram system. The relay allows users to connect or disconnect the load, which improves energy management and system safety.

The rectifier circuit is used to convert AC supply into stable 5V DC required for the ESP32 and other components. This ensures proper power supply and stable operation of the system. A push button is connected to the ESP32 to reset energy and cost values, allowing users to start a new billing cycle when required. The overall hardware design is compact, efficient, and suitable for practical implementation in residential and small industrial environments.

VII. RESULTS AND DISCUSSION

The proposed Smart Energy Meter system was successfully designed and tested to monitor electrical parameters in real time and provide remote access through IoT platforms. The system was implemented using ESP32, ACS712 current sensor, ZMPT101B voltage sensor, LCD display, relay module, Blynk IoT dashboard, and Telegram bot. The experimental results show that the system is capable of measuring voltage, current, power, total energy, and cost accurately and displaying the data on both local and remote platforms.

The LCD display shows real-time electrical parameters such as voltage, current, power, and total energy consumption, allowing users to monitor the system locally. The readings are updated continuously, which helps in observing the performance of connected loads. The system maintains stable operation and provides consistent readings during testing.

The Blynk IoT dashboard provides real-time monitoring and remote control of electrical loads. Users can view voltage, current, power, total energy, and cost directly on their smartphones. The relay module allows remote connection and disconnection of loads, which improves energy management and reduces unnecessary power consumption. The cost reset button on the dashboard helps in resetting energy and cost values for a new billing cycle. The Blynk platform provides a smooth and user-friendly interface for monitoring and control.

The Telegram bot provides instant notifications and energy reports, which enhance the functionality of the system. The Telegram dashboard shows load connected or disconnected status, voltage, current, power, total energy, and cost calculated at ₹6 per unit. The cost value is highlighted in the message to make billing information easily visible. This feature helps users track their electricity usage and expenses in real time. The Telegram bot also provides quick updates whenever the load status changes, making the system more responsive and efficient.

The overall performance of the Smart Energy Meter system is reliable and efficient. The integration of IoT platforms ensures real-time monitoring, remote control, and automated billing. The system reduces manual monitoring and provides accurate energy data, making it suitable for residential and small industrial applications. The results demonstrate that the proposed system is a practical and low-cost solution for smart energy monitoring and management.

VIII. CONCLUSION

The proposed Smart Energy Meter with real-time monitoring and load control using ESP32, Blynk IoT, and Telegram provides an efficient and reliable solution for modern energy management. The system successfully measures electrical parameters such as voltage, current, power, and total energy using ACS712 and ZMPT101B sensors and displays the data on a 16×2 LCD for local monitoring. The ESP32 microcontroller processes the sensor data and transmits it to the Blynk IoT dashboard and Telegram bot through Wi-Fi, enabling remote monitoring and control of electrical loads.

The integration of Blynk IoT allows users to monitor energy consumption in real time and control connected loads using relay modules, while the Telegram bot provides instant notifications and billing information, including load status, voltage, current, power, total energy, and cost calculated at ₹6 per unit. The push button reset feature helps in managing monthly billing cycles by resetting energy and cost values. The system is low-cost, user-friendly, and easy to install, making it suitable for residential and small industrial applications.

The results show that the proposed system improves energy monitoring, reduces manual effort, and provides real-time control and billing information. The combination of IoT monitoring, Telegram notification, and load control makes the system more practical and efficient compared to traditional energy meters. In the future, the system can be enhanced by adding cloud data storage, mobile application integration, advanced billing analytics, and renewable energy monitoring to further improve performance and usability.

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