

# INDUSTRY LEVEL-SMART METER

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**Abstract:** The rapid growth in energy demand and the need for efficient power utilization have accelerated the adoption of intelligent energy monitoring systems. Conventional electricity meters lack real-time monitoring, user interaction, and automated control, which often results in inefficient energy usage and billing inaccuracies. To address these challenges, this paper presents the design and implementation of a Smart Prepaid Energy Meter with Automatic Power Cut-Off based on Internet of Things (IoT) technology.

The proposed system employs a Wemos D1 microcontroller integrated with voltage and current sensing modules to continuously monitor electrical parameters and compute power consumption in real time. The measured data is displayed locally on a 16x2 LCD and transmitted to a web-based application through Wi-Fi for remote monitoring and analysis. A prepaid billing mechanism is incorporated, where users recharge their account using a simulated currency for demonstration purposes. The system dynamically deducts the balance according to energy usage, and when the balance reaches zero, the power supply is automatically disconnected using a relay module.

Additionally, the web application provides features such as consumption history, graphical visualization, and intelligent recommendations for energy conservation. The proposed system is cost-effective, scalable, and suitable for industrial and residential applications. It promotes energy awareness, enhances user control, and ensures efficient power management through automation and real-time data accessibility.

**Keywords:** Smart Meter, IoT, Prepaid Energy Meter, Wemos D1, Power Monitoring, Automatic Power Cut, Energy Management, Web Application.

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## I. INTRODUCTION

The increasing dependence on electrical energy in industrial, commercial, and residential sectors has created a strong need for efficient energy monitoring and management systems. Conventional electricity meters primarily record cumulative energy consumption and require manual intervention for billing and monitoring. Such systems lack real-time visibility, user interaction, and intelligent control, which often results in energy wastage, delayed billing cycles, and inefficient usage patterns.

With the evolution of the Internet of Things (IoT), modern energy systems are becoming more interconnected and data-driven. Smart metering technologies enable continuous monitoring of electrical parameters such as voltage, current, and power, allowing users to access real-time information remotely. These systems not only improve transparency but also help in identifying consumption patterns and optimizing energy usage. Furthermore, IoT-based solutions facilitate integration with web and mobile platforms, enhancing user engagement and decision-making capabilities.

Prepaid energy metering systems have emerged as an effective solution to overcome billing inefficiencies and promote responsible energy consumption. In such systems, users pay for electricity in advance, and the consumption is deducted from the available balance. This approach eliminates the need for manual billing, reduces revenue losses, and encourages users to manage their energy usage more effectively. Additionally, the integration of automatic control mechanisms, such as relay-based power disconnection, ensures that electricity supply is regulated based on the available balance.

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In this context, the proposed system introduces a Smart Prepaid Energy Meter with Automatic Power Cut-Off, which combines IoT-based monitoring with a web-enabled user interface. The system continuously measures electrical parameters using sensing modules and processes the data through a Wemos D1 microcontroller. The collected data is displayed locally and transmitted to a web application for visualization, analysis, and storage. A simulated recharge mechanism is incorporated to demonstrate prepaid functionality without involving real financial transactions.

The key contributions of this work include:

- Real-time monitoring of electrical parameters using IoT technology
- Integration of a prepaid billing system with automated balance deduction
- Automatic power cut-off using relay control when balance is exhausted
- Web-based dashboard for data visualization, history tracking, and energy-saving recommendations

The proposed system aims to enhance energy efficiency, improve user awareness, and provide a scalable solution for smart energy management in industrial and residential applications.

### A. Problem Statement

Traditional electricity metering systems provide only cumulative energy readings and lack real-time monitoring, user interaction, and automated control. This limitation reduces transparency and prevents users from effectively managing their energy consumption. Additionally, postpaid billing systems often lead to delayed payments, billing inaccuracies, and inefficient usage patterns due to the absence of immediate feedback.

In industrial and residential settings, the lack of automated control mechanisms makes it difficult to regulate power usage based on predefined limits or available budget. Furthermore, existing systems are not well integrated with web-based platforms, restricting remote monitoring and data analysis capabilities.

Therefore, there is a need for an IoT-based smart energy meter that enables real-time monitoring, supports prepaid billing, and automatically disconnects power when the balance is exhausted, while also providing remote access and usage insights through a web application.

## II. LITERATURE SURVEY

Recent advancements in smart energy systems have focused on integrating IoT technologies with traditional metering infrastructure to improve efficiency, transparency, and user control. Several researchers have proposed solutions combining real-time monitoring, wireless communication, and intelligent billing mechanisms.

A smart energy meter based on IoT was proposed in [10], where real-time energy consumption data is transmitted to a cloud platform for monitoring and analysis. The system improved accessibility but lacked a prepaid billing mechanism, limiting its control over user consumption.

In [11], a prepaid energy meter using GSM technology was developed, allowing users to recharge their balance through SMS-based communication. While the system introduced prepaid functionality, it relied on outdated communication methods and lacked web-based visualization features.

An IoT-enabled smart meter with mobile application support was presented in [12], enabling users to monitor electricity usage remotely. However, the system did not include an automatic power cut-off feature, which is essential for enforcing consumption limits.

The work in [13] introduced a smart metering system with real-time monitoring and load control using relay modules. Although the system demonstrated effective automation, it did not incorporate a structured billing or recharge mechanism.

A cloud-based energy monitoring system was proposed in [14], where data analytics and visualization tools were used to provide insights into consumption patterns. Despite its advanced analytics capabilities, the system lacked integration with prepaid energy management.

In [15], a prepaid smart meter with automatic disconnection was developed, ensuring that power supply is cut when the balance reaches zero. However, the system had limited user interface capabilities and did not provide detailed consumption analytics.

Another study in [16] focused on energy optimization using IoT and machine learning techniques to predict usage patterns. While it offered intelligent recommendations, it did not address real-time billing or user-level financial control.

A wireless smart metering system using Wi-Fi-based microcontrollers was presented in [17], demonstrating efficient real-time data transmission. However, the system lacked a comprehensive web application for visualization and user interaction.

From the existing literature, it is evident that most systems address individual aspects such as monitoring, prepaid billing, or automation, but lack a unified solution integrating all these features into a single platform.

**TABLE 2.1: Literature Summary Table**

Ref	System Type	Key Features	Limitations
[10]	IoT Smart Meter	Real-time monitoring, cloud storage	No prepaid system
[11]	GSM Prepaid Meter	Recharge via SMS	No web interface
[12]	IoT + Mobile App	Remote monitoring	No auto power cut
[13]	Smart Meter + Relay	Load control	No billing system
[14]	Cloud Monitoring	Data analytics, visualization	No prepaid feature
[15]	Prepaid Meter	Auto disconnection	Limited analytics
[16]	IoT + ML	Usage prediction	No billing integration
[17]	Wi-Fi Smart Meter	Real-time transmission	No full web dashboard

**B. Research Gap**

Based on the literature review, the following gaps are identified:

- Lack of integrated systems combining monitoring, prepaid billing, and automation
- Limited use of web-based dashboards for visualization and user interaction
- Absence of real-time balance tracking with automatic power cut-off
- Insufficient focus on user-friendly recharge systems (demo or scalable)
- Minimal implementation of energy-saving recommendations

**III. PROPOSED METHODOLOGY**

The proposed system presents an Internet of Things (IoT)-based smart prepaid energy metering solution designed to monitor, control, and manage electricity consumption efficiently. The system integrates sensing modules, a microcontroller unit, a relay-based control mechanism, and a web-based interface to provide a unified platform for real-time monitoring and automated power regulation.

The core of the system is the Wemos D1 microcontroller, which is responsible for acquiring data from the voltage and current sensing modules. These sensors continuously measure the electrical parameters of the connected load, and the acquired analog signals are processed to determine instantaneous voltage and current values. Based on these measurements, the system computes power consumption using standard electrical relationships. The energy consumed over time is calculated and used as the basis for billing and balance deduction.

A prepaid billing mechanism is incorporated into the system to ensure controlled energy usage. In this approach, the user recharges the system using a simulated currency for demonstration purposes. The recharge amount is mapped to equivalent energy units, and the system continuously deducts the consumed energy from the available balance. This real-time balance tracking ensures that users remain aware of their consumption and encourages efficient usage behavior.

To enforce consumption limits, a relay module is integrated into the system for power control. The relay operates based on the available balance: when the balance is greater than zero, the relay remains in the ON state, allowing power to flow to the load. Conversely, when the balance is depleted, the relay is automatically switched OFF, thereby disconnecting the power supply. This automated power cut-off mechanism eliminates the need for manual intervention and ensures strict adherence to the prepaid model.

The system also incorporates wireless communication capabilities through the Wi-Fi-enabled Wemos D1 module. The processed data, including voltage, current, power consumption, energy usage, and remaining balance, is transmitted to a web-based application. The web interface provides real-time monitoring, historical data analysis, graphical visualization, and user-friendly interaction. Additionally, the platform can generate energy-saving recommendations based on consumption patterns, further enhancing the efficiency of the system.

Overall, the proposed methodology combines real-time sensing, prepaid billing, automated control, and remote monitoring into a single integrated framework. This approach addresses the limitations of conventional metering systems by providing improved transparency, user control, and energy management capabilities, making it suitable for both industrial and residential applications.

#### IV. SYSTEM ARCHITECTURE

The system architecture of the proposed smart prepaid energy meter is designed to integrate hardware components and software modules into a unified IoT-based framework. It consists of four primary layers: the sensing layer, processing layer, control layer, and application layer. These layers work together to ensure real-time monitoring, data processing, automated control, and remote accessibility.

At the sensing layer, voltage and current sensor modules are employed to continuously measure the electrical parameters of the connected load. The voltage sensor detects the supply voltage, while the current sensor measures the load current. These sensors provide analog signals proportional to the measured values, which are then forwarded to the processing unit for further computation.

The processing layer is centered around the Wemos D1 microcontroller, which is based on the ESP8266 Wi-Fi module. This unit performs analog-to-digital conversion and processes the incoming sensor data to calculate key parameters such as power and energy consumption. The microcontroller also manages the prepaid billing logic by tracking the available balance and deducting the consumed energy in real time. Additionally, it handles communication with external systems through its built-in Wi-Fi capability.

The control layer incorporates a relay module that is responsible for regulating the power supply to the load. The relay is directly controlled by the microcontroller based on the prepaid balance status. When sufficient balance is available, the relay remains activated, allowing uninterrupted power flow. However, when the balance is exhausted, the microcontroller sends a signal to deactivate the relay, thereby disconnecting the load from the power supply. This mechanism ensures automatic enforcement of energy usage limits without human intervention.

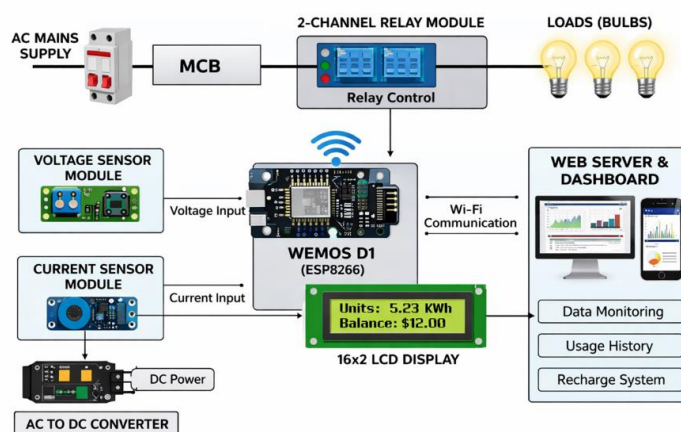


Figure 4.1: System Architecture

The application layer consists of a web-based platform that enables remote monitoring and data visualization. The processed data is transmitted from the microcontroller to the web server using wireless communication. The web application displays real-time parameters such as voltage, current, power consumption, energy usage, and remaining balance. It also maintains a database of historical records, allowing users to analyze consumption trends through graphical representations such as bar charts and line graphs. Furthermore, the system can provide recommendations for efficient energy usage based on observed patterns.

In addition to remote monitoring, a 16x2 LCD display is integrated into the system to provide local feedback to the user. The display shows essential information such as current consumption and remaining balance, ensuring accessibility even without internet connectivity.

Overall, the proposed system architecture establishes a seamless interaction between hardware and software components, enabling efficient energy monitoring, automated control, and user-friendly data access. This layered approach enhances system scalability, reliability, and adaptability for real-world applications in smart energy management systems.

### V. IMPLEMENTATION

The implementation of the proposed smart prepaid energy meter system involves the integration of hardware components with embedded programming and a web-based application. The system is developed as a prototype to demonstrate real-time energy monitoring, prepaid billing, and automatic power control using IoT technology.

The hardware implementation begins with the connection of the AC supply, which is routed through a Miniature Circuit Breaker (MCB) for safety purposes. The output of the MCB is connected to a relay module that controls the power supply to the load, represented by multiple bulbs in the prototype setup. The relay acts as a switching device and is controlled by the Wemos D1 microcontroller based on the available prepaid balance.

To measure electrical parameters, a voltage sensor module and a current sensor module are interfaced with the microcontroller. The voltage sensor is connected in parallel with the load to measure supply voltage, while the current sensor is connected in series with the load to measure current flow. The sensor outputs are fed into the analog input pins of the Wemos D1, where they are converted into digital values for processing.

An AC-to-DC converter is used to provide a regulated DC power supply to the microcontroller and associated components. The Wemos D1 operates as the central processing unit, executing the embedded program developed using the Arduino IDE. The program is responsible for reading sensor values, calculating power and energy consumption, updating the prepaid balance, and controlling the relay module accordingly.

A 16x2 LCD display is integrated into the system using an I2C interface to minimize wiring complexity. The display provides real-time information such as voltage, current, energy consumed, and remaining balance, enabling local monitoring without requiring internet access.

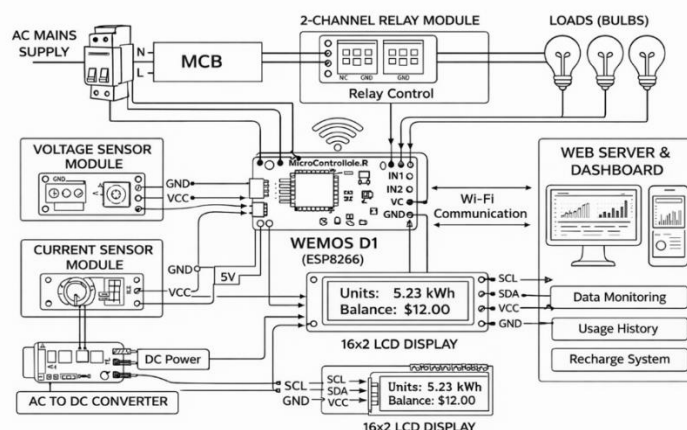


Figure 5.1: Circuit Diagram

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For communication, the built-in Wi-Fi capability of the Wemos D1 is utilized to transmit data to a web server. The system sends periodic updates containing electrical parameters and balance information. On the server side, a web application is developed to receive, store, and visualize the data. The application includes features such as real-time dashboards, historical data tracking, graphical analysis using charts, and a simulated recharge system.

The prepaid functionality is implemented through a software-based logic where the user adds a predefined amount of virtual currency via the web interface. This amount is converted into equivalent energy units, and the system continuously deducts the consumed energy from the available balance. When the balance reaches zero, the microcontroller triggers the relay to disconnect the load, thereby cutting off the power supply automatically.

The entire system operates in a continuous loop, ensuring real-time monitoring and control. The implementation demonstrates a reliable and scalable solution for smart energy management, combining hardware efficiency with software intelligence and user-friendly interaction.

## VI. RESULTS AND DISCUSSION

The performance of the proposed smart prepaid energy meter system was evaluated based on its ability to accurately measure electrical parameters, manage prepaid balance, and provide real-time monitoring through a web-based interface. The system was tested using multiple loads (bulbs) under varying operating conditions to analyze its reliability and effectiveness.

The voltage and current sensing modules were observed to provide stable and consistent readings when compared with standard measuring instruments. Minor variations were recorded due to sensor tolerance and environmental factors; however, the overall accuracy remained within acceptable limits for practical applications. The calculated power and energy consumption values closely matched the expected theoretical values, demonstrating the correctness of the implemented mathematical model.

The prepaid billing mechanism was tested by initializing the system with a predefined balance using simulated currency. As the load consumed energy, the balance was reduced proportionally in real time. The system successfully maintained accurate tracking of the remaining balance, and the deduction process was smooth and continuous without noticeable delays. When the balance reached zero, the relay module was automatically deactivated, resulting in an immediate disconnection of the load. This confirmed the reliability of the automatic power cut-off feature.

The web-based application effectively displayed real-time data, including voltage, current, power consumption, and remaining balance. The data transmission via Wi-Fi was stable, with minimal latency observed during testing. The application also stored historical data, which was used to generate graphical representations such as bar charts and line graphs for energy consumption analysis. These visualizations helped in identifying usage patterns and peak consumption periods.

Furthermore, the system demonstrated good responsiveness in updating data on both the LCD display and the web interface. The integration of local and remote monitoring ensured that users could access system information even in the absence of internet connectivity. The energy-saving recommendation feature provided basic insights based on consumption trends, enhancing user awareness and promoting efficient energy usage.

Overall, the proposed system achieved reliable performance in terms of measurement accuracy, real-time monitoring, prepaid balance management, and automated control. The results validate the effectiveness of the system in providing a practical and scalable solution for smart energy management applications.

## VII. CONCLUSION & FUTURE SCOPE

The proposed Smart Prepaid Energy Meter with Automatic Power Cut-Off system successfully demonstrates an efficient and reliable solution for modern energy management. By integrating IoT technology with real-time monitoring, prepaid billing, and automated control, the system addresses the key limitations of conventional energy meters. The implementation using a Wemos D1 microcontroller, along with voltage and current sensing modules, enables accurate measurement of electrical parameters and continuous tracking of energy consumption.

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The system effectively manages prepaid balance through a simulated recharge mechanism, ensuring controlled energy usage. The automatic power cut-off feature, implemented via a relay module, provides a reliable method for enforcing consumption limits without manual intervention. Additionally, the integration of a web-based application enhances user interaction by offering real-time monitoring, historical data analysis, and graphical visualization of energy usage. The overall system is cost-effective, scalable, and suitable for both industrial and residential applications, promoting energy efficiency and user awareness.

Despite its effectiveness, there are several opportunities for further enhancement. Future work can focus on integrating secure digital payment gateways to replace the simulated recharge system, making the solution suitable for real-world deployment. The system can also be extended by developing a dedicated mobile application to improve accessibility and user experience. Advanced data analytics and machine learning techniques can be incorporated to provide more accurate energy consumption predictions and personalized recommendations.

Moreover, the inclusion of alert mechanisms such as SMS or email notifications for low balance and abnormal usage can improve system responsiveness. Hardware improvements, including higher precision sensors and enhanced safety mechanisms, can further increase system reliability. Integration with smart grid infrastructure and renewable energy sources can also be explored to expand the scope of the system in future smart city applications.

In conclusion, the proposed system provides a comprehensive and practical approach to smart energy management by combining monitoring, control, and user interaction into a single platform. It lays a strong foundation for future advancements in intelligent energy systems and contributes to the development of sustainable and efficient power management solutions.

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