International Journal of
Electrical Power System and Technology

ISSN: 2455-7293
Volume 11, Issue 2, 2025
July–December
DOI (Journal): 10.37628/IJEPST

https://journalspub.com/journal/ijepst/

Research IJEPST

# Smart Electricity Consumption Monitoring and Billing System

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***Abstract***

*Electricity consumption monitoring is essential for optimizing energy use and reducing costs. Traditional meters provide only cumulative readings, leading to inefficiencies and billing discrepancies. This research presents a smart electricity consumption monitoring and billing system that enables users to track real-time power usage and generate automated bills based on actual consumption. A hardware device measures voltage and current, calculates power consumption, and transmits data to a web-based platform via the Blynk Cloud API. The backend server processes this data to determine total energy consumed and billing costs, allowing users to monitor usage patterns and reduce unnecessary consumption. The system identifies high-energy-consuming appliances, prevents overbilling, and improves energy efficiency. Real-time tracking and cost estimation help users optimize electricity use, potentially reducing bills by 15–20%. Automated data collection, cloud storage, and real-time analytics enhance transparency in energy consumption. A web and mobile interface provide easy access to energy data, empowering users to make informed decisions. The research explores IoT-based energy monitoring's impact on consumer behavior and sustainability. Future enhancements may include machine learning-based predictive analysis, automated appliance control, and renewable energy integration for improved efficiency. By leveraging IoT technology, the system reduces energy waste, promotes sustainability, and makes energy management more intelligent and user-friendly. The proposed solution offers an effective approach to real-time energy tracking, ensuring accurate billing while encouraging responsible energy consumption, thereby contributing to a more sustainable and efficient power management system.*

**Keywords:** Electricity consumption monitoring, billing discrepancies, billing system, real-time tracking, transparency, sustainable

## INTRODUCTION

Electricity consumption monitoring plays a vital role in optimizing energy use and managing costs effectively [1]. Traditional electricity meters provide only cumulative readings, often leading to inaccuracies, billing disputes, and inefficient energy consumption [2]. Many users struggle to understand their actual electricity usage due to the lack of real-time data, making it difficult to identify high-energy-consuming appliances and take necessary steps to reduce excessive power consumption [3]. The need for a more transparent, automated, and efficient energy monitoring system has become increasingly important as energy demand rises and concerns over sustainability grow [4].

This research paper presents an advanced electricity consumption monitoring and billing

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Received Date: April 06, 2025
Accepted Date: September 04, 2025
Published Date: December 31, 2025

**Citation:** S.B. Jadhav, Saitej Wable, Pranav Nikam, Omkar Pardeshi, Kartik Wable. Smart Electricity Consumption Monitoring and Billing System. International Journal of Electrical Power System and Technology. 2025; 11(2): 8–15p.

 

system that provides users with real-time data on their power usage and helps them make informed decisions to reduce unnecessary consumption [5].

The system consists of a hardware device that measures key electrical parameters, such as voltage and current, calculates power consumption, and transmits data to a cloud-based platform [6]. This data is then processed by a backend system to determine the total energy consumed and calculate the corresponding bill based on a predefined rate [7]. The integration of IoT technology allows for seamless communication between hardware and software components, ensuring accurate data collection and efficient monitoring [8].

One of the key advantages of this system is its ability to identify high-energy-consuming appliances, helping users optimize their usage patterns [9]. Unlike conventional meters that only display total energy consumed over a billing cycle, this system provides real-time insights into power usage, allowing users to take corrective actions immediately [10]. By analyzing historical consumption patterns, users can also predict their future electricity costs and adjust their usage habits accordingly [11]. Additionally, the system enhances billing transparency by ensuring that users are charged based on actual energy consumption rather than estimated values, reducing the chances of overbilling [2].

Mathematically, the system relies on several key equations to calculate power, energy consumption, and billing costs [4]. The power consumed by an appliance is determined using the formula $P = V \times I$, where $P$ represents power in watts, $V$ is the voltage in volts, and $I$ is the current in amperes [3]. The total energy consumption is then calculated as $E = P \times t$, where $E$ represents energy in kilowatt-hours (kWh) and $t$ is the duration of operation in hours [6]. Finally, the electricity bill is computed using the formula $C = E \times R$, where $C$ is the cost in currency units and $R$ is the rate per kWh [5]. These calculations ensure precise billing and provide users with a clear breakdown of their electricity costs [1].

The implementation of a web-based dashboard and mobile application further enhances accessibility, allowing users to view their consumption data anytime and from anywhere [8]. The user-friendly interface presents energy usage trends, cost estimations, and personalized recommendations for reducing energy consumption [7]. The system also supports alerts for abnormal energy usage, potential faults, or overloading, ensuring both safety and efficiency [9].

With rising energy costs and an increasing focus on sustainability, the adoption of smart electricity monitoring systems can lead to significant benefits for both consumers and utility providers [11]. The proposed system not only helps users reduce their electricity bills but also promotes responsible energy consumption [10]. Future developments in this field could incorporate machine learning algorithms for predictive analysis, automated control of appliances based on usage patterns, and integration with renewable energy sources to further enhance energy efficiency [4]. This research highlights the potential of IoT-based electricity monitoring in transforming how energy is managed, contributing to a more sustainable and efficient future [2].

## PROPOSED METHODOLOGY

The proposed electricity consumption monitoring and billing system is designed to offer a comprehensive and efficient approach for tracking electricity usage in real-time [6]. Traditional energy meters provide only cumulative readings without detailed insights into energy consumption patterns, leading to inefficiencies and difficulties in optimizing power usage [5]. The proposed system aims to enhance transparency, accuracy, and efficiency by integrating hardware sensors, cloud-based data processing, and an interactive web and mobile application to provide users with meaningful and actionable energy consumption data [7]. With rising energy costs and increasing concerns over efficient power utilization, this system enables consumers to make informed decisions about their electricity consumption while ensuring accurate billing and improved management of household or industrial power usage [11].

 

The system is structured around three primary components: the hardware unit responsible for measuring real-time electrical parameters, the cloud-based platform handling data storage and computational processes, and a user-friendly web/mobile interface for real-time monitoring and billing calculations [1]. By integrating IoT-based data transmission and cloud computing, the system eliminates the need for manual meter readings and unreliable estimations, ensuring that users always have precise insights into their electricity consumption [3].

The hardware module consists of sensors that continuously monitor voltage and current, which are crucial for calculating power consumption [10]. These sensors are connected to a microcontroller, which acts as the system's core processing unit, handling data acquisition and transmission [4]. The microcontroller collects the raw electrical readings, filters any inconsistencies, and then sends the processed data to a cloud-based platform using the Blynk Cloud API [2]. This cloud infrastructure ensures secure and efficient storage of consumption data, allowing users to access historical trends and gain deeper insight into their electricity usage over time [8].

One of the key advantages of cloud-based data processing is its ability to perform continuous energy usage calculations and cost estimations, helping users track and optimize their power consumption [9]. The cloud system also includes data validation mechanisms to prevent inaccuracies due to sensor fluctuations, power surges, or electrical anomalies [7]. By ensuring real-time updates, the system allows users to view instantaneous energy consumption, projected billing amounts, and alerts for unusual energy patterns directly on their mobile or web applications [5].

The web and mobile interface are designed to be intuitive and informative, providing users with an interactive dashboard to monitor power usage and access billing information [3]. The application supports a range of features, including:

- *Real-time Monitoring:* Displays live energy consumption data for appliances, ensuring users can track their power usage instantly [6].
- *Billing Insights:* Automatic calculation of electricity costs based on energy consumption and predefined rate structure, ensuring users always have an accurate estimate of their bills [7].
- *Downloadable Bills & Reports:* Users can generate and save detailed reports on their electricity consumption, useful for record-keeping and financial planning [11].

A critical aspect of the proposed system is scalability. The system architecture is designed to accommodate additional features and enhancements, ensuring its adaptability for future advancements [8]. Some of the possible future improvements include:

- AI-based energy consumption prediction, allowing users to forecast their future power usage based on historical data and behavioral patterns [2].
- Smart appliance scheduling, which enables users to automate appliance operations to optimize power consumption and reduce unnecessary wastage [9].
- Renewable energy integration, offering insights into solar or alternative energy contributions alongside conventional grid consumption, allowing users to assess their reliance on renewable energy sources [10].

By leveraging the power of IoT, cloud computing, and advanced data analytics, the proposed system enhances the way electricity is monitored and billed [4]. This approach ensures that consumers have complete control over their electricity consumption, helping them manage costs more efficiently while contributing to energy conservation and sustainability [7]. The ability to access energy insights in real-time, receive notifications about irregular consumption, and generate accurate bills makes this system a modern and effective solution for residential, commercial, and industrial electricity monitoring [5].

The proposed Smart Electricity Consumption Monitoring and Billing System is built on a robust and efficient architecture that seamlessly integrates hardware components, cloud-based data processing, and

 

a user-friendly web and mobile interface [5]. This architecture ensures accurate measurement of electricity consumption, efficient data storage and processing, and real-time visualization for users [2]. The system is designed to provide a transparent, accessible, and scalable solution for monitoring energy usage and generating Automated bills from Figure 1 [1].

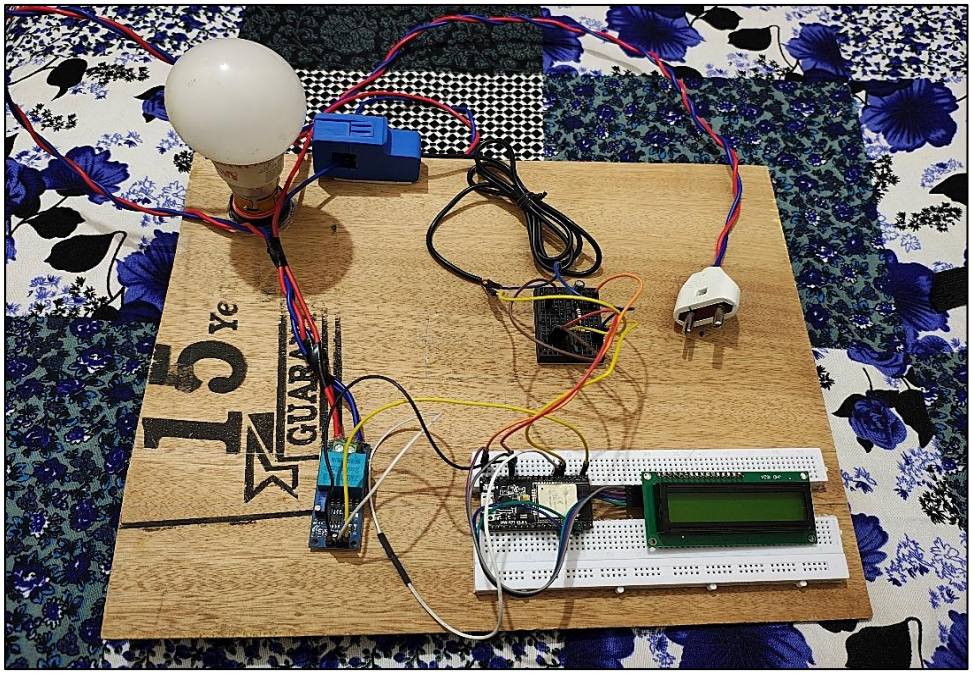

**Figure 1.** Prototype of smart electricity consumption monitoring device SYSTEM.

## ARCHITECTURE

At the core of the system lies the hardware unit, which consists of essential components required for measuring voltage, current, and power consumption [3]. The ESP32 Wi-Fi module acts as the central processing unit, responsible for gathering sensor data, performing preliminary calculations, and transmitting the information to the cloud [7]. The ZMPT101B AC voltage sensor module is used to measure the voltage level of connected appliances, ensuring precise readings that are essential for accurate power calculations from Figure 2 [6]. Simultaneously, the SCT013-030 non-invasive AC current sensor detects the current flow without requiring a direct connection to the circuit, making the system safer and more adaptable [8]. These sensors work together to provide real-time electrical parameter measurements, which are then used to calculate power consumption using the formula \(P = V \times I\) [4].

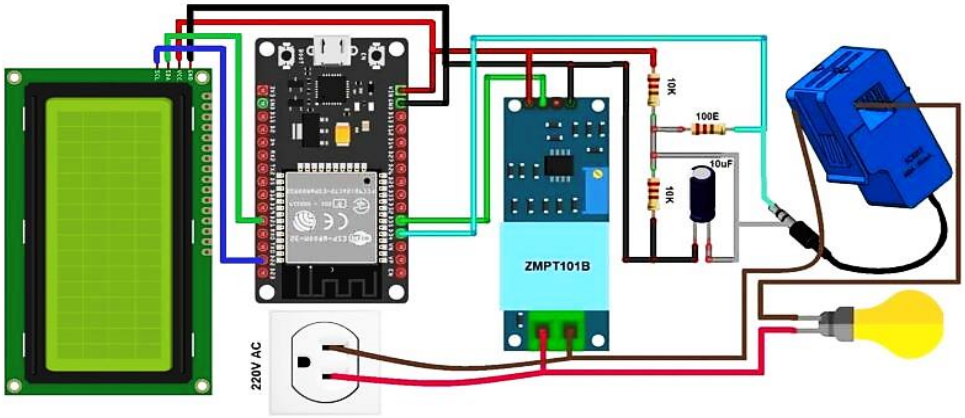


**Figure 2.** System architecture.

 

To ensure the accuracy and stability of readings, additional electronic components are incorporated into the hardware setup [9]. A 100-ohm resistor is included for current limiting and signal conditioning, preventing excessive current flow that could affect the readings [10]. A 10 μF capacitor is used to filter voltage fluctuations, maintaining a steady supply and improving signal clarity [11]. The data collected by the ESP32 is displayed locally on an LCD screen, allowing users to view real-time consumption values without needing to access the web or mobile application [6]. A breadboard and connecting wires facilitate the assembly of the circuit, enabling modularity and ease of maintenance [2]. The hardware is powered through a micro-USB cable, which provides the necessary energy for both data transmission and sensor operations [5].

Once the hardware gathers the required parameters, the ESP32 transmits the data to a cloud-based platform via the Blynk Cloud API [1]. The cloud infrastructure plays a crucial role in processing and storing the data, ensuring that users have continuous access to historical consumption records [4]. The cloud also handles automated calculations to determine total energy usage, measured in kilowatt-hours (kWh), and computes the cost based on the predefined electricity rate [3]. By maintaining a secure database, the system prevents data loss and provides users with valuable insights into their electricity consumption over time [9]. Additionally, data validation techniques are implemented to filter out sensor anomalies and external disturbances, ensuring that users receive only accurate and reliable information [10].

The processed data is then made available through an intuitive web and mobile application, offering users a seamless interface to monitor their energy usage [11]. The application provides real-time visualization of power consumption, allowing users to track trends and identify high-energy-consuming appliances [8]. It also enables automated bill generation, where users can view and download their electricity expenses based on actual consumption [7].

Moreover, the system includes alert mechanisms that notify users in case of unusual consumption patterns, helping them take corrective actions to avoid unnecessary energy wastage [7]. By integrating hardware, cloud computing, and interactive user interfaces, this system provides a comprehensive solution for electricity consumption monitoring [6]. Its scalable design allows future enhancements such as AI-based consumption predictions, smart appliance scheduling, and renewable energy integration [5]. This ensures that users can not only monitor their energy use but also optimize their consumption habits, leading to reduced electricity bills and improved energy efficiency [2].

**WORKING**

The smart electricity consumption monitoring and billing system operates by continuously measuring power consumption habits, leading to reduced electricity bills and improved energy efficiency [6]. The system continuously tracks the usage of connected appliances and provides real-time insights to users through a web-based platform [5]. The system relies on sensors, microcontrollers, cloud storage, and a user-friendly interface to ensure accurate energy tracking and cost calculation [7].

The ZMPT101B AC Voltage Sensor and SCT-013-030 Current Sensor are used to measure voltage and current, respectively [3]. These sensors provide real-time data, which is processed by the ESP32 Wi-Fi module [7]. The ESP32 acts as the central controller, collecting the raw sensor values and computing power consumption using the formula \(P = V \times I\) [4]. The calculated power data is then transmitted to the Blynk Cloud via Wi-Fi [8]. The Blynk Cloud stores historical data and ensures that the user can access their energy usage at any time [9]. The cloud-based system enables real-time monitoring, allowing users to view power consumption trends through the website [2]. The web application fetches the stored data, calculates total energy consumption (kWh), cost (based on rate), and generates the electricity bill [10].

The user interacts with the website to monitor their electricity usage, check past consumption, and download the bill [11]. The system also alerts users about unusual power usage patterns, helping them

 

manage energy more efficiently [7]. Appliances, such as an LED bulb and fan, are used in the demonstration to showcase how real-time tracking helps in better energy management [5]. By integrating IoT-based monitoring, cloud storage, and web-based analytics, the system provides a transparent and automated billing solution, ensuring that users can track and optimize their electricity Consumption effectively from Figure 3 [6].

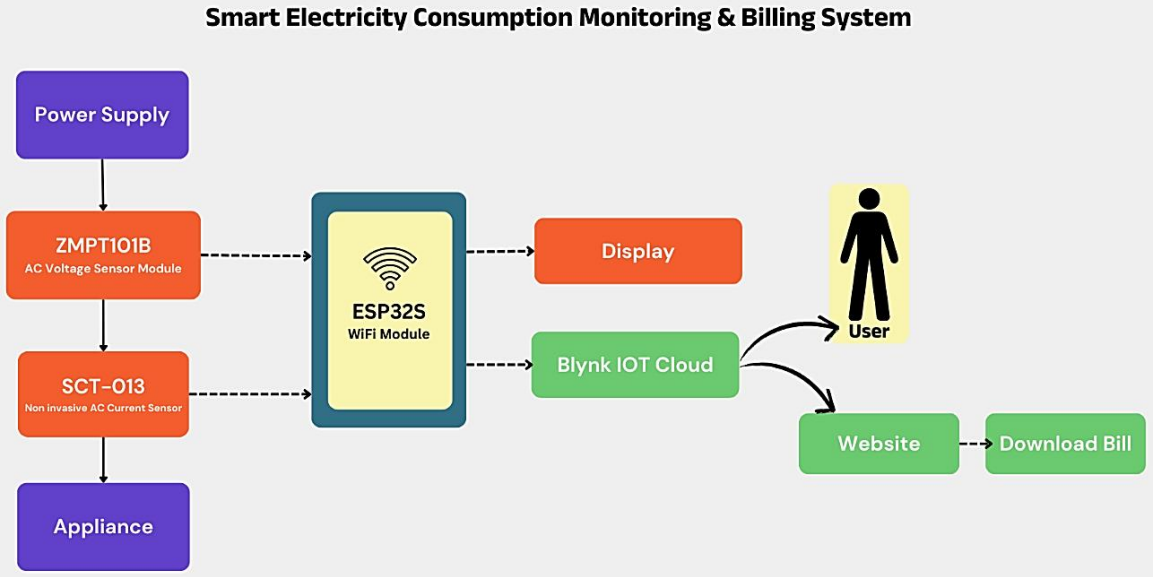


**Figure 3.** Working of smart electricity consumption monitoring device, cloud and websites.

## TABLES AND FIGURES

The comparison highlights the advantages of the proposed smart electricity monitoring system over traditional meters [1]. Unlike conventional systems, the smart system enables real-time monitoring, appliance-wise usage tracking, and improved billing transparency [2]. Users gain better control over consumption, ensuring cost-effectiveness and accurate billing [3], ultimately leading to efficient energy management and reduced expenses from Table 1 [5].

**Table 1.** Comparison of traditional vs. smart monitoring system.

| Feature | Traditional Electricity Meters | Proposed Smart System |
|---|---|---|
| Real-time Monitoring | No | Yes. |
| Appliance-wise Usage | No | Yes. |
| Billing Transparency | Limited | High. |
| Cost-effectiveness | Standard | Affordable. |
| User Control | No | Yes. |

**Table 2.** Sample appliance-wise energy consumption and cost calculation.

| Appliance | Voltage (V) | Current (A) | Power (W) | Usage Time (hours) | Energy (kWh) | Cost (₹) |
|---|---|---|---|---|---|---|
| LED Bulb | 230 | 0.1 | 23 | 10 | 0.23 | 1.15 |
| Ceiling Fan | 230 | 0.5 | 115 | 5 | 0.575 | 2.88 |
| Refrigerator | 230 | 1.2 | 276 | 8 | 2.208 | 11.04 |
| Air Conditioner | 230 | 7.5 | 1725 | 4 | 6.9 | 34.50 |

The table presents sample energy consumption and cost calculations for various household appliances [6]. It shows voltage, current, power, and usage time to determine energy consumption in kWh and corresponding costs [11]. The smart system enables precise tracking, helping users identify high-consumption appliances [7] and optimize usage to reduce electricity expenses efficiently from Table 2 [9].

 

## MATH FORMULAE

Electricity consumption monitoring requires accurate calculations to track energy usage and determine billing costs [1]. The system uses fundamental electrical principles to measure power, energy consumption, and cost estimation [3]. Sensors detect voltage and current values, which are processed to calculate real-time power usage [2].

The following mathematical formulas are used:

- *Power Calculation:* $P = V \times I$ [5].
  (Power in watts is obtained by multiplying voltage and current values.)
- *Energy Consumption:* $E = P \times t$ [4].
  (Energy in kilowatt-hours (kWh) is calculated using power and time.)
- *Billing Calculation:* $C = E \times \text{rate}$ [8].
  (The total electricity cost is determined by multiplying energy consumption with the rate.)

## CONCLUSIONS

The proposed smart electricity consumption monitoring and billing system enhances energy efficiency by providing real-time tracking, accurate billing, and greater transparency [6]. Unlike traditional meters that offer only cumulative readings, this system enables users to monitor appliance-wise consumption, identify high-energy devices, and make informed decisions to reduce costs [5]. By integrating IoT-based hardware, cloud-based data storage, and a user-friendly web and mobile interface, the system ensures seamless data accessibility and management [7]. The hardware setup consisting of an ESP32 Wi-Fi module, ZMPT101B voltage sensor, SCT013-030 current sensor, LCD display, and necessary electrical components, collects real-time data and transmits it to the cloud via the Blynk platform [9]. The cloud server processes voltage and current readings to calculate power, energy consumption, and the total electricity cost based on predefined rates [3]. Users can access detailed usage insights through a web or mobile application, allowing them to track trends, optimize consumption, and download bills [10]. By implementing automated monitoring, the system helps prevent overbilling, detect anomalies, such as overloads or faults, and promote energy conservation [2]. Additionally, it provides flexibility in scaling, with potential future enhancements such as AI-based consumption predictions and renewable energy integration [11].

In conclusion, this system offers an innovative approach to energy monitoring, bridging the gap between conventional metering and modern smart technology [4]. It empowers users with precise data, reduces inefficiencies, and supports sustainable energy consumption [8]. The project demonstrates the potential of IoT in revolutionizing electricity management, making energy use smarter, more transparent, and cost-effective [1].

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