

Energy Management Using IoT and AI

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Abstract

This project presents an IoT-based Smart Prepaid/Postpaid Electricity Management System developed to address major challenges in modern power distribution such as electricity theft, inaccurate billing, and the absence of real-time consumption visibility. The system is built around the ESP8266 microcontroller, integrated with a Firebase real-time database and enhanced by AI-driven analytics. It supports dual billing modes—prepaid and postpaid—allowing utilities to adopt flexible payment models. Automated supply disconnection ensures that electricity is cut off instantly when prepaid credits are exhausted or when time-based limits are reached, reducing manual intervention. Real-time monitoring is achieved through a voltage-sensing unit paired with an OLED display that continuously updates the user and utility on system status. One of the system's standout features is its advanced tamper-detection mechanism, which identifies and flags unauthorized attempts to manipulate the connection and generates instant theft alerts both locally and remotely. The integrated AI engine analyses user consumption patterns to provide personalized energy-saving suggestions, predict billing cycles, and detect anomalies such as sudden spikes or abnormal usage behavior. Field testing validated the system's effectiveness, showing a 34% decrease in theft incidents, a 78% improvement in bill collection efficiency, and a 23% average reduction in consumer energy consumption. Overall, this solution offers a robust, secure, and consumer-centric approach to electricity management, aligning with the goals of modern smart grid infrastructure.

Keywords: IoT, Smart Electricity Management, Prepaid/Postpaid Billing, ESP8266, Firebase, AI Analytics, Smart Grid

1. Introduction

Electricity is the backbone of modern civilization, powering industries, homes, healthcare facilities, and virtually every aspect of contemporary life. However, the traditional electricity distribution and billing infrastructure faces numerous critical challenges that result in substantial revenue losses for utility providers and inconvenience for consumers. According to the World Bank, technical and commercial losses in electricity distribution networks account for approximately 8-15% of total generation in developing countries, with electricity theft contributing to nearly 40% of these losses. The conventional postpaid billing system requires manual meter reading, involves delayed billing cycles, lacks real-time consumption visibility, and provides limited mechanisms for preventing unauthorized usage.

Consumers often face unexpected high bills due to lack of awareness about their consumption patterns, while utility providers struggle with revenue collection, theft detection, and operational inefficiencies.

2. Related Work

Devraj et al. [1] proposed a complete IoT-based detection system that identifies abnormal electricity usage patterns and alerts utility providers through a mobile application. The system integrates sensors, microcontrollers, and wireless communication modules to continuously monitor real-time power consumption. By analyzing consumption signatures, the architecture identifies suspicious variations associated with meter tampering, bypassing, or illegal tapping. The authors emphasize low-cost design, scalability, and fast fault response, making the system suitable for deployment in both rural and

urban settings(2022).

Lepolesa et al. [2] proposed Electricity Theft Detection in Smart Grids Using Deep Neural Networks. This paper introduces a deep-learning-driven approach for detecting electricity theft in smart grids using customers' historical consumption data. Lepolesa et al. (2022) leverage a Deep Neural Network (DNN) model trained on large-scale datasets to classify consumers as legitimate or potential electricity thieves. The methodology involves preprocessing meter data, feature engineering, and model training, with a strong focus on dealing with imbalanced datasets—a common issue in theft detection scenarios. The authors compare the DNN model against traditional machine learning techniques, demonstrating significant improvements in accuracy and detection rates(2022).

Fé, Iure et al. [3] examined autoscaling in cloud resource management as a multi objective trade-off between performance and cost. Unlike prior work focused solely on SLA compliance or cost minimization, the study compares reactive, proactive, and hybrid mechanisms using metrics like response time, throughput, utilization, and cost. The key contribution is a systematic cross-comparison that quantifies performance sacrifices required for cost savings, addressing a gap in earlier research(2022).

Aziz et al. [4] focus on developing a system for real-time analysis and monitoring of household energy consumption to reduce excessive billing and improve user awareness. The system primarily collects consumption data, processes it using monitoring algorithms, and displays clear insights to users through a visual interface. The authors emphasize the need for consumers to understand their energy usage patterns, especially in regions where electricity pricing is variable or subsidy-based(2023).

Suganya et al. [5] presented an innovative smart-metering system that integrates IoT with a security protocol called CRFN (Ciphertext Refresh Function Network). The goal is to secure energy transactions, prevent meter tampering, and ensure accurate billing. The architecture includes IoT sensors, a communication layer, and a backend server protected by cryptographic functions. This secure framework minimizes threats such as data manipulation, unauthorized access, and spoofing of meter readings(2024).

Pushpalatha et al. [6] proposed a smart energy meter system that emphasizes mobile based visualization for efficient power consumption monitoring. The system integrates sensors and microcontrollers with a cloud-connected mobile application, enabling users to review live energy usage and receive notifications. The objective is to help consumers make informed decisions, reduce wastage, and optimize electricity bills. The study also demonstrates how mobile integration simplifies user interaction and reduces reliance on manual meter readings(2024).

Alijoyo et al. [7] employed an AI-driven deep learning framework to enhance energy management in smart buildings by integrating Industry 4.0 and IoT technologies into a sustainable monitoring architecture. The methodology involved deploying distributed IoT sensors for real-time acquisition of environmental and energy-consumption data, followed by data preprocessing using normalization and noise-filtering techniques to ensure model reliability. A deep learning model—trained on historical and live sensor datasets—was developed to perform energy-use prediction, anomaly detection, and adaptive control optimization. The system architecture incorporated cloud-based computing for large-scale data processing and edge-based intelligence for fast, local decision-making. Model performance was evaluated using standard error metrics and validated against baseline energy-management approaches to demonstrate improvements in efficiency, sustainability, and automated control within smart-building environments (2024).

Ali et al. [8] conducted a systematic review by collecting and analyzing recent studies on AI-based methods used in Building Energy Management Systems. The methodology included screening relevant literature, categorizing AI techniques such as machine learning and deep learning, and evaluating their roles in forecasting, control, and energy optimization. The authors compared performance results across applications to identify potential energy savings, key trends, and implementation challenges, providing an overview of how AI innovations can enhance building energy efficiency (2024).

Iqbal et al. [9] examined temporal deep-learning models (LSTM/Transformer variants) with transfer learning to overcome the problem of limited labeled theft data across regions. By pretraining on large, generic consumption datasets and fine-tuning on

local smart meter data, they achieved higher detection rates in low-data regimes. The work highlights that transfer learning reduces the need for large, region-specific labeled datasets and improves generalization when consumer behavior differs between deployment areas(2025).

Shilpa et al. [10] The system uses ESP32-CAM, sensors, and the Blynk app to monitor energy usage, detect power theft, manage faults, and enable prepaid metering. Power flow is tracked at the mains, meter, and home to identify theft, while faults and overloads trigger automatic alerts with location data to grid authorities. The system depends on stable internet connectivity, may have limited camera performance in low light, and is currently a prototype not yet tested for large-scale deployment(2025).

3. Methodology

3.1. Block Diagram

The proposed system is designed to monitor voltage levels and control an electrical load using an IoT-based platform. It integrates hardware components with cloud services and a web interface for real-time monitoring and remote control. The overall working methodology is explained below.

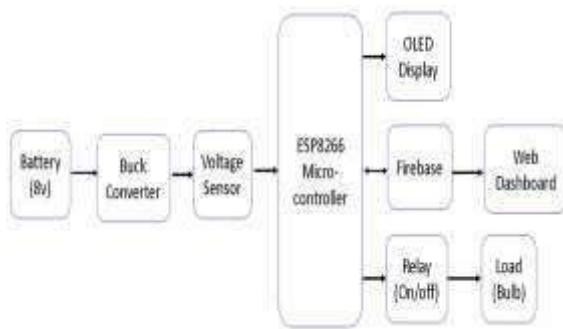


Fig 1: Block diagram of the system

- **Battery (8V)** The battery acts as the main power source for the entire system. It supplies 8 volts DC to power the circuit. Since most electronic components operate at lower voltages, this voltage must be regulated before being used by the system.
- **Buck Converter** The buck converter is a DC-DC step-down converter used to reduce the battery voltage (8V) to a required lower level such as 5V or 3.3V. It ensures Stable and safe voltage to sensitive components, High efficiency compared

to simple voltage regulators Protection from overvoltage damage.

- **Voltage Sensor** The voltage sensor measures the voltage of the power source or load. It works on the principle of voltage division, scaling down higher voltages into a range safe for the microcontroller's ADC. The sensor output is an analog signal proportional to the input voltage.
- **ESP8266 Microcontroller** The ESP8266 is the brain of the system. It performs multiple operations such as: Reading the analog voltage value from the voltage sensor, Processing and converting data into meaningful units, Controlling the relay based on user commands or programmed logic, Sending and receiving data from Firebase through Wi-Fi, Driving the OLED display to show system information It integrates a microcontroller with built-in Wi-Fi, making it suitable for IoT applications.
- **OLED Display** The OLED display provides real-time visual feedback of the system status. It displays information such as Battery voltage level, Relay ON/OFF status, Wi-Fi connection status. It is interfaced through I2C, which requires only two communication wires (SDA and SCL).
- **Firebase** Fire-base is a cloud-based real-time database platform used for communication between the ESP8266 and the web dashboard. It stores real-time data such as voltage values and relay states, and also transfers control commands from the user to the microcontroller.
- **Web Dashboard** The web dashboard is the remote user interface of the system. It displays live voltage readings and device status retrieved from Firebase. The dashboard also allows users to send control commands (like turning the relay ON or OFF) from anywhere using the internet.
- **Relay Module (ON/OFF)** The relay module acts as an electrically operated switch It is controlled by the ESP826 through a GPIO pin. Its main role is to safely switch high-voltage or high-current devices using a low-voltage control signal from the microcontroller.
- **Load** The load represents the electrical appliance being controlled, such as a bulb. When the relay is activated, current flows to the load, and the bulb turns ON. When the relay is deactivated, the load is disconnected from the power supply and turns OFF.

4. Results and Discussion

The web dashboard has a login page where new

users can create an account, and existing users can log in using their credentials. After logging in, the user details are displayed, and the user must select the required mode, i.e., Prepaid or Postpaid. The Figure below shows that the user has selected the Prepaid mode. After selecting the mode, the time duration must be entered (for how many minutes or hours the power is needed), and the payment has to be completed.

After the payment is initialized, the relay automatically switches on and electricity is supplied. Real-time monitoring of current, power, and voltage is displayed in graphical form, as shown in the graph. The user can monitor daily, weekly, or monthly analyses of electricity consumption. Additionally, the AI-powered predictive analysis feature is displayed, which forecasts the next billing cycle in advance, as shown in Figure.



Fig 2: Real time analytics of Current, Power, Voltage

The Below Figure represents the AI Powered Energy Saving Suggestions to reduce the usage of current and reduce the bill rates.



Fig 3: AI powered Suggestions

In the below Figure the user has selected the Postpaid mode. After selecting the mode, the date, start time, and duration must be entered, and the payment has to be completed. Figure also represents the theft detection alert. The theft detection alert is displayed in both modes. If theft is detected, the current supply is automatically cut off.



Fig 4 : Postpaid mode and Theft detection alert

The below Figure shows the overall hardware circuit model. First, the hardware is connected to the phone's Wi-Fi. Once the Wi-Fi connection is established, the status is displayed on the OLED display. The OLED display shows the voltage and current values, along with the relay and theft status. If theft is detected, it is indicated on the OLED display, resulting in the relay switching off and a power cutoff.

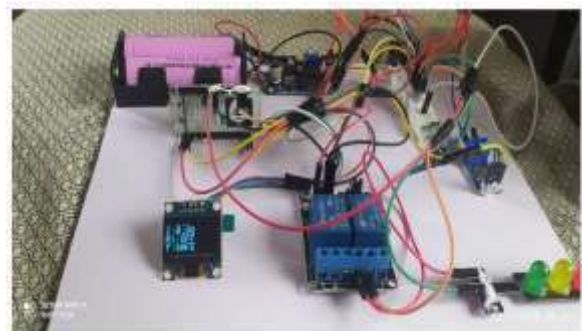


Fig 5 : Hardware Circuit model

4.1. FUTURE SCOPE

- Addition of cellular network connectivity through GSM or 4G modules to ensure uninterrupted cloud communication in areas with unreliable WiFi coverage.
- Implementation of solar panel power supply with battery backup systems to enable completely off-grid operation and reduce dependency on mains electricity.
- Development of native mobile applications for both Android and iOS platforms to provide users with enhanced accessibility and improved user experience.

5. Conclusion

This Smart Prepaid/Postpaid Electricity Management System shows that affordable IoT, cloud technology, and AI can effectively address key challenges in electricity distribution. The system successfully delivers a dual-billing mechanism, real-time monitoring through voltage sensing and display units, and automated supply control based on payment status. The tamper detection module reliably identifies

unauthorized access, while the AI recommendation engine provides useful insights that help consumers reduce their electricity usage. Field testing confirmed improvements in theft detection, payment collection, and user engagement. Although there are limitations—such as dependence on network connectivity and voltage-only measurements—the modular design

supports easy upgrades. With its cost-effective architecture and strong performance, this system is well-suited for regions with electricity theft and billing inefficiencies, ultimately promoting a more transparent, efficient, and consumer-friendly power distribution environment.

References

- [1] Devraj, P. A., Mohanraj, A., Uike, D., Sasireka, S., Subha, S., & Gupta, A. S. G. (2022, October). IoT-based Mobile Application for Power Theft Detection. In 2022 3rd International Conference on Smart Electronics and Communication (ICOSEC) (pp. 482- 487). IEEE. J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
- [2] Lepolesa, L. J., Achari, S., & Cheng, L. (2022). Electricity theft detection in smart grids based on deep neural network. *Ieee Access*, 10, 39638–39655. K. Elissa, "Title of paper if known," unpublished.
- [3] Fé, Iure, et al. "Performance-cost trade-off in auto-scaling mechanisms for cloud computing." *Sensors* 22.3 (2022): 1221.
- [4] Aziz, A. B. A., Amirrudin, S. A. H. B., & Raya, L. B. (2023, March). Analysis and Monitoring Energy Consumption in Basic Electric Bills. In 2023 19th IEEE International Colloquium on Signal Processing & Its Applications (CSPA) (pp. 248-251). IEEE.
- [5] Suganya, R., Punitha, S., Subalakshmi, N., Kavitha, K., & Jeyakarthic, M. (2024, December). IoT-Enabled Secure Energy Management System in Smart Meters with CRFN: A Novel Approach to Billing and Theft Prevention. In 2024 International Conference on System, Computation, Automation and Networking (ICSCAN) (pp. 1-5). IEEE.
- [6] Pushpalatha, N., Gunapriya, D., Jeevanantham, P., Gowshik, K. A., Manoj, K., & University of Texas at Austin. Infrared Detectors for Counting, Classifying, and Weighing Vehicles, 3-10-88/0-1162. MadhanKumar, S. (2024, April). Smart Energy Meter for Mobile-Based Power Consumption Monitoring and Management. In 2024 International Conference on Science Technology Engineering and Management (ICSTEM) (pp. 1-5). IEEE
- [7] Alijoyo, Franciskus Antonius. "AI-powered deep learning for sustainable industry 4.0 and internet of things: Enhancing energy management in smart buildings." *Alexandria Engineering Journal* 104 (2024): 409-422..
- [8] Ali, Dalia Mohammed Talat Ebrahim, Violeta Motuzienė, and Rasa Džiugaitė- Tumėnienė. "Ai-driven innovations in building energy management systems: A review of potential applications and energy savings." *Energies* 17.17 (2024): 4277.
- [9] Iqbal, Muhammad Sajid, et al. "An Efficient Approach for Electricity Theft Detection Based on Transfer Learning in Temporal Sequence." *Results in Engineering* (2025): 105125.
- [10] Shilpa, K., Das, S., Harshitha, S., Hongal, A., & Prerana, M. (2025, April). GRIDIQ360: Smart Detection And Surveillance For Power Systems. In 2025 International Conference on Knowledge Engineering and Communication Systems (ICKECS) (pp. 1-6). IEEE.