# Smart Electric Meter System

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***Abstract* —The demand for electricity has grown rapidly through residential, commercial, and industrial sectors, and thus efficient energy monitoring and management have become necessary. Classic energy meters rely on a manual reading mechanism. This gives very restricted views regarding real-time consumption and leads to delays in billing, costliness of operation, and inefficient usage of energy. In this paper, we go through the design and implementation of an IoT- and AI-based Smart Electric Meter System for these listed limitations.**

**The system is equipped with an Arduino-based energy metering unit and an ESP32 communication module for continuous voltage and current parameter measurement. The measured data is wirelessly sent to a cloud-based server for real-time visualization and storage. Basic monitoring in the system will be extended with AI-based load forecasting and load classification techniques to predict future energy demand and appliance-level usage patterns. A web-based dashboard will provide the user with real-time insights, historical consumption trends, predicted energy usage, and automated billing information.**

**Experimental results ensure reliable real-time data transmission, accurate energy measurement, and meaningful prediction performance under normal household load conditions. The system improves energy awareness, supports demand-side management, and encourages sustainable electricity usage. This solution is scalable and can be extended towards smart home, commercial building, and smart grid environments.**

***Keywords* — Smart Electric Meter, IoT, Load Forecasting, Energy Monitoring, and Artificial Intelligence**

## I. INTRODUCTION

The use of electric energy has increased, leading to intensified levels of energy consumption across the world. The conventional electric measurement systems use electro-mechanical or digital meters that require manual data reading to produce monthly consumption reports devoid of real-time consumer feedback. In this regard, the system does not allow consumers to be adequately informed about their consumption levels, thereby hindering the efforts to adopt consumption-reducing measures. Furthermore, the service providers encounter issues related to billing errors, delayed fault notifications, and increased operating costs.

Smart electric meters can be viewed as a major part of a contemporary energy distribution network, facilitating automatic acquisition of data, remote monitoring, and two-way communication between consumer and energy companies. With the implementation of IoT, smart electric meters enable the bi-directional transfer of usage information from consumers to central servers. But simple smart metering does not entail a comprehensive analysis of usage patterns or predicted demands.

The recent development in the field of artificial intelligence and machine learning has made predictive and analysis tools available for the energy sector. The main application here is the use of "load forecasting," which allows prediction about the electricity demand based on past consumption patterns, and "load classification," which uses "electrical signatures" to determine the appliances using the energy.

Proposed in this paper is an IoT-based Smart Electric Meter System, which is accompanied by AI-based load forecasting and classification services. It is designed to deliver live energy consumption analysis, intelligent insights, and automated billing services with easy-to-use web interface functionality.

## II. SURVEY OF LITERATURE

Dudek et al. [1] have conducted a detailed analysis on the smart meter datasets and proved the significance of the monitoring activity related to the consumption of electricity in order to take proper decisions on saving electricity.

Another proposed design was by Abate et al. [2], who developed an IoT architecture for smart meters that enabled two-way communication for the consumer and the utility company. Although the design could accurately determine and transmit consumption readings, it centered more on the hardware aspect rather than predictive models or consumer interfaces.

Yet another design came from Visalatchi et al. [3], who developed a smart energy meter using GSM communication for automatic billing and theft identification. Although it helped immensely in decreasing non-technical losses, it relied on cellular communication and didn't offer real-time consumer interfaces or smart forecasts.

Recent research has increasingly explored the use of machine learning to enhance smart energy meter performance. Wang et al. [4] illustrated that advanced forecasting can enhance residential electricity load prediction significantly by learning from long-term consumption trends. The caveat is that these models generally require very large datasets and are cloud processed, further complicating an already complex system.

Patel et al. [5] proposed an AI-driven approach to identify abnormal energy usage patterns that would improve the reliability of smart grids. The method obtained high accuracy in detecting abnormalities, but most of the work was done for utility-level analysis, with minimal interaction or feedback provided at the end-user level.

A machine learning-based appliance-wise energy disaggregation model has been employed by Singh and Verma [6], which helps consumers detect the appliances that consume the highest amount of energy. Though the model performs well from a classification accuracy perspective, the need for a control and automation system had not been met.

Anitha et al. [7] have discussed the implementation of a smart energy surveillance system based on IoT.It is clear from the literature review that the existing systems address individual aspects such as monitoring, billing, theft, or prediction. There are very few systems that offer the complete feature of real-time monitoring, automation, smart prediction, and instantaneous notification to the user with low-cost hardware. Further, the dependence on the single mode of communication affects the integrity of the entire system.

The Smart Electric Meter System being proposed has removed these drawbacks by integrating IoT sensing, machine learning for demand prediction, billing, control functions, and alerts through Telegram on a single platform. The addition of manual control through Bluetooth provides continuity in functionality irrespective of internet connectivity. The use of open-source tools and light backend frameworks makes the proposed system a more pragmatic and scalable solution, as it is friendlier and more comprehensive and appropriate for home as well as commercial use, compared to the existing solutions.

## III. PROPOSED METHODOLOGY

The proposed Smart Electric Meter System will offer real-time energy consumption monitoring, auto-billing, appliance management, and energy consumption prediction through a combination of IoT hardware and machine learning. The system will consist of a modular framework that integrates sensing, processing, and decision-making into one system. This will ensure that the system is reliable, scalable, and user-friendly.

The architecture of the overall system comprises three main layers, namely the hardware sensing layer, the backend processing layer, and the user interface layer. The hardware layer is involved in the collection of real-time electric and environmental data using sensors attached to a microcontroller. The backend layer is where data is processed, stored in the database, and billing and machine learning models for energy estimation are carried out. The user interface layer is where the user can access his or her consumption data and billing information using a web interface.

The data flows from the sensors to the backend server through the use of serial communication, ensuring that the data being used for monitoring is always up to date. Notifications and control signals travel bidirectionally for both automated and manual control.

In the proposed block diagram, the current sensors measure the current consumption of appliances on a per-appliance basis, whereas other sensors like temperature sensors, humidity sensors, or motion sensors provide additional information on a practical basis. All these sensors send signals to the microcontroller. The microcontroller does the preliminary acquisition and formatting of the obtained results.

The backend system is involved in data storage, data visualization, billing calculation, and predictive tasks using a machine learning approach. Using predefined rules or user feedback, the system returns control signals that command the microcontroller to switch on and off the connected electrical appliances. Services provide notifications regarding the status change and usage of electricity.

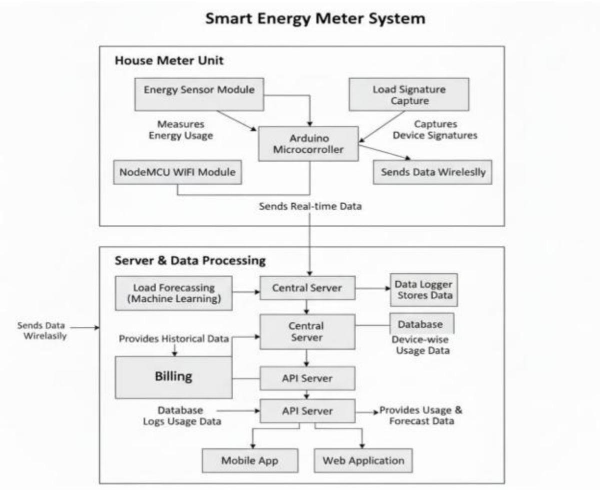



Figure 3.1:Block Diagram: Smart energy metering system using esp32

3.1. Hardware Components

Arduino Mega: Arduino Mega is the major processing unit of this setup. It receives the analog signals from the voltage and current sensors, calculates the power and energy values, and then passes the processed information to the communication module.

ESP32 Wi-Fi module: The ESP32 module is used for wireless data transmission between the smart meter and the server. The ESP32 module transmits the consumption data using IoT protocols.

Current Sensor (ACS712): The ACS712 current sensor measures currents passing through connected electrical loads. It generates an analog output corresponding to the value of currents passing through connected loads.

Voltage Sensor: The sensor monitors the supply voltage that the electrical load uses. The use of the voltage measurements, along with the current, is essential in the determination of the power and total energy.

Relay Module: Relay modules make it possible to control the switching of electrical appliances according to user control or logic control. They mediate electrical isolation and the proper usage of high-power devices.

Power Supply Unit: The regulated power supply helps to provide stable voltage to all the electronic components. This ensures that the system operates effectively.

3.2. Software Components

Python Programming Language: Python is used as the backend programming language for data processing, billing calculation, and machine learning tasks. Python is flexible and has many libraries, so it can be used for IoT projects.

Flask Framework: Flask is a light web framework that assists in the implementation of the backend server and web APIs for the data transmission process. Flask takes care of user authentication, data routing, and interaction between hardware and the web interface.

SQLite Database: SQLite acts as a database service to store data from sensors, users, and billing. SQLite has the advantage of being light, which makes SQLite useful for real-time energy monitoring systems.

Machine Learning Libraries (Scikit-Learn, Panda): These libraries help with data preprocessing, load analysis, and energy consumption predictions. They help the system analyze past data and predict future consumption trends.

Web Application Development (HTML, CSS, Bootstrap): HTML, CSS, and Bootstrap components are employed in the design of the web dashboard. Additionally, the user interface includes the current reading, historical data, future predictions, and billing information.

Telegram Bot API: The Telegram Bot API is used to offer immediate notification to the user. It notifies the user regarding changes to appliance status as well as abnormal usage.

## IV. IMPLEMENTATION & RESULTS

4.1. Implementation

The Smart Electric Meter System has been designed and developed to be functionally integrated using a combination of hardware components and software applications on a unified platform. The Arduino Mega has been programmed to read the voltage and current values from various sensors connected to it continuously. The values acquired have been processed in real-time to compute power and total consumption of electric energy. The ESP32 Wi-Fi module has been programmed to transfer the processed information to the server wirelessly.

The software component includes the creation of the backend server using Flask for receiving sensor readings, storage, and processing the data for bill generation based on predetermined tariff rates. The machine learning algorithms were trained on the energy data for predicting the energy usage patterns for the coming periods, and the resulting machine learning model was deployed on the backend for the real-time predictions.

A web dashboard was developed using HTML, CSS, and Bootstrap for offering an interactive interface for the users. The web dashboard offers the real-time energy consumption, past consumption, predicted consumption values, and billing information of the users. Relay modules were connected with the Arduino system for controlling the appliances based on the inputs from the users. Further, the Telegram Bot API was connected for immediate notifications about the changes in the appliance states and the anomalous energy consumptions. Bluetooth manual control was also developed for handling the system in case of internet connectivity problems.

4.2. Results and Discussion

The experimental setup was proven by using some household appliances with varying loads. Real-time voltage and current readings were measured and accurate power and energy calculations were done by the experimental setup. The data collected was transmitted to the backend server, and the web dashboard showed the data without any delays.

Screenshots of the dashboard ensured the correct representation of real-time data, historical information, and billing information. The tables produced from the database proved the regular accumulation of energy over time, ensuring the validation of the process of energy measurement. Graphic representation of consumption patterns of energy enabled the viewers to easily distinguish between peak and off-peak consumption.

The machine learning algorithm showed the ability to predict the short-term energy usage based on past data. Although slight variations occurred depending on the load, the data was accurately reflected in the predictions. The notifications on the telegram arrived instantly, hence raising more awareness.

The overall system performance has been identified as reliable, responsive, and adequate enough to monitor real-time. The combination of IoT sensing, intelligent forecasting, and automation solutions within the platform has enhanced the overall efficiency of energy management. The fact that the solution adopts low-cost hardware and open-source resources makes the solution truly scalable and applicable to residential as well as commercial purposes.

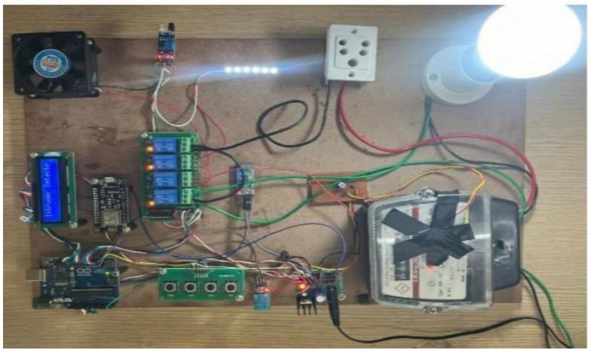


Figure 4.1: Automatic mode example where light turns ON due to motion

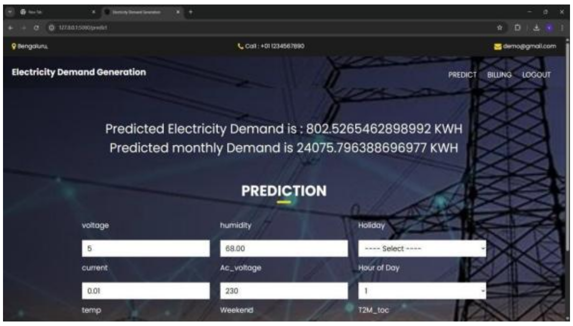
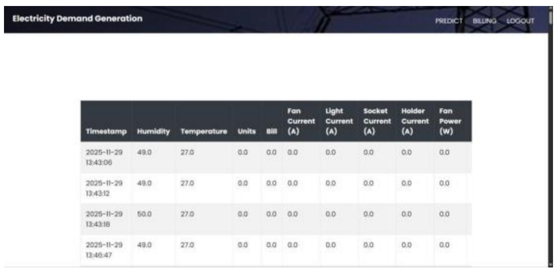



Figure 4.2: Prediction interface showing input parameters



Electricity Demand Generation PREDICT BILLING LOGOUT

| Timestamp | Humidity | Temperature | Units | Bill | Fan Current (A) | Light Current (A) | Socket Current (A) | Holder Current (A) | Fan Power (W) |
|---|---|---|---|---|---|---|---|---|---|
| 2025-11-29 13:43:06 | 49.0 | 27.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2025-11-29 13:43:12 | 49.0 | 27.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2025-11-29 13:43:18 | 50.0 | 27.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2025-11-29 13:46:47 | 49.0 | 27.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |


Figure 4.3: Billing table displaying real-time consumption and appliance-wise current

## V. CONCLUSION

In this study, the design and development of the Internet of Things-Based Smart Electric Meter System with integrated Artificial Intelligence-based load forecasts and classifications had been discussed for real-time electricity monitoring and analysis, along with auto billing using a web interface.

Experimental outcomes validate the effectiveness of the proposed solution in improving energy awareness and assisting in efficient electricity consumption. With the incorporation of AI methods, predictions can be made to help users and companies take appropriate actions. It is scalable to be used in smart homes, offices, and smart grids.

Future work would involve enhancing the accuracy of the classifications, incorporating the monitoring of renewable energy sources, and employing state-of-the-art edge AI for rapid and secure processing of the data.

## VI. FUTURE SCOPE

The proposed smart electric meter system can be further upgraded by merging sophisticated machine learning algorithms and deep learning algorithms that would improve the precision level of energy consumption estimation and anomaly detection mechanisms. The system can be further upgraded to implement energy disaggregation at an appliance level that would allow consumers to trace high-energy consuming devices in a more precise manner. Cloud data storage and analysis solutions would help in carrying out long-term analyses and mass-scale deployments. The scalability issues could be resolved by merging meters in a single dashboard that would make it feasible for deployment in apartments, offices, and industrial sectors. Other communication mechanisms like LoRa or NB-IoT can be integrated that would improve connectivity in low-network density areas. Other areas that could be concentrated in future up-gradations would include mobile app development, dynamic tariffs, renewable energy sources tracking, and smart grid infrastructure integration.

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