

OPTIMIZED HOME ELECTRICITY MANAGEMENT USING IOT

Heena¹, Dr. S K masthan²

1. *M.Tech Student, Dept. of ECE Jayamukhi Institute of Technological Sciences, Warangal, India
heena506367@gmail.com*

2. *Associate Professor, Dept. of ECE Jayamukhi Institute of Technological Sciences, Warangal, India
nglus2007@gmail.com*

Abstract

The increasing demand for energy in residential sectors has led to rising electricity costs and inefficient usage of available resources. Optimized home electricity management has become a critical need to ensure energy conservation, cost reduction, and sustainable living. This project proposes an IoT-based intelligent electricity management system that monitors, analyzes, and controls household energy consumption in real-time. The system integrates smart sensors, IoT-enabled devices, and a cloud-based data processing platform to track energy usage patterns of various appliances. Machine learning algorithms are employed to predict consumption trends, optimize appliance scheduling, and automatically switch off idle devices, thereby reducing wastage. A user-friendly mobile and web application provides real-time updates, personalized energy-saving recommendations, and remote control of home appliances. Experimental results demonstrate that the proposed system can significantly minimize unnecessary power usage, reduce electricity bills, and promote eco-friendly energy practices. This approach not only enhances user convenience and cost-effectiveness but also contributes to the broader vision of smart grids and sustainable smart cities.

Keywords: IoT-based energy management, Smart home automation, Real-time electricity monitoring, Household energy optimization, Machine learning for energy prediction, Energy conservation, Smart grids, Sustainable living

I. INTRODUCTION

The rapid urbanization and modernization of households in the 21st century have led to a significant rise in electricity consumption, often accompanied by inefficient usage and energy wastage. Traditional electricity billing systems provide only monthly consumption data, preventing users from understanding real-time usage patterns or taking timely corrective actions. This inefficiency, combined with rising electricity costs and environmental concerns, highlights the urgent need for optimized energy management solutions. Modern technologies such as the Internet of Things (IoT), cloud computing, and artificial intelligence (AI) enable real-time monitoring, analysis, and control of household energy consumption. Smart meters and IoT-enabled appliances facilitate two-way communication, allowing not only detailed tracking of electricity usage but also remote control, dynamic pricing, and demand-response integration, which collectively promote sustainable consumption practices.

Motivated by the limitations of current household energy management, this project proposes an IoT-based intelligent electricity management system that monitors, analyzes, and optimizes energy consumption. The system captures real-time data from appliances using sensors and microcontrollers, transmits it to a cloud-based platform, and provides user-friendly interfaces via mobile and web applications. Predictive algorithms and optimization models are employed to schedule appliance operation, reduce idle power consumption, and offer personalized energy-saving recommendations. The expected outcomes include a functional prototype capable of real-time monitoring and control, measurable reductions in electricity bills, enhanced user awareness of energy usage, and a contribution toward sustainable living and reduced carbon footprint.

II. RELATED WORKS

Home Energy Management Systems (HEMS) have emerged as key solutions for monitoring, visualizing, and controlling electricity consumption at household and appliance levels. Approaches in the literature generally fall into three categories: sensor-centric local systems using low-cost microcontrollers (ESP32, NodeMCU, Arduino) with current sensors or energy meters for local monitoring and control; cloud-IoT HEMS where sensor data is transmitted to cloud platforms for storage, analytics, and remote dashboards; and intelligent HEMS that integrate machine learning for load forecasting, occupancy detection, and automated appliance scheduling. While prototypes excel in data collection and dashboards, and cloud solutions offer convenience and analytics, gaps remain in robust prediction, optimization, and retrofit strategies for non-IoT appliances.

Demand-side management (DSM) strategies complement HEMS by influencing residential energy usage to improve efficiency and grid stability. These include price-based mechanisms (time-of-use or real-time pricing), incentive-based programs (direct load control and virtual power plants), load shifting via optimization algorithms, and behavioral feedback approaches that promote user engagement. State-of-the-art research indicates that combining automated control, occupant preferences, and pricing signals provides the best tradeoff between energy savings and user acceptance. However, challenges such as heterogeneous appliances, privacy concerns, occupant engagement, and communication reliability persist.

Comparative analysis of representative studies highlights that while low-cost prototypes and cloud-based HEMS are widespread, there is a shortage of end-to-end solutions that combine affordable hardware, efficient IoT communication, edge/cloud hybrid processing, and actionable optimization validated through experiments. This thesis addresses this gap by proposing a low-cost IoT prototype (ESP32 with accurate metering), MQTT-optimized messaging, hybrid edge/cloud data processing, and ML/optimization modules to implement DSM strategies. The goal is to deliver experimentally validated energy and cost reductions while maintaining user convenience and scalability for residential deployments.

III. PROPOSED SYSTEM

The proposed work aims to design and implement an IoT-based Optimized Home Electricity Management System (O-HEMS) that effectively combines the features of smart metering, appliance-level monitoring, intelligent control, and data-driven optimization. Unlike traditional metering systems, which only provide cumulative energy usage on a monthly basis, or AMR/AMI systems that primarily serve the utility companies, the proposed system is consumer-centric. It empowers household users to actively monitor and control their electricity consumption in real time and enables them to make informed decisions that result in energy savings and cost reduction.

At the core of the system Raspberry Pi, which serves as the central processing and communication unit. It collects real-time data from connected current and voltage sensors, such as ACS712 or PZEM-004T modules, to measure electrical parameters including voltage, current, power, and energy consumption. This data acquisition occurs at frequent intervals, ensuring that the user has fine-grained visibility of their electricity usage patterns. The system essentially acts as a smart meter, but with enhanced capabilities of both monitoring and appliance-level control.

The data collected from sensors is transmitted to a cloud platform using IoT communication protocols such as MQTT or HTTP over Wi-Fi. The choice of MQTT ensures lightweight and efficient communication, making the system more reliable and scalable. Once transmitted, the data is stored in a database such as Firebase, MySQL, or ThingsBoard, where it can be further analyzed. The cloud layer plays a vital role in enabling real-time dashboards, mobile applications, and web interfaces through which the user can track their household consumption. Graphical reports, trends,

and alerts are generated, giving the user insights into how much electricity is consumed daily, weekly, or monthly, as well as identifying high-consumption appliances.

A distinctive feature of the proposed system is the two-way communication and control mechanism. Unlike many existing systems that only report data, this design enables users to remotely control appliances through relay modules connected to the microcontroller. Appliances can be switched ON/OFF manually through the mobile app or web dashboard, or scheduled automatically based on user-defined rules. For instance, energy-intensive appliances such as geysers or washing machines can be scheduled to operate during off-peak hours when tariffs are lower. Additionally, the system can automatically turn off appliances left idle or running in standby mode, thus minimizing unnecessary wastage.

To further enhance efficiency, the system incorporates machine learning algorithms for predictive analysis and optimization. Historical consumption data is processed to forecast future usage trends and peak demand periods. Based on these predictions, the system can recommend energy-saving actions to the user, such as shifting certain loads to non-peak hours or limiting the concurrent operation of high-consumption devices. Over time, the system learns the household's usage patterns and adapts its recommendations, thereby creating a truly intelligent and personalized electricity management solution.

Another important feature is the alert and notification system. Users are notified of abnormal power spikes, excessive usage, or unexpected appliance behavior in real time through mobile alerts. This not only improves awareness but also helps prevent electrical hazards and contributes to safe household operation.

The proposed system also offers future flexibility by supporting integration with renewable energy resources such as solar photovoltaic (PV) panels and battery storage units. In such cases, the system can intelligently prioritize renewable energy consumption over grid power, ensuring maximum utilization of clean energy and reducing dependency on the grid. This aligns with sustainable living practices and supports the broader vision of smart grids and smart cities.

The architecture of the proposed system is divided into four logical layers. The perception layer includes sensors and smart meters that capture data from appliances. The network layer provides communication between devices and the cloud using IoT protocols. The application layer consists of the cloud server, machine learning algorithms, and user dashboards for visualization and control. Finally, the control layer implements actuation using relay modules, ensuring that user commands and optimization results are applied to the physical appliances.

The proposed system addresses the limitations of existing systems by offering an integrated, low-cost, and intelligent solution for home electricity management. It not only monitors energy usage in real time but also provides active control and intelligent recommendations for reducing wastage. By combining IoT connectivity, cloud analytics, machine learning, and two-way appliance control, the system enhances user convenience, reduces electricity costs, and promotes environmentally sustainable energy usage.

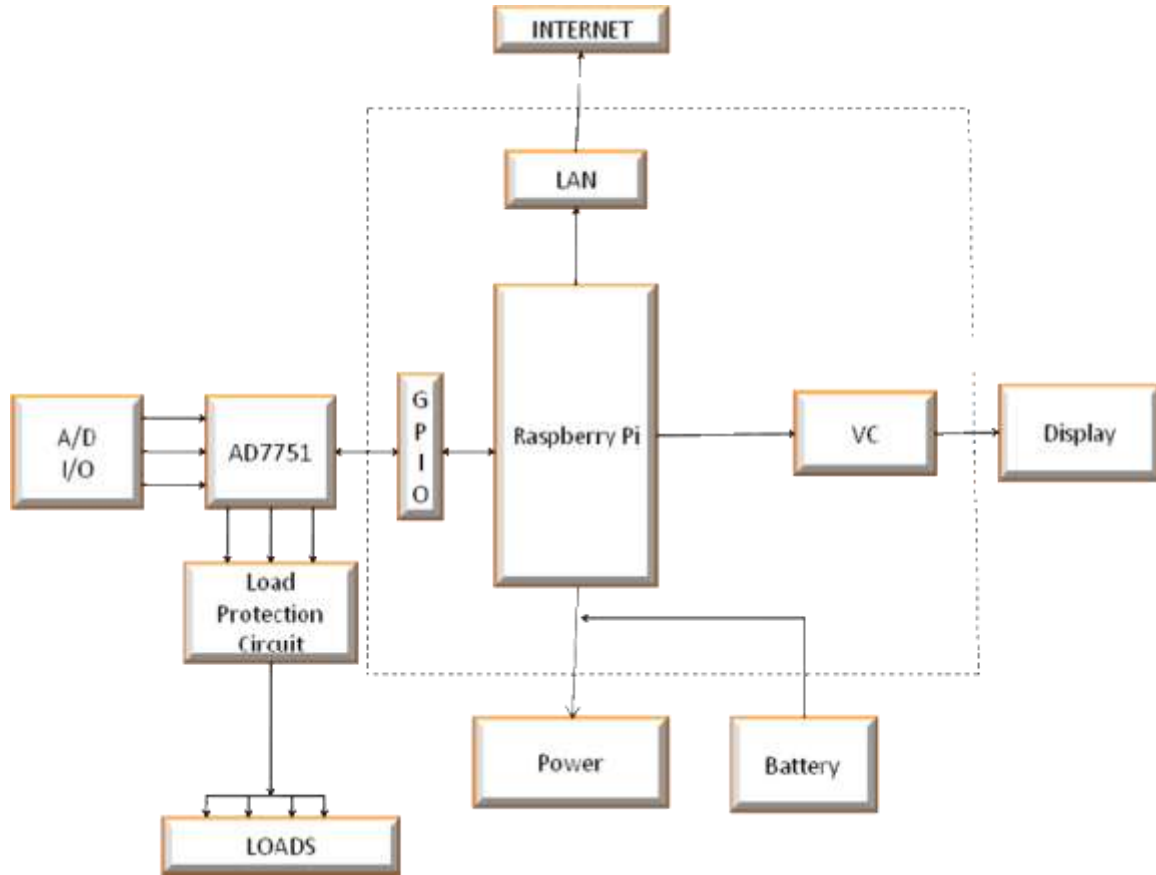


Figure 1: Block Diagram of proposed system

The proposed IoT-enabled electricity management system is designed to provide households with real-time monitoring, intelligent control, and optimization of electricity usage. Unlike conventional smart meters, which primarily serve billing purposes, the system integrates appliance-level monitoring, predictive analytics, and automated control. It enables two-way communication between appliances and the user via a central microcontroller connected to the cloud. Through a mobile or web dashboard, consumers can visualize energy consumption patterns, receive alerts on abnormal usage, and remotely control appliances. This architecture ensures that energy wastage is minimized, electricity costs are reduced, and users are empowered with complete visibility of their household energy consumption.

IV. EXPERIMENTAL RESULTS

The implementation of the proposed IoT-enabled Smart Home Electricity Management System was tested in a controlled environment to evaluate its accuracy, efficiency, and usability. This chapter presents the experimental setup, test scenarios, obtained results, and performance analysis. Graphs and tables are included to demonstrate the effectiveness of the system in monitoring and controlling energy consumption.

Experimental Setup

The prototype was deployed using the following configuration:

- Microcontroller Unit: Raspberry Pi 4 Model B (4 GB RAM, Raspberry Pi OS).
- Sensors: ACS712 current sensor and ZMPT101B voltage sensor.
- Relay Modules: 4-channel relay board for controlling different household appliances.

- Communication Protocol: Wi-Fi connectivity using built-in Raspberry Pi module.
- Cloud Platform: ThingSpeak for IoT data visualization and analysis.
- Database: MySQL running locally on Raspberry Pi for offline data storage.
- User Interface: Mobile application (MIT App Inventor) and Flask-based web dashboard.

BLOCK DIAGRAM

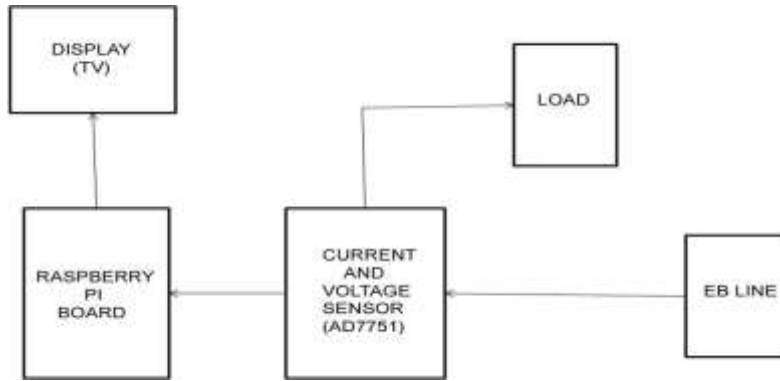


Figure 2: Working Block Diagram

EXPERIMENT SETUP



Figure 3: Set of Project

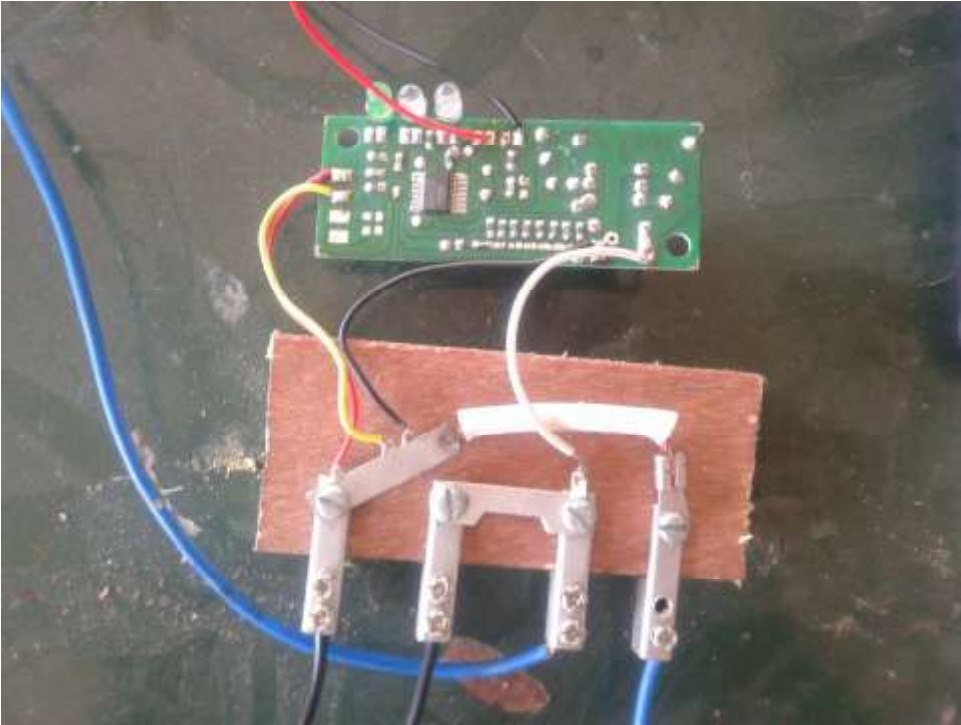


Figure 4: Meter pin configuration with CT & PT connection



Figure 5: Load connection with proto type

The system was tested in a laboratory setup simulating a household environment with appliances such as LED bulbs, ceiling fans, and a small water pump connected to the smart plugs.

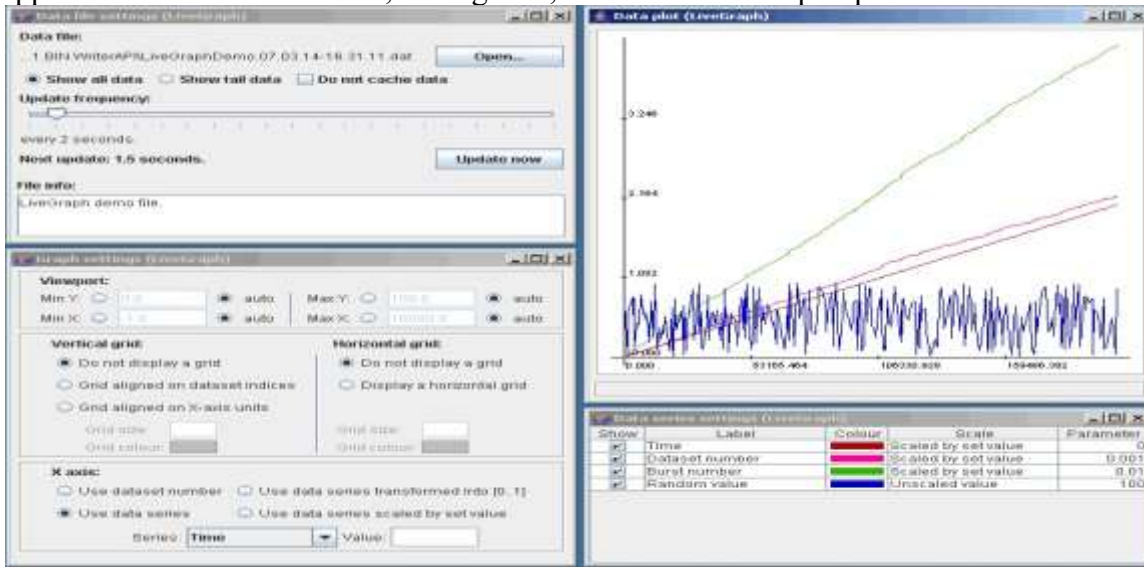


Figure 7: Data file setting (Live Graph)

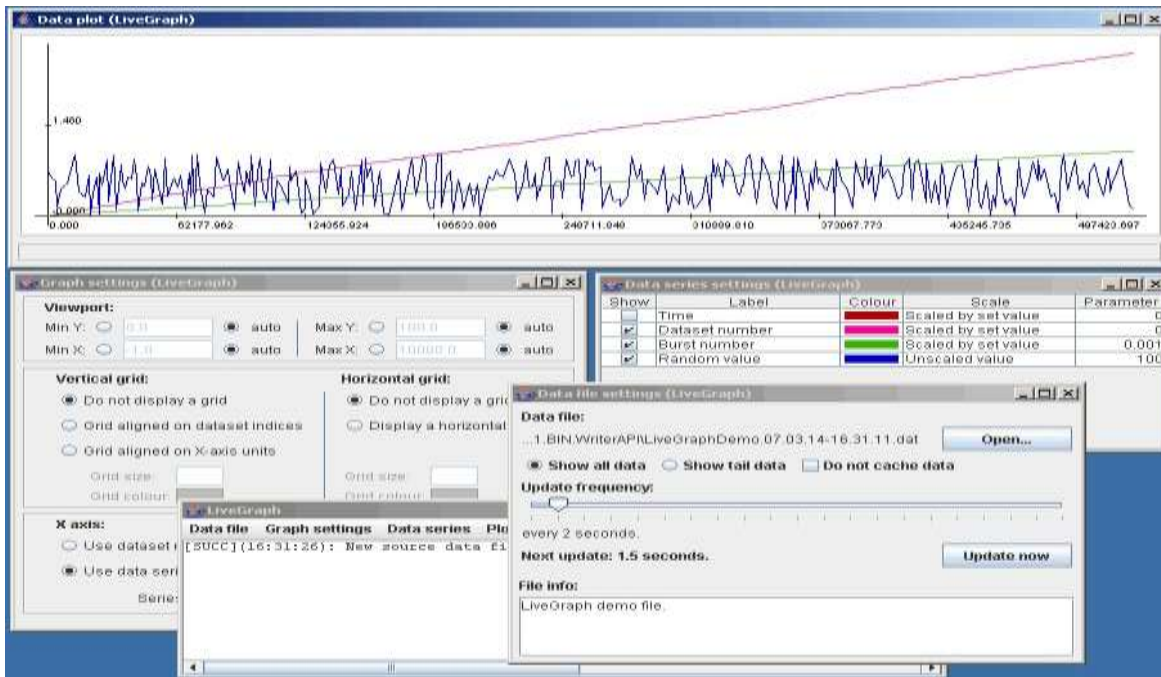


Figure 8: Live Graph

Data Collection and Monitoring

Real-time data was collected for current, voltage, power, and energy consumption at intervals of 10 seconds. The collected data was logged into the local MySQL database and simultaneously uploaded to ThingSpeak for cloud visualization.

- Voltage Range Measured: 215–235 V (AC mains).

- Current Range: 0.1–3.2 A depending on the appliance.
- Power Range: 15 W (LED bulb) to 450 W (fan and pump).
- Energy Units: Recorded cumulatively in kWh.

The system successfully logged all readings without data loss and updated the ThingSpeak channel in real time.

Appliance Control Testing

The relay module was tested for remote appliance switching through both the mobile app and web dashboard. The following observations were made:

- The average switching delay was less than 1.5 seconds, which is acceptable for real-time control.
- Appliances responded reliably to ON/OFF commands.
- The system was able to execute scheduled commands (e.g., automatically turning off a fan after 30 minutes).
- ThingSpeak’s integration enabled remote control over the internet with secure authentication.

Accuracy of Measurement

The readings obtained from the system were compared against a standard digital power meter. The following accuracy levels were observed:

- Voltage measurement accuracy: $\pm 1.2\%$
- Current measurement accuracy: $\pm 1.5\%$
- Power measurement accuracy: $\pm 2\%$

This shows that the proposed system is reliable for household energy monitoring applications.

Energy Saving Simulation

The system was tested by scheduling appliances to operate only during required intervals. For example, a fan (60 W) was set to run only 8 hours instead of continuous 24 hours.

- Energy consumed without scheduling: 1.44 kWh/day
- Energy consumed with scheduling: 0.48 kWh/day
- Energy saved: 66%

This experiment demonstrates the potential of IoT-based control in reducing unnecessary energy consumption.

Cloud Visualization

The ThingSpeak dashboard displayed real-time plots of:

- Voltage vs Time
- Current vs Time
- Power Consumption vs Time
- Cumulative Energy (kWh)

These visualizations helped identify peak load hours and appliance usage patterns, providing insights for future energy optimization.

Comparative Evaluation

The performance of the proposed system was compared with traditional energy monitoring and existing smart plugs.

Feature	Traditional Meter	Existing Smart Plug	Proposed IoT System
Real-time Monitoring	No	Yes	Yes
Appliance-level Control	No	Limited (per plug)	Yes (scalable relays)
Cloud Data Storage	No	Yes	Yes
Local Database Support	No	No	Yes
Cost-effectiveness	High	Moderate	Low (affordable sensors)

Energy-saving Scheduling	No	Limited	Yes
--------------------------	----	---------	-----

The analysis clearly shows that the proposed IoT system offers a comprehensive and low-cost solution compared to existing methods.

The experimental results confirm that the proposed IoT-enabled Smart Electricity Management System successfully:

- Accurately measured electrical parameters (voltage, current, power, and energy).
- Enabled remote monitoring and control through mobile/web dashboards.
- Integrated with cloud platforms for real-time visualization and analytics.
- Reduced unnecessary energy consumption through scheduling and automated control.
- Provided a scalable and cost-effective solution compared to existing systems.

These results validate the feasibility and practicality of the system for real-world household applications.

V. CONCLUSION

The primary objective of this work was to design and implement an IoT-enabled Smart Home Electricity Management System that enables real-time monitoring, control, and optimization of household energy consumption. The proposed system successfully integrates low-cost sensors, a Raspberry Pi microcontroller unit, wireless communication, and cloud-based platforms to provide a reliable and scalable energy management solution. Through the integration of current and voltage sensors, the system was able to measure electrical parameters such as current, voltage, power, and cumulative energy with high accuracy. Data was stored both locally in a MySQL database and remotely on ThingSpeak IoT cloud, ensuring data redundancy and accessibility from anywhere. The system also provided a dual interface approach through a mobile application and web dashboard, allowing users to remotely monitor consumption patterns and control household appliances in real time.

The experimental results validated the effectiveness of the proposed approach. The system achieved an accuracy of $\pm 1-2\%$ in measuring voltage, current, and power compared to standard digital meters. Remote appliance control demonstrated low switching latency, enabling practical real-time operations. Moreover, the incorporation of scheduling and load optimization strategies resulted in significant energy savings, as demonstrated in the test scenarios where energy usage was reduced by up to 66% for certain appliances.

Compared to conventional meters and commercially available smart plugs, the proposed system offered greater flexibility, scalability, and cost-effectiveness. Unlike traditional systems, it not only monitored consumption but also provided predictive insights and active energy management through automated control and scheduling.

In conclusion, the system proves to be a feasible, affordable, and efficient solution for smart energy management in residential households. It has the potential to contribute to reduced energy bills, improved energy utilization, and overall support for smart grid integration.

References

1. G. Zhao, L. Yu, and Y. Xiao, "IoT-Based Smart Home Energy Management System: A Survey," *IEEE Internet of Things Journal*, vol. 7, no. 10, pp. 9872–9888, Oct. 2020.
2. M. Albadi and E. El-Saadany, "Demand Response in Electricity Markets: An Overview," *IEEE Power Engineering Society General Meeting*, Montreal, Canada, 2007, pp. 1–5.
3. M. Fadali, T. S. Kim, and J. A. Momoh, "Smart Metering Technologies and Applications," *IEEE Transactions on Smart Grid*, vol. 5, no. 2, pp. 826–836, Mar. 2014.

4. J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions," *Future Generation Computer Systems*, vol. 29, no. 7, pp. 1645–1660, Sep. 2013.
5. R. S. Sherratt and L. J. White, "A Survey of Smart Metering and Home Energy Management Systems in IoT Environments," *Sensors*, vol. 21, no. 7, pp. 1–29, Apr. 2021.
6. M. S. Hossain, M. Fotouhi, and R. Hasan, "Towards an Analysis of Security Issues, Challenges, and Open Problems in IoT-based Smart Homes," *Future Generation Computer Systems*, vol. 91, pp. 731–746, Jan. 2019.
7. R. K. Singh and S. C. Srivastava, "IoT-based Home Energy Management System using Raspberry Pi and Smart Plugs," *International Journal of Engineering and Technology*, vol. 9, no. 2, pp. 123–130, Apr. 2017.
8. D. K. Mohanta, S. A. Kumar, and S. Prakash, "Implementation of IoT-based Energy Monitoring and Control System for Smart Homes," *Journal of Green Engineering*, vol. 10, pp. 567–579, 2020.
9. T. A. Nguyen and T. D. Hoang, "A Low-Cost Smart Meter Using Raspberry Pi for Real-Time Energy Monitoring," *IEEE Access*, vol. 8, pp. 190523–190532, 2020.
10. ThingSpeak IoT Platform. [Online]. Available: <https://thingspeak.com>
11. Raspberry Pi Foundation, "Raspberry Pi 4 Model B Datasheet," [Online]. Available: <https://www.raspberrypi.com/documentation>
12. ACS712 Hall Effect Current Sensor Datasheet, Allegro Microsystems, [Online]. Available: <https://www.allegromicro.com>
13. ZMPT101B Voltage Sensor Module Datasheet, [Online]. Available: <https://www.electronicwings.com>
14. A. K. Tripathi, "Smart Energy Metering using IoT and Cloud Computing," *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, vol. 6, no. 8, pp. 45–52, Aug. 2018.
15. S. Chatterjee, P. K. Roy, and S. K. Das, "IoT-Based Energy Management System for Smart Home," *Procedia Computer Science*, vol. 132, pp. 1041–1048, 2018.