NITTE MEENAKSHI INSTITUTE OF TECHNOLOGY

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PROJECT REPORT on

SMART ENERGY OPTIMIZATION USING IoT AND MACHINE LEARNING: ADDRESSING MODERN POWER CHALLENGES

Submitted in partial fulfillment of the requirements for the award of the degree of

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in
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Abstract

Standby power, or phantom load, is a major source of energy waste in households, with many appliances consuming electricity even when not in active use. This idle power can account for up to 10% of total household energy consumption, leading to unnecessary costs and environmental impact. To address this issue, this project proposes an IoT-based standby power saving device designed to reduce energy consumption in home appliances.

The system utilizes IoT sensors and smart plugs to monitor appliances' power usage in real time. When an appliance enters standby mode, the device automatically disconnects its power supply, preventing further energy waste. A mobile application allows users to track energy usage, set schedules, and receive notifications when an appliance is left in standby mode or consumes excessive power. This empowers users to optimize their energy consumption and reduce waste without manual intervention.

The system offers several benefits, including lower electricity bills by eliminating idle power consumption, promoting environmental sustainability through reduced energy usage, and raising awareness of energy efficiency. It is designed to be cost-effective and compatible with various household appliances, making it accessible to a wide range of users.

In conclusion, the IoT-based standby power saving device provides an effective, user-friendly solution to reduce standby power consumption. By automating power control and offering realtime monitoring, the system enhances energy efficiency and contributes to sustainable living practices.

Table of Contents

Acknowledgement 2

Abstract 3

Chapter 1: INTRODUCTION 6

1.1 Background

1.2 Motivation for the Study

1.3 Research Questions and Hypothesis

1.4 Scope of the Study

Chapter 2: LITERATURE REVIEW **7**

2.1 Historical Background of Energy Management

2.2 IoT in Home Automation

2.3 Machine Learning in Predictive Analytics

2.4 Current Solutions for Standby Power Reduction

2.5 Integration of IoT and ML for Energy Efficiency

2.6 Gaps in Existing Research and Potential Innovations

Chapter 3: PROBLEM STATEMENT 10

3.1 Understanding Standby Power Consumption

3.2 Economic and Environmental Impacts

3.3 Challenges with Existing Solutions

3.4 Need for a New Approach

Chapter 4: OBJECTIVES 11

Chapter 5: METHODOLOGY 11

5.1 Requirement Analysis

5.2 System Architecture Design

5.3 Prototype Development

5.4 Testing and Validation

5.5 Implementation of Machine Learning Algorithms

5.6 IoT Integration

5.7 Result analysis

Chapter 6: WORK DONE SO FAR **14**

6.1 Identifying Appliances and Researching IoT Components

6.2 Circuit Design
6.3 Cloud Integration
6.4 Machine Learning Integration:

Chapter 7: RESULTS AND DISCUSSIONS 17
7.1 Summary of Experimental Setup
7.2 Key Findings
7.3 Data Analysis and Visualization
7.4 Comparative Analysis
7.5 Lessons Learned
Chapter 8: SUMMARY AND FUTURE SCOPE 18
8.1 Summary of Findings
8.2 Implications for Energy Management
8.3 Limitations of the Current Study
8.4 Future Scope
References

Chapter 1. Introduction

1.1 Background

In recent decades, there has been a dramatic increase in household energy consumption due to the proliferation of electronic devices. These devices, even when not in active use, draw power in standby mode, which accounts for a significant portion of household energy use. This phenomenon, often referred to as "phantom load" or "standby power," has raised concerns among energy researchers and environmentalists. A review of energy consumption trends indicates that while appliances are becoming more energy-efficient, the cumulative effect of standby power has become a hidden contributor to global energy consumption. This project aims to address the issue of standby power by leveraging advancements in Internet of Things (IoT) technology and machine learning (ML) to create an automated solution that is both efficient and user-friendly.

1.2 Motivation for the Study

Reducing standby power consumption is crucial for both economic and environmental reasons. Households spend a considerable amount of money each year on wasted energy due to appliances left in standby mode, while the environmental impact contributes to increased carbon emissions. This report explores the motivations behind the development of a smart IoT system designed to minimize these costs and promote sustainable energy use. By integrating machine learning, the system aims to predict user behaviour and automate energy-saving processes, thus requiring minimal user intervention.

1.3 Research Questions and Hypothesis

The primary research question driving this study is: Can IoT and ML technologies be effectively combined to significantly reduce standby power consumption in household appliances? Additional sub-questions include inquiries into the accuracy of ML predictions in real-world scenarios, the scalability of the proposed system, and its user-friendliness. The hypothesis posits that an IoT-enabled device, utilizing ML algorithms for predictive analysis, can autonomously manage appliance power states, resulting in substantial energy savings.

1.4 Scope of the Study

The scope of this study is confined to household appliances with significant standby power consumption, including televisions, monitors, printers, and other common devices. The project focuses on designing a system that integrates with existing appliances using non-invasive IoT technology, minimizing installation complexity. Industrial applications, non-electrical energy sources, and highly specialized devices are outside the scope of this research.

Chapter 2. Literature Review

2.1 Historical Background of Energy Management

The study begins with an exploration of how energy consumption has evolved over the past century, emphasizing the role of electronic devices in modern households. This section includes a discussion of the early 20th-century electrical devices, the rise of energy-efficient appliances in the late 20th century, and the advent of smart devices in the 21st century. The concept of standby power emerged as devices became more sophisticated, leading to a need for continuous energy supply even when idle.

2.2 IoT in Home Automation

This section reviews the development of IoT technology and its integration into home automation. It covers the evolution of IoT from simple, single-function sensors to complex networks capable of managing entire homes. Case studies on early smart home systems provide insights into how IoT devices have improved convenience, security, and energy efficiency.

Current communication protocols, such as Zigbee, Z-Wave, Bluetooth, Arduino Nano and WiFi, are analysed for their suitability in energy management applications.

2.3 Machine Learning in Predictive Analytics

Machine learning's role in predictive analytics is discussed in detail, highlighting algorithms that have proven effective in energy management. These include linear regression for consumption forecasting, decision trees for user behaviour analysis, and neural networks for more complex pattern recognition. The section explores academic studies and real-world applications where ML has successfully optimized energy use, setting the stage for its potential application in this project.

2.4 Current Solutions for Standby Power Reduction

A comprehensive review of existing solutions aimed at reducing standby power is provided, including smart plugs, energy-saving switches, and automated power strips. Each solution's strengths and weaknesses are evaluated, focusing on aspects like user adoption, ease of installation, cost, and technological constraints.

2.5 Integration of IoT and ML for Energy Efficiency

This subsection examines the synergy between IoT and ML, highlighting case studies where their combination has led to significant energy savings. Discussions include the architecture of combined systems, challenges faced in deployment, and successes documented in academic and industrial settings. This section sets the technical foundation for the proposed system's design, emphasizing the benefits of a data-driven, adaptive approach to energy management.

2.6 Gaps in Existing Research and Potential Innovations

Despite advancements, there remain significant gaps in the integration of IoT and ML for household energy management. This section identifies the shortcomings in current research, including limited predictive accuracy, high costs, and the need for extensive user training. Potential innovations discussed include the development of more intuitive user interfaces, enhanced security protocols, and adaptive learning algorithms capable of handling diverse user behaviours. Papers referred

- Franco, Patricia, et al. "A framework for IoT based appliance recognition in smart homes." *IEEE Access* 9 (2021): 133940-133960: This paper helps us to identify the study developed an IoT-based framework for appliance recognition in smart homes, utilizing sensors and machine learning algorithms to identify and monitor various household devices.
- Wang, Wenpeng, et al. "The standby energy of smart devices: Problems, progress, & potential." *2020 IEEE/ACM Fifth International Conference on Internet-of-Things Design and Implementation (IoTDI)*. IEEE, 2020: This paper provided us information of the study focused on reducing standby power consumption in household equipment

by developing a smart system based on the Arduino Nano microcontroller. Power consumption for three household devices was measured in standby mode over a month. The system used sensors, a relay module, and a Bluetooth-connected.

Cotti, Luca, et al. "Enabling End-User Development in Smart Homes: A Machine Learning-Powered Digital Twin for Energy Efficient Management." *Future Internet* 16.6 (2024): 208: The study developed an IoT-based system to monitor and reduce standby power consumption using sensors, a mobile app, and visual indicators to alert users about unnecessary energy usage.

Gopalakrishnan, R., et al. "Reducing Energy Consumption by Stand-by Mode." *2024 5th International Conference on Mobile Computing and Sustainable Informatics (ICMCSI)*. IEEE, 2024: By utilizing the Digital Twin, end users can tailor the behavior of their smart homes through informed decisions, leading to more energy-efficient management and reduced consumption

Gheorghe, andrei-cosmin, et al. "Smart system for standby power consumption reduction of household equipment." *Revue roumaine des sciences techniques-serie electrotechnique et energetique* Vol 68.4 (2023): 413-418. The study analyzed standby energy use in smart IoT devices, assessing patterns and mitigation strategies It found that IoT devices increase standby power consumption and emphasized better design and user practices for energy savings.

Chapter 3. Problem Statement

3.1 Understanding Standby Power Consumption

Standby power, often overlooked by consumers, is a major contributor to unnecessary energy usage. This section defines standby power and its impact, focusing on the most common household devices that consume significant energy while idle. A breakdown of typical standby consumption rates for various devices is provided, along with statistical data illustrating the cumulative effect on electricity bills and carbon footprints.

3.2 Economic and Environmental Impacts

The economic implications of standby power are examined, including the average costs incurred by households due to idle energy consumption. Additionally, the environmental impact of excess energy production required to meet standby demands is analyzed, highlighting the relationship between electricity generation, fossil fuel consumption, and greenhouse gas emissions. This analysis strengthens the case for a new solution that targets standby power specifically.

3.3 Challenges with Existing Solutions

This subsection discusses the limitations of current standby power reduction solutions. These include high costs, complexity of installation, and the need for manual user intervention, which often discourages widespread adoption. The challenges also include technological constraints, such as communication latency in IoT systems and limited compatibility with older devices. Each challenge forms the basis for the project's objectives.

3.4 Need for a New Approach

The need for an innovative approach is emphasized in this section, proposing a system that addresses the identified challenges by automating standby power management through a predictive, IoT-enabled device. The aim is to develop a solution that is affordable, easy to install, and capable of learning and adapting to user behaviour without direct input. This section forms the foundation for the project's design and implementation strategy.

Chapter 4. Objectives

1. **Minimize Standby Power Loss**: Develop a solution to automatically reduce energy consumption of devices in standby mode.
2. **Integrate IoT and ML**: Leverage IoT for real-time appliance monitoring and ML models to predict usage patterns and optimize energy savings.
3. **Enhance Usability and Affordability**: Create a scalable, user-friendly, and cost-effective system requiring minimal manual intervention, promoting widespread adoption.

Chapter 5. Methodology

5.1 Requirement Analysis:

The initial phase focused on identifying the components necessary for the home automation system. Sensors such as IR and PIR were selected to detect motion and environmental conditions. Relays were chosen to control home appliances, while an Arduino microcontroller was designated as the central unit for processing and coordination. Requirements for cloud connectivity and machine learning models for load forecasting were also defined.

5.2 System Architecture Design:

Hardware Design: IR and PIR sensors integrated with Arduino to monitor motion and environmental parameters.

- Relays connected to Arduino to control appliances like lights and fans.
- Energy meter modules included to monitor power consumption.

Software Design: Cloud platform (e.g., Ubidots) for storing and analyzing sensor data.

- Machine learning models implemented to predict energy consumption patterns.
- Mobile application developed to provide users with real-time control and monitoring capabilities.

5.3 Prototype Development

Hardware Development:

- IR sensors configured to detect motion and control LEDs and motors via relays.
- PIR sensors integrated to detect human presence and automate appliance control.
- Relays used to enable ON/OFF switching of appliances based on data processed by Arduino.

Software Development:

- Arduino code written to collect sensor data, send it to the cloud, and automate appliance control logic.
- Machine learning models developed and tested to predict energy usage and optimize system operation.

5.4 Testing and Validation

- Testing: The system was tested to ensure accurate functioning of sensors, relays, and communication modules. Sensor calibration was performed to improve accuracy.
- Data Collection and Analysis: Energy consumption data from various appliances was collected and preprocessed to train the machine learning models.
- Machine Learning Model Validation: Algorithms like Decision Tree Regression, Random Forest, and KNN were trained using an 80%-20% data split and evaluated based on their prediction accuracy.

5.5 Implementation of Machine Learning Algorithms

- Machine learning algorithms, including Decision Tree Regression, Random Forest, and Support Vector Regression, were implemented to forecast load based on collected historical data.
- Python libraries such as TensorFlow and Scikit-learn were used for algorithm development, enabling accurate prediction of energy consumption patterns and optimization of appliance control.

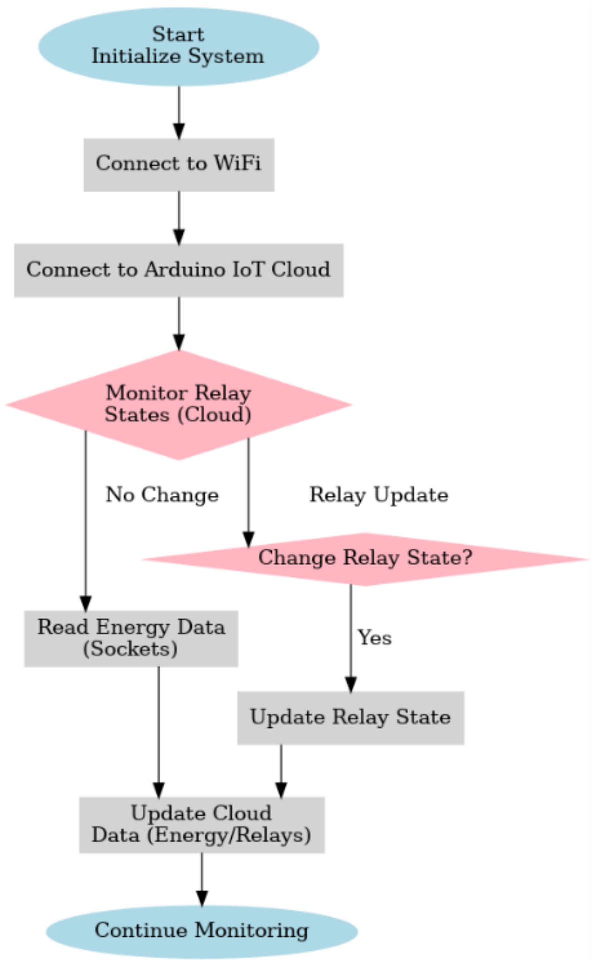
5.6 IoT Integration

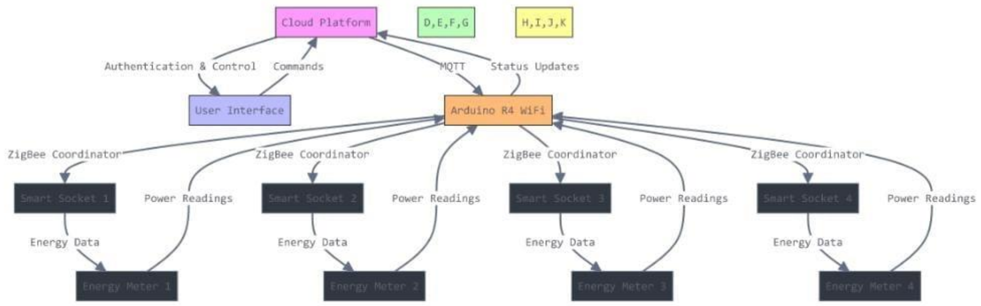
Sensor data collected by Arduino was transmitted to the cloud for analysis and real-time monitoring. The mobile application enabled users to visualize energy usage trends, control appliances remotely, and receive actionable insights for optimizing energy consumption.

5.7 Result Analysis

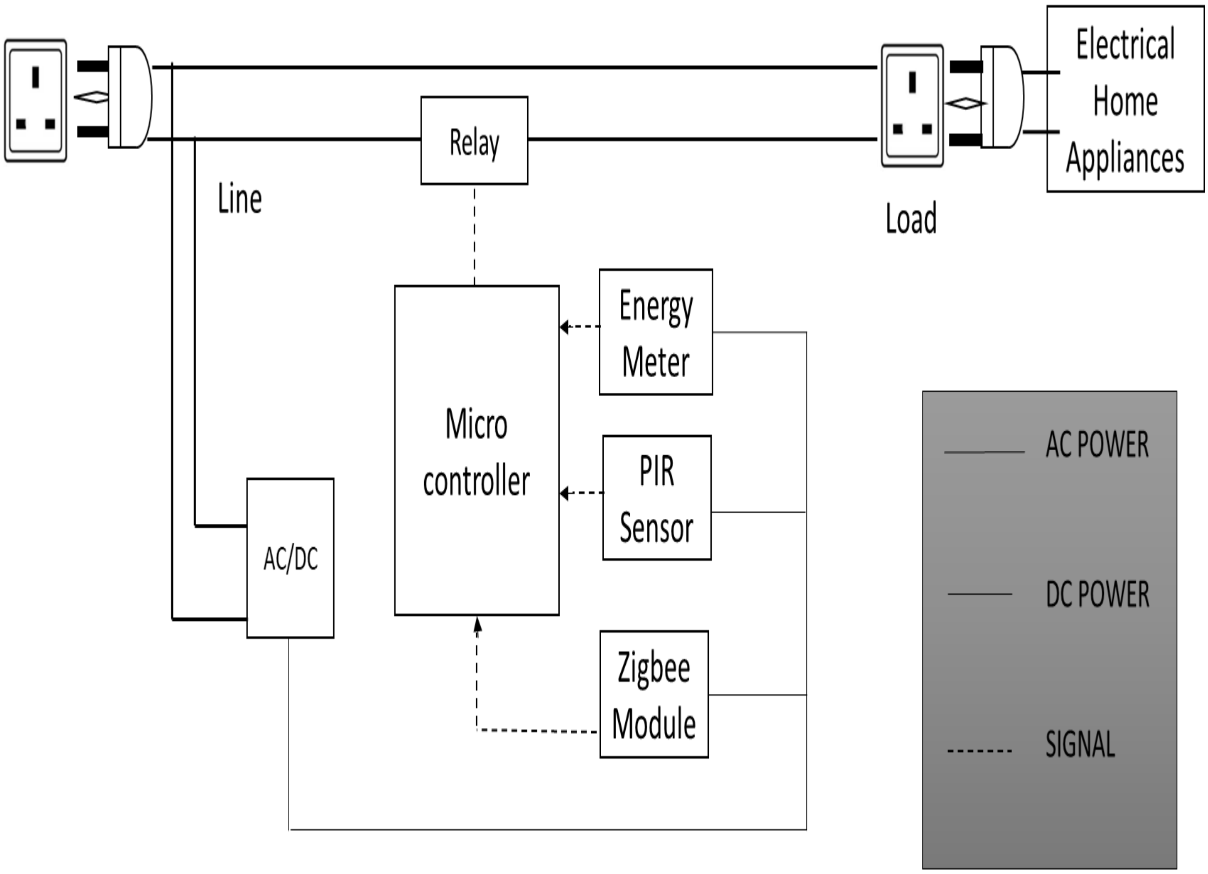
A comparative analysis of machine learning models revealed that Decision Tree Regression achieved the highest accuracy in predicting energy loads. The system demonstrated its capability to conserve energy by automating appliance control and reducing unnecessary power consumption, making it effective and user-friendly.

FLOW CHART





BLOCK DIAGRAM



Chapter 6. Work done so far

6.1 Identifying Appliances and Researching IoT Components:

- Conducted a detailed analysis of common household appliances with significant standby power consumption. This included identifying devices that consume unnecessary power when idle, such as TVs, microwaves, or chargers.
- Researched and selected appropriate IoT components for power monitoring and control:
  - Sensors: For detecting power usage and operational states.
  - Arduino boards: As a microcontroller for integrating and controlling the system.
  - Relays: To enable switching of appliances between active and off states.
  - Power monitors: For measuring and tracking electricity consumption in real time.

6.2 Circuit Design:

- Successfully designed a circuit integrating IoT components, including sensors and relays, with the Arduino for monitoring power usage and enabling automatic switching of appliances.
- Ensured compatibility and synchronization between all hardware components.
- Achieved real-time monitoring of appliance power consumption and implemented automatic switching to turn off appliances in standby mode.
- Incorporated cloud integration for remote monitoring and control functionality.

6.3 Software and Cloud Integration:

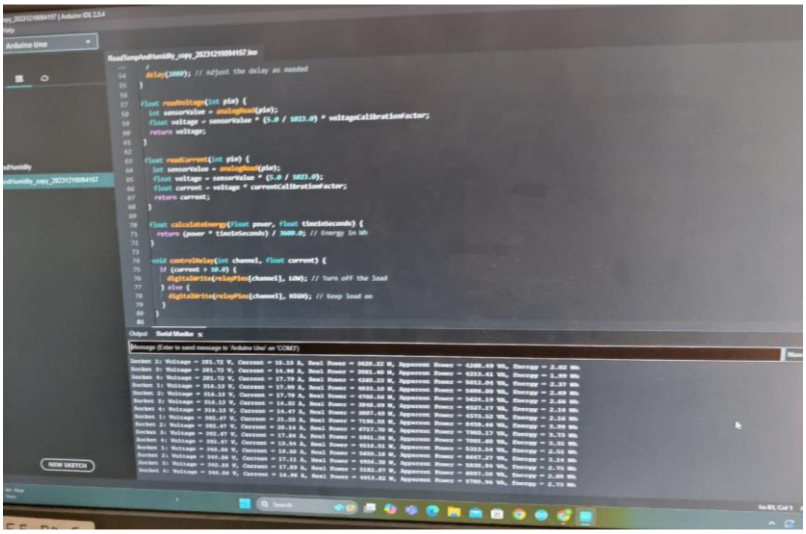
- Implemented real-time control of relays through the Arduino Cloud for remote management of appliances.
- Achieved continuous data transmission and storage for real-time power usage visualization.
- Enhanced cloud connectivity for better control of the relay through the cloud platform.

6.4 Machine Learning and Automation:

- Planning optimization of machine learning models for accurate detection and prediction of standby modes.
- Developing advanced automation rules to manage multiple appliances, aiming to improve overall energy efficiency.

6.5 Output Achievements:

- Granular Energy Monitoring: Successfully implemented separate energy consumption readings for each socket, enabling precise tracking and analysis of individual appliance usage.
- Enhanced Energy Optimization: Provides real-time insights and supports customized automation rules for efficient energy management and reduced wastage.



Chapter 7. Results and Discussions

7.1 Summary of Experimental Setup

The experimental setup is described in detail, including the environment in which the system was tested, the types of appliances used, and the specific parameters measured. A step-by-step guide to setting up the system for testing is provided, with photographs and diagrams to illustrate the setup.

7.2 Key Findings

The key findings from the experiments are presented, focusing on how effectively the system predicted standby times and managed power states. Detailed tables and charts illustrate the energy savings achieved for different types of appliances and scenarios. The performance of various ML algorithms used during testing is compared.

7.3 Data Analysis and Visualization

This section provides a comprehensive analysis of the data collected during testing. Statistical methods such as regression analysis, ANOVA (Analysis of Variance), and error rate calculations are used to validate the accuracy of the ML predictions. Graphs, bar charts, and pie charts are included to present the data visually.

7.4 Comparative Analysis

The proposed system is compared with existing energy-saving solutions, focusing on metrics like efficiency, ease of use, cost, and user satisfaction. This analysis highlights the strengths and weaknesses of the developed system and offers insights into areas for improvement.

7.5 Lessons Learned

Lessons learned during the development and testing phases are discussed, covering technical challenges, user feedback, and the overall development process. The section includes suggestions for how future iterations of the system could be improved based on these experiences.

Chapter 8: Summary and Future Scope

8.1 Summary of Literature Review

This section summarizes the findings from the literature reviewed so far. The review highlights the potential of IoT and Machine Learning (ML) in optimizing energy consumption through smarter energy management systems. Key insights include the advancements in sensor technology, communication protocols like Zigbee, and the role of ML in predicting user behavior to reduce standby power consumption. Challenges related to integrating IoT and ML technologies with existing household systems were also identified, providing valuable context for the project.

8.2 Implications for Energy Management

The reviewed literature underscores the potential benefits of smart energy systems for reducing standby power usage. These systems could lead to significant economic savings for users and contribute to broader sustainability goals by reducing carbon footprints. The integration of IoT and ML is particularly promising for enhancing the efficiency and scalability of energy management solutions.

8.3 Limitations Identified in the Literature

The literature reveals certain limitations, such as:

- The variability in user behavior, which complicates the prediction of energy usage patterns.
- Hardware constraints like sensor sensitivity and communication delays in real-time applications.
- Challenges in deploying robust ML algorithms due to limited datasets and computational resources.

These findings highlight areas that need to be addressed for effective implementation of IoT and ML-based energy systems.

8.4 Future Scope

Based on the literature reviewed, the following areas hold potential for future work:

- **Hardware Enhancements**: Incorporating more energy-efficient sensors and advanced communication modules to improve system reliability and responsiveness.
- **Machine Learning Algorithms**: Developing sophisticated ML models that can handle dynamic user behavior and adapt to different environments.
- **Integration with Emerging Technologies**: Exploring opportunities to integrate the system with smart grids, renewable energy sources, and blockchain for energy trading.
- **Scalability**: Extending the application of the system to larger installations such as commercial buildings and industries.
- **Long-Term Studies**: Conducting longitudinal studies to validate the effectiveness of these systems over time, particularly in varied environments.

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