ENERGY SAVING AND MANAGEMENT SYSTEM USING MACHINE LEARNING

PROJECT REPORT

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BONAFIDE CERTIFICATE

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DECLARATION

We affirm that the project work titled **"ENERGY SAVING AND MANAGEMENT SYSTEM USING MACHINE LEARNING"** being submitted in partial fulfillment for the award of the degree of **Bachelor of Engineering** in **DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING** is the record of original work done by us under the guidance of **Ms.PRIYADHARSHNI S**, Assistant Professor**,** Department of Artificial Intelligence and Data Science. It has not formed a part of any other project work(s) submitted for the award of any degree or diploma, either in this or any other University.

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ABSTRACT

The increasing demand for energy efficiency and power reliability in Indian households has created a need for intelligent energy management systems. Traditional energy usage patterns often lead to wastage, high electricity bills, and vulnerability during power outages. This project proposes a machine learning-based, smart energy-saving and management system designed to optimize home energy usage and renewable generation. The system predicts next-day energy consumption and renewable (solar and wind) generation using weather and historical data, offering intelligent suggestions for optimal appliance usage and battery management.

The solution consists of an Android application that integrates real-time data visualization, usage predictions, and smart suggestions. It connects to a backend powered by machine learning models hosted on a local Flask server, and processes weather and usage data to forecast energy patterns. A dynamic decision logic determines when to use solar/wind energy, draw from the battery, or switch to the grid, ensuring maximum efficiency and cost savings. Additionally, a scraping mechanism fetches power cut alerts to reserve battery power in advance.

Key findings show that the system can reduce grid dependency by intelligently utilizing stored and renewable energy, while providing users with actionable, personalized suggestions. This approach presents a scalable and customizable solution for energy-conscious households, especially in regions with unreliable power supply.

Keywords: Energy Management System, Machine Learning, Android Application, Solar and Wind Prediction, Battery Optimization, Power Cut Alerts, Real-Time Monitoring.

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CHAPTER 1

INTRODUCTION

1.1 EVOLUTION OF ENERGY MANAGEMENT AND OPTIMIZATION

In recent years, global energy consumption has risen significantly due to increased demand from residential, industrial, and commercial sectors. As energy resources become scarce and environmental concerns grow, the need for efficient energy management and conservation has become critical. Traditional energy management systems rely on manual monitoring and rule-based controls, which often lead to inefficiencies and energy wastage.

The advancement of machine learning (ML) and the Internet of Things (IoT) has enabled the development of smart energy management systems that predict, analyze, and optimize energy usage in real time. By integrating data-driven decision-making, these systems can help reduce power wastage, lower electricity costs, and improve the sustainability of energy consumption.

This project aims to develop an energy management and saving system using machine learning, which will:

- Monitor and analyze household energy consumption patterns.
- Optimize battery usage and manage renewable energy sources.
- Predict power cuts and adjust energy storage dynamically.
- Reduce reliance on the grid by prioritizing stored energy usage.

The system will use an Android Studio application to display energy consumption data, suggest energy-saving measures, and provide real-time insights on battery energy levels. The backend, developed in Python, will process sensor data and implement ML algorithms to optimize energy distribution and consumption.

1.2 IOT AND AI INTEGRATION IN ENERGY MANAGEMENT

The combination of **IoT and artificial intelligence (AI)** has revolutionized energy management by enabling:

- **Real-time energy tracking** through smart meters and sensors.
- **Predictive analytics** for energy consumption forecasting.
- **Automated load balancing** to reduce wastage and optimize power usage.
- **Smart battery management** for better energy utilization during power cuts.

This project leverages **IoT sensors, machine learning models, and a cloud-based data processing framework** to create an adaptive energy-saving system. Key components include:

- **ESP32 Microcontroller:** Captures and transmits energy data from household appliances.
- **Smart Energy Meters:** Monitor energy usage and provide real-time consumption reports.
- **Machine Learning Algorithms:** Predict consumption trends and optimize power allocation.
- **Battery Energy Storage System:** Stores excess energy for use during peak hours or power cuts.
- **Mobile Application (Android Studio):** Displays energy analytics and provides energy-saving recommendations.

By **analyzing historical energy data**, the system can identify peak consumption periods, suggest cost-saving strategies, and automatically switch between **grid power and battery storage** to minimize electricity costs.

1.3 ROLE OF MACHINE LEARNING IN ENERGY OPTIMIZATION

Machine learning plays a crucial role in improving energy efficiency and management. The system will implement ML models to:

Predict energy demand based on past usage patterns.Optimize battery usage by forecasting power cuts and adjusting storage dynamically.Classify appliances based on energy consumption to identify high-energy devices.Suggest energy-saving actions tailored to user behavior.The convergence of IoT (Internet of Things), machine learning (ML), and renewable energy has opened new opportunities for smart home automation and energy management. With increasing adoption of rooftop solar panels and small wind turbines in residential areas, there is a need for systems that can analyze, predict, and control energy flow dynamically.

Machine learning models in this project are trained using weather conditions and historical energy data to forecast both energy usage and renewable generation. The system dynamically decides when to store energy, when to use it directly, and when to switch to the grid. This improves reliability, especially in areas prone to load-shedding or unpredictable power cuts.

Unlike traditional EMS, which operate on fixed rules, this project uses adaptive algorithms that learn from past data to make better decisions over time. The system also considers real-world constraints like battery capacity, power source switching delays, and peak hour costs. In cases where no real-time data is available, the system relies on simulated dummy data to continue functioning smoothly.

The Android application acts as a user interface for the entire system, providing real-time monitoring, future usage predictions, and appliance usage suggestions. This integration of ML, IoT, and mobile technologies brings energy awareness and control directly to the hands of users.

1.4 PROBLEM STATEMENT

The motivation behind this project is to build an affordable and intelligent EMS that addresses the specific challenges of Indian households. Frequent power cuts, reliance on grid electricity, and limited awareness about efficient energy usage often lead to high electricity bills and low renewable energy utilization. While solar and battery systems are becoming more common, there is still a lack of smart logic to manage these systems efficiently.

Key challenges include predicting energy consumption accurately, forecasting renewable generation based on weather, and managing batteries intelligently to ensure backup during outages. This system also faces challenges such as data noise, real-time response handling, and decision-making under uncertain conditions like sudden power cuts.

To address these, this project implements a modular machine learning pipeline for predictions and decision-making, a scraping module for fetching localized power cut alerts, and a simulated real-time energy flow system using dummy data. The goal is to provide a robust, customizable EMS that can scale with actual sensor inputs and adapt to changing user patterns.

By offering real-time insights, personalized suggestions, and smart automation, this project aims to empower users to make informed energy decisions, save costs, and improve power reliability in their homes.

CHAPTER-II

LITERATURE SURVEY

In recent years, energy management and optimization have gained significant attention due to increasing power consumption, rising electricity costs, and the need for sustainable energy solutions. With the goal of developing an ML-based energy-saving system with IoT integration, this literature survey explores recent studies, critiques existing methods, identifies gaps, and outlines the challenges in current energy management systems. By evaluating the limitations of traditional energy monitoring and recent advancements in AI-driven energy optimization, this survey contextualizes the need for an intelligent, automated, and cost-effective energy management system.

2.1 AI-DRIVEN ENERGY OPTIMIZATION IN SMART HOMES (CHEN ET AL., 2020)

Chen et al. (2020) studied the application of machine learning and artificial intelligence (AI) in energy management for smart homes. Their research demonstrated that predictive modeling could significantly enhance energy efficiency by analyzing usage patterns and suggesting energy-saving strategies.

Their study utilized neural networks and reinforcement learning to optimize energy consumption. The results showed that AI-driven energy prediction reduced electricity bills by 15-20% in controlled environments. However, the study noted challenges in integrating real-time energy data and handling dynamic energy usage patterns in households.

This research supports the use of ML models in forecasting power demand and optimizing energy storage. However, it highlights the need for a more adaptable and scalable solution capable of adjusting to real-time energy usage variations while integrating IoT-based monitoring.

2.2 IOT-BASED SMART METERING FOR ENERGY CONSUMPTION ANALYSIS (KUMAR & DAS, 2021)

Kumar & Das (2021) focused on the role of IoT-based smart meters in monitoring and analyzing household energy consumption. Their study highlighted that real-time data collection via smart meters improves energy efficiency by identifying energy wastage and advising corrective measures.

Their findings indicated that IoT-based systems:

- Enable real-time tracking of electricity usage.
- Reduce human dependency by automating energy monitoring.
- Provide detailed consumption insights, allowing users to make informed decisions.

However, the study pointed out a limitation in data processing efficiency, as high-frequency energy data required advanced computational models for real-time analysis. This underscores the necessity of machine learning algorithms for handling large-scale energy data effectively.

2.3 BATTERY ENERGY STORAGE OPTIMIZATION FOR RENEWABLE ENERGY (LEE ET AL., 2019)

Lee et al. (2019) explored the use of battery energy storage systems (BESS) to optimize energy usage in renewable energy-powered homes. Their research found that excess energy storage from solar panels could be efficiently managed using AI-driven prediction models.

Key insights from the study include:

AI-enhanced battery storage systems improve energy utilization by forecasting demand.Machine learning models can predict energy production and adjust battery usage dynamically.Grid disconnection strategies reduce dependency on external power sources.

Despite these advantages, challenges such as battery degradation, charging inefficiencies, and cost concerns were noted. The study emphasized the need for intelligent battery management algorithms to extend battery life and optimize energy storage.

2.4 ENERGY CONSUMPTION PREDICTION USING MACHINE LEARNING (SHARMA ET AL., 2022)

Sharma et al. (2022) developed an energy consumption prediction model using supervised learning algorithms. Their study tested various ML techniques, including Random Forest, Decision Trees, and LSTM (Long Short-Term Memory) networks, to forecast household energy consumption.

Findings revealed that:

- LSTM models provided the highest accuracy in predicting energy usage patterns.
- Decision Trees performed well in classifying high-energy-consuming appliances.
- Random Forest models efficiently handled large datasets but required significant computational resources.

While the research demonstrated high accuracy in energy predictions, it lacked an integrated mobile application for user interaction. This indicates the need for a real-time energy tracking system, which our project aims to address through an Android-based application.

CHAPTER-III

OBJECTIVES AND METHODOLOGY

This chapter outlines the proposed work for developing a home automation system that integrates Android-based control with IoT devices, focusing on manual and automated control of household appliances. It details the objectives derived from the findings in the literature survey, describes the procedure with a flow diagram, and elaborates on the selection of components, tools, techniques, and testing methods used in the project. Additionally, this chapter discusses system design challenges, ethical considerations, and potential use cases to provide a comprehensive view of the work. The chapter concludes with a detailed summary of its contents.

3.1 OBJECTIVES OF THE PROPOSED WORK

The objectives of this work were established based on the gaps identified in the literature survey. These objectives guided the development of the home automation system and are expanded below to provide more depth and technical detail:

Objective 1: Development of a User-Friendly Android Application

The primary objective is to design an intuitive Android application that serves as the central interface for manual control of appliances, with additional features like scheduled automation and real-time feedback.

- **Interface Design:**
    - The application utilizes modern UI/UX design principles, ensuring ease of navigation and visual appeal. Key features include toggles for device control, visual indicators for device status, and an organized layout for efficient interaction.
    - An adaptive interface ensures compatibility across devices with varying screen sizes and resolutions, allowing users to switch between tablets and smartphones without compromising functionality.

- **Accessibility:**
  - Features such as dynamic font scaling, dark mode for low-light environments, and clear visual indicators ensure the app is accessible to all users, including those with disabilities.
  - Multilingual support allows the app to cater to a diverse user base.
- **Optimization:**
  - The app leverages asynchronous programming models to handle multiple operations concurrently without causing delays.
  - Background processes are optimized to minimize battery drain, enabling prolonged usage.
- **Customization and Advanced Features:**
  - The application offers a customizable dashboard, allowing users to prioritize frequently accessed devices and set up custom automation.
  - Integrated network diagnostics help troubleshoot connectivity issues.

Objective 2: Integration of ESP8266 for Real-Time Appliance Control

The ESP8266 NodeMCU microcontroller is the core of the system, facilitating seamless communication between the Android app and connected appliances.

- **Communication Framework:**
  - The system uses lightweight HTTP protocols for command transmission, ensuring efficient control of appliances. WebSocket protocols can be implemented for real-time, bidirectional communication.
  - JSON data formats allow flexible communication and easy parsing of commands.

- **Relay Control and Circuit Safety:**
    - High-current relays ensure safe control of appliances while adhering to electrical safety standards.
    - Optocouplers provide electrical isolation between the ESP8266 and high-voltage appliances, ensuring user safety.
- **Scalability and Modularity:**
    - The system supports up to eight devices per NodeMCU, with options for further expansion via additional modules or daisy-chaining.
    - Over-the-air (OTA) firmware updates ensure the system stays up-to-date.
- **Firmware Development and Testing:**
    - The ESP8266 is programmed using the Arduino IDE with libraries like ESPAsyncWebServer to handle HTTP requests efficiently.
    - Stress tests ensure the ESP8266 can handle multiple simultaneous commands without dropping connections.

Objective 3: Comprehensive Testing and Validation of System Performance

Testing is essential for ensuring the system's reliability, accuracy, and usability under various conditions.

- **Command Execution Testing:**
    - Stress testing is performed to evaluate system performance under heavy command loads, simulating scenarios where multiple users issue commands simultaneously.
    - Latency benchmarks are established to ensure near-instantaneous execution of commands.

- **Relay Safety and Reliability:**
    - Load testing is conducted to ensure relays operate efficiently with both low-power devices (e.g., LEDs) and high-power appliances (e.g., air conditioners).
    - Circuit safety tests include insulation resistance measurements and high-voltage tolerance checks.
- **End-User Testing:**
    - User trials gather feedback on app usability, command accuracy, and overall satisfaction.
    - Iterative improvements are made based on this feedback to enhance the system's usability and functionality.
- **Network Performance Testing:**
    - Simulated weak signal environments test the app's ability to maintain stable communication with the ESP8266.
    - Automatic reconnection mechanisms are validated to ensure reliable performance even with network interruptions.

3.2 SYNTHETIC PROCEDURE OF THE PROPOSED WORK

The proposed system integrates machine learning-based energy usage prediction, renewable energy generation forecasting, and smart battery management into a cohesive system designed to optimize energy consumption in homes. Below is a detailed explanation of the system flow and its key components:

1. Data Collection

The process begins with gathering various data inputs that are crucial for accurate energy prediction and generation forecasting:

- **Weather Data**: Real-time weather information, such as temperature, humidity, and solar radiation, is fetched using an API like OpenWeatherMap.

- **Energy Usage Data**: Historical energy consumption data from home appliances (using CSV files like energydata_complete.csv) is used to understand patterns and trends.

- **Renewable Energy Generation Data**: Solar and wind energy generation data (from CSV files like solar_output_3_panels.csv and estimated_wind_output_EN600.csv) helps estimate the availability of renewable energy.

2. Data Preprocessing

Once the data is collected, it is cleaned and prepared for input into machine learning models:

- **Missing Data Handling**: Any missing or incomplete data points are addressed using imputation techniques or by removing incomplete entries.

- **Feature Engineering**: Data such as the time of day, weather conditions, and historical usage patterns are transformed into features that can be fed into the model (e.g., 'hour', 'day', 'month', 'T_out', 'Prev_Hour_Usage').

3. Energy Usage Prediction

The core of the system is the machine learning model that predicts the next day's energy usage and renewable energy generation:

- **Model Training**: A Random Forest or other suitable model is trained using historical energy data to predict the next day's energy usage and renewable generation (solar/wind).

- **Input Features**: The model takes input features like weather data, time-based features, and historical usage to make predictions on future energy consumption and generation.

4. Battery State-of-Charge (SoC) Management

Using predictions from the energy usage model, the system dynamically manages battery charging and discharging:

- **Battery Charge Decision**: Based on predicted usage and renewable generation, the system decides whether to charge the battery, use energy directly from solar, wind, or the grid.

- **Smart Battery Logic**: The battery management system ensures that the battery is charged during periods of high renewable energy generation and discharged when needed to avoid reliance on the grid during power cuts.

5. Power Cut Detection and Response

The system integrates real-time power cut data scraped from the web (India-specific) to anticipate and mitigate the impact of power outages:

- **Power Cut Detection**: The app fetches power cut alerts from news sources and updates the user on upcoming outages in the region.

- **Adaptive Battery Management**: The battery system adjusts its strategy based on upcoming power cuts, ensuring that reserves are maintained for critical times.

6. Real-Time Monitoring and Suggestions

The system continuously monitors energy usage and generation in real-time and provides smart suggestions to the user:

- **Real-Time Energy Usage**: Displays current energy usage, generation, and battery status on the app, allowing users to track energy consumption in real-time.

- **Smart Suggestions**: Based on predicted generation and usage patterns, the app suggests optimal times to use appliances (e.g., "Run the washing machine at 2 PM when solar generation is highest").

7. User Interface and Feedback

The energy management system provides a user-friendly interface for the homeowner:

- **App Interface**: An Android app displays key metrics such as current energy usage, predicted usage, battery state, and power source (solar/grid/battery).

- **User Feedback**: The app notifies the user when actions are taken (e.g., battery charging, appliance usage suggestions) and alerts them of power cuts or system malfunctions.

3.3 SELECTION OF COMPONENTS, TOOLS, DATA COLLECTION, TECHNIQUES, AND STANDARDS

This section outlines the selection of components, tools, data collection methods, techniques, and standards used in the development of the energy-saving and management system.

3.3.1 Selection of Components

ESP8266 NodeMCU

The **ESP8266 NodeMCU** has been chosen as the primary microcontroller for controlling appliances due to its distinct advantages in home automation systems:

- **Wi-Fi Capability**: The ESP8266 has built-in Wi-Fi, which facilitates seamless communication between the Android app and the hardware for remote appliance control.

- **Low-Cost Solution**: It provides an affordable platform for controlling appliances in the home environment.

- **Ease of Use**: It can be easily programmed to handle the necessary HTTP requests that control the connected appliances.

- **GPIO Pins**: The ESP8266 supports multiple GPIO pins, which are essential for controlling relays connected to household appliances like lights, fans, and other devices.

Relay Module

The **Relay Module** is an essential component for safely controlling high-voltage appliances:

- **Safe Switching**: The relay provides an interface for low-voltage control signals from the ESP8266 to safely switch high-voltage appliances on and off.

- **Multi-Channel Support**: The relay module can manage multiple appliances simultaneously, enabling the control of several devices through a single microcontroller.

- **Durability**: Relays are well-suited for continuous switching of electrical devices, ensuring the long-term reliability of the system.

Android Device

An **Android Device** serves as the interface for the user to interact with the energy-saving system:

- **User Interface**: The Android app, developed using Kotlin and Jetpack Compose, provides a responsive and interactive interface for users to monitor and control appliance usage based on predictions.

- **App Features**: The app is capable of fetching real-time data, displaying energy usage statistics, showing weather information, and controlling connected appliances.

- **Real-Time Communication**: The Android device communicates with the ESP8266 and Flask server to transmit data and receive predictions, ensuring real-time monitoring and decision-making.

3.3.2 Tools

The development of the energy-saving system required the use of several tools to integrate various components, analyze data, and build the user interface.

Google Colab for Machine Learning Development

Google Colab was chosen for developing and training the machine learning models used in predicting energy usage and renewable energy generation:

- **Cloud-Based Platform**: Colab provides a cloud-based environment that is easy to use and allows collaboration among team members.

- **Resource Efficiency**: Google Colab provides free access to powerful GPUs, making it possible to train machine learning models faster without the need for expensive hardware.

- **Integrated Python Libraries**: With libraries like TensorFlow, Pandas, and Scikit-learn, Google Colab offers all the tools necessary to preprocess data, train models, and evaluate performance.

Android Studio and Kotlin for App Development

Android Studio, the official IDE for Android development, was used to create the Android app:

- **Kotlin Programming Language**: Kotlin was selected due to its modern features and compatibility with Android development, making the app easy to develop, maintain, and extend.

- **Jetpack Compose**: For building a responsive user interface, Jetpack Compose was employed. It offers a declarative approach to UI design, reducing the complexity of the layout and enabling the app to update dynamically with real-time data.

- **Integration with Machine Learning Models**: Android Studio is used to integrate the app with the Flask server, sending and receiving prediction data for energy management.

Flask for Hosting Machine Learning Models

Flask serves as the framework for deploying the machine learning models as a REST API:

- **Lightweight Framework**: Flask is a simple and efficient Python web framework, ideal for serving lightweight machine learning models through APIs.

- **Hosting Predictions**: The trained machine learning models are deployed on the Flask server, and the Android app communicates with the server to get energy usage predictions, solar/wind generation forecasts, and other relevant data.

- **Ease of Integration**: Flask provides easy integration with Python-based machine learning models, making it a straightforward choice for serving the predictions.

Retrofit for Network Communication

Retrofit is used to manage network communication between the Android app and the Flask server:

- **Asynchronous Communication**: Retrofit ensures that the app communicates with the server asynchronously, ensuring smooth user interactions even while fetching predictions.

- **Efficient Data Parsing**: Retrofit parses data between the server and the Android app in JSON format, ensuring efficient data transfer without overhead.

- **Seamless API Integration**: Retrofit simplifies API requests, making the integration between the Android app and Flask server seamless.

3.3.3Data Collection

Accurate and real-time data collection is crucial for making reliable predictions and providing users with actionable insights.

Energy Usage Data

The **energy usage data** is collected from historical records of electricity consumption in the home:

- **CSV Files**: The energy consumption data is stored in CSV format (energydata_complete.csv), which includes hourly energy usage, appliance-specific data, and other relevant metrics.

- **Feature Set**: This dataset includes features like the hour of the day, day of the week, temperature, humidity, and previous energy consumption, which are essential for predicting future usage.

- **Prediction Target**: The target variable is the energy consumption of the following day, which is predicted based on the collected features.

Weather Data

Real-time **weather data** is fetched from the **OpenWeatherMap API**:

- **Temperature and Humidity**: These parameters play a crucial role in predicting energy consumption, as high or low temperatures can directly affect appliance usage, such as air conditioners or heaters.

- **Solar Radiation**: Solar radiation data is used to estimate solar energy generation for the upcoming day, helping optimize the use of solar-powered appliances.

- **Location**: The system uses weather data for the default location, **Sathyamangalam**, to provide accurate forecasts and predictions.

Renewable Energy Generation Data

Data regarding **solar and wind energy generation** is collected to estimate renewable energy production:

- **Solar Data**: Historical solar output data (solar_output_3_panels.csv) is used to estimate solar power generation based on weather conditions.

- **Wind Data**: Data from small wind turbines (estimated_wind_output_EN600.csv) helps predict the amount of energy generated by wind, providing a more complete picture of the available renewable resources.

3.3.4 Techniques and Standards

Several techniques and standards are applied to ensure that the system operates efficiently, safely, and reliably.

Machine Learning Techniques

- **Random Forest Model**: The Random Forest algorithm is used to predict energy consumption and renewable energy generation, as it is robust to overfitting and performs well with non-linear data.

- **Feature Engineering**: Key features such as time of day, weather conditions, and past usage are extracted and processed to train the model.

- **Cross-Validation**: Cross-validation techniques are employed to assess the accuracy and performance of the model on unseen data.

Energy Standards

- **IEEE Smart Grid Standards**: The system aligns with the IEEE standards for smart grid technology, ensuring that it can integrate with existing energy infrastructure and meet industry requirements for safety and interoperability.

- **IEC Electrical Safety Standards**: The relay modules used in the system adhere to the International Electrotechnical Commission (IEC) standards, ensuring that the system is safe for handling high-voltage appliances.

Communication Standards

- **Wi-Fi Protocols**: Communication between the Android app and ESP8266 is conducted over secure Wi-Fi protocols, ensuring a stable and secure connection.

- **JSON for Data Transfer**: Data exchanged between the Android app and Flask server is transmitted in JSON format, which is lightweight and easy to parse.

3.4 Additional Considerations

In developing an energy-saving and management system, there are several aspects to consider beyond the core functionality. These include addressing system design challenges, ensuring ethical standards, and exploring potential use cases. This section discusses these key areas, which contribute to the robustness, accessibility, and security of the system.

3.4.1System Design Challenges

- **Dynamic Data**: Energy usage, renewable generation, and weather data must be fetched and displayed in real-time. The system needs to handle interruptions in data transmission, such as slow network connections or lost packets, and update the app interface smoothly to maintain a consistent user experience.

- **Error Handling**: In cases of dropped data packets or failure in the data retrieval process, the system must ensure that the user is informed with minimal disruption to their experience. A robust error-handling mechanism ensures that the app gracefully recovers from network failures and continues to function as expected.

- **Power Fluctuations**: In a home setting, power cuts or surges are common. The system needs to be able to handle such interruptions in power supply, ensuring that the appliance control features continue to function smoothly when power returns. The system must also manage the state of connected appliances during power outages to avoid unexpected behavior once power is restored.

3.4.2Network Reliability:

A significant challenge in any IoT-based system is maintaining reliable communication between devices, especially over wireless networks. This project involves an Android app that communicates with an ESP8266 microcontroller over Wi-Fi, which introduces a range of potential challenges.

- **Wi-Fi Connectivity**: Intermittent or weak Wi-Fi signals are common in many home environments, especially in areas with poor coverage or heavy interference. To mitigate this issue, the system includes a retry mechanism, where commands are re-sent if a communication failure occurs. Additionally, the app could periodically check the network status and prompt the user to reconnect if connectivity is lost.

- **Communication Latency**: Even in stable network conditions, communication delays can occur due to the nature of wireless data transmission. These delays may be more noticeable during the transmission of real-time energy usage or appliance control data. To address this, the app implements asynchronous communication methods (via Retrofit) to ensure that the user interface remains responsive even when waiting for data from the server.

- **Signal Range and Coverage**: The Wi-Fi network's coverage must be robust enough to handle communication across different areas of the home. Placement of the ESP8266 NodeMCU and the Android device must be considered carefully to ensure signal strength and reliability. If signal range is an issue, additional network infrastructure such as Wi-Fi extenders could be employed.

3.4.3Ethical Considerations

While developing and deploying a home automation system, ethical considerations related to data privacy, accessibility, and user fairness are paramount. These factors ensure the system remains both secure and inclusive for all users.

Data Privacy:
One of the primary ethical concerns in any IoT-based application is the handling of user data. Given that the energy management system may process sensitive information such as energy usage patterns and appliance control behaviors, it is essential to ensure privacy.

- **Data Encryption**: All communication between the Android app and the Flask server is encrypted using secure HTTP (HTTPS). This prevents unauthorized access to the data while it is being transmitted across the network.

- **Minimal Data Collection**: The system only collects essential data required for predictions, such as energy consumption, weather conditions, and appliance statuses. No personally identifiable information (PII) is collected or shared with third parties.

- **Local Data Storage**: Any data that is necessary for the app's operation, such as the user's energy consumption history or appliance settings, is stored locally on the device, ensuring that the data does not need to be transferred over the internet unless absolutely necessary.

- **User Control**: Users have control over their data. They can access and manage the stored information at any time, including the option to delete historical usage data from the app if desired. Furthermore, no personal information is shared without explicit user consent.

3.4.4 User Accessibility:

Ensuring the system is accessible to all users, including those with disabilities, is an important ethical consideration.

- **Visual Accessibility**: The app provides clear and readable text with high contrast for users with visual impairments. It also includes options to adjust font sizes and screen colors for better legibility.

- **Tactile Feedback**: For users with physical disabilities, the app incorporates tactile feedback, such as vibration responses when interacting with certain elements (e.g., turning an appliance on or off). This feedback ensures that users can confirm their actions without needing to rely on sight alone.

- **Voice Accessibility**: Although the system does not utilize voice control, the app supports integration with voice accessibility tools, such as screen readers and voice assistants. This ensures that visually impaired users can interact with the app through auditory feedback.

- **Multilingual Support**: To make the app accessible to a broader audience, including users in diverse regions of India, multilingual support will be incorporated. The app will support multiple languages, including Hindi and regional languages, ensuring that language is not a barrier to usability.

Potential Use Cases

- **Home Automation:**
    - A convenient way to control household appliances through manual commands or automation schedules.

Standards

- **Electrical Safety Standards:**
    - Ensures proper insulation, relay control safety, and protection against electrical hazards.
- **Network Protocol Standards:**
    - Uses secure HTTP for data transfer to prevent vulnerabilities during communication.

CHAPTER-IV

PROPOSED WORK MODULE

This chapter presents an overview of the proposed work aimed at developing an energy-saving and smart home management system using machine learning and embedded control. The system is designed to optimize household energy usage by predicting energy consumption and renewable generation, providing smart suggestions, and managing battery operations based on real-time and forecasted data. The proposed system integrates a custom Android application with local CSV simulation, weather APIs, and an ESP-based control circuit, offering a user-friendly, responsive, and cost-effective solution tailored for Indian homes. This chapter details the major components of the proposed work, highlighting the development of the Android application, machine learning backend, hardware logic, and communication protocols. Furthermore, the methodology adopted is discussed to demonstrate a structured approach in achieving system objectives.

4.1 PROPOSED WORK

4.1.1 DEVELOPMENT OF THE ANDROID APP

The Android application serves as the primary interface for users, enabling real-time monitoring and control of energy flow, along with smart suggestions. Developed using Android Studio and Jetpack Compose, the app integrates multiple modules such as weather forecasting, current energy usage/generation, prediction screens, and appliance usage recommendations. Focus was placed on clean UI/UX design and modular layout to ensure usability across a broad user base. This section outlines the design choices, modular screen architecture, and simulation using dummy CSV data.

4.1.2 MACHINE LEARNING BACKEND INTEGRATION

The machine learning component forms the predictive intelligence of the system. Models were developed using Python and trained on historical weather and energy data to predict daily usage, solar, and wind energy generation. These models are hosted on a local Flask server, which the Android app communicates with via Retrofit. This section explores model input features, server integration, and the techniques used to reduce latency and improve accuracy.

4.1.3 ESP MICROCONTROLLER AND POWER SOURCE SWITCHING

This component involves programming the ESP8266 NodeMCU to manage dynamic switching between grid, solar, and battery sources based on real-time conditions and predictions. The ESP module processes logic such as battery state-of-charge (SoC), power cut predictions, and generation forecasts to decide the optimal energy source. This section details the embedded logic, relay control, and safeguards implemented to ensure seamless and safe transitions.

4.1.4 INTEGRATION OF HARDWARE COMPONENTS

The system integrates hardware components like the ESP8266, 4-channel relay modules, and power monitoring sensors. Wiring configurations were planned to support modular expansion and safety protocols. Emphasis was placed on thermal and electrical protection. The testing processes confirmed reliable response to control signals from both the Android interface and ML-based logic.

4.1.5 TESTING AND EVALUATION

Testing and evaluation focused on both software and hardware reliability. The Android app was tested for UI responsiveness, data accuracy, and Retrofit communication with the Flask backend. The ESP logic was evaluated under simulated power cuts and SoC fluctuations. User feedback was collected during mock demo sessions, and the system was validated against daily usage scenarios. Metrics like prediction error rates, switching delay, and user satisfaction were used to assess performance.

4.2 METHODOLOGY OF THE PROPOSED WORK

4.2.1 REQUIREMENT ANALYSIS AND DESIGN

Initial requirements for hardware, software, and user expectations were gathered via literature reviews and informal surveys. System design began with architecture planning: UI layout for the app, feature set prioritization, and data flow diagrams. Weather APIs and CSV datasets were selected as input sources for simulation and training. Model prototypes were iteratively refined based on test results.

4.2.2 DEVELOPMENT OF THE ANDROID APP

The Android app was developed using Kotlin in Android Studio. A modular approach was adopted with Jetpack Compose, dividing the app into multiple sections such as

Weather Info, Real-Time Energy Display, Prediction View, and Smart Suggestions. Dummy CSV data was parsed locally to simulate real-time usage/generation every 10 seconds. Retrofit was used to integrate ML model predictions from a local Flask backend.

4.2.3 ML MODEL DEVELOPMENT AND FLASK INTEGRATION

Python and scikit-learn were used to train RandomForest models using preprocessed datasets for energy usage and renewable generation. Each model was exported as a .pkl file and served via a lightweight Flask server. Inputs were formatted JSON payloads simulating sensor or API data. Accuracy was evaluated using metrics like MAE and RMSE. The app fetches predictions and updates UI dynamically.

4.2.4 ESP8266 PROGRAMMING AND CONTROL LOGIC

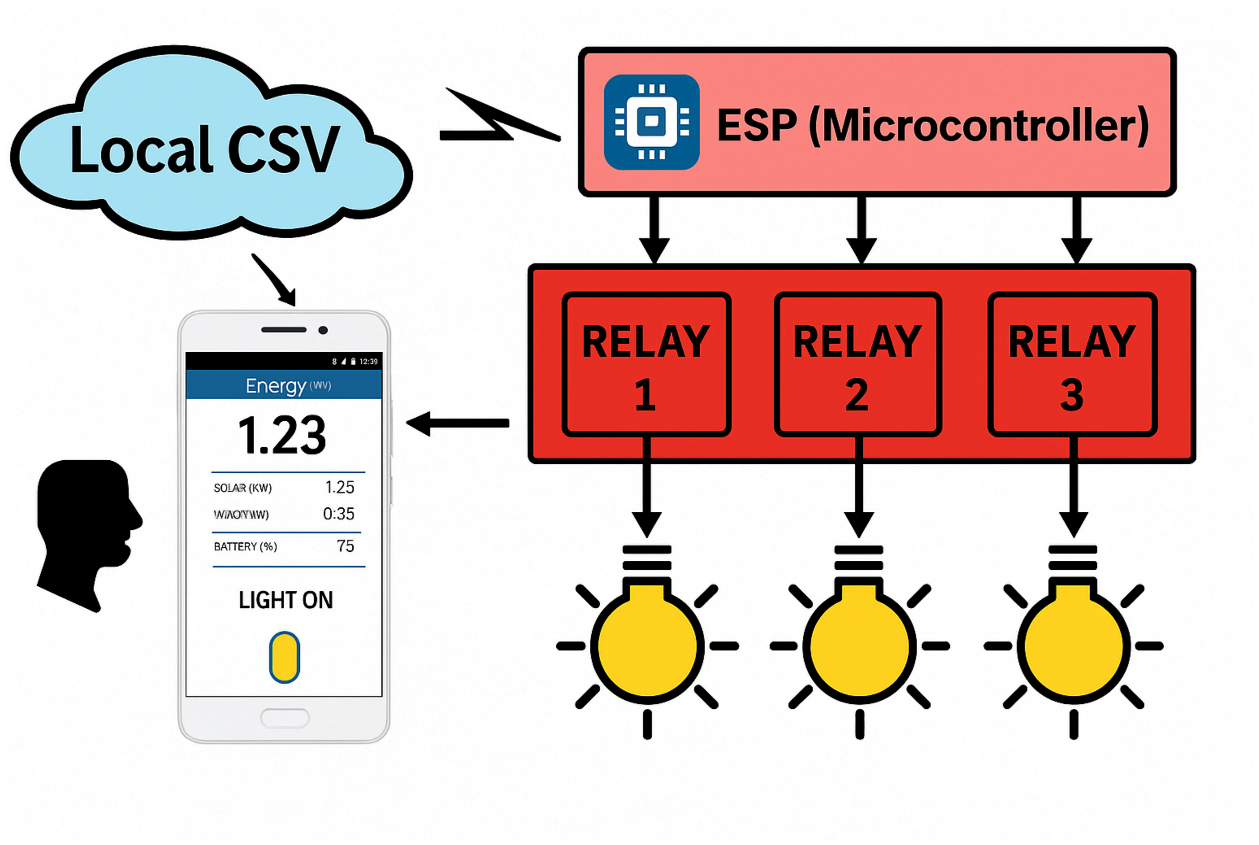
The ESP8266 was programmed using the Arduino IDE. Control logic included reading weather and usage predictions, evaluating SoC levels, and switching relays accordingly. Safety mechanisms were embedded for overcurrent protection and fallback to the grid in case of generator/battery failure. Real-time feedback was sent via serial output and LED indicators during testing.

4.2.5 SYSTEM TESTING AND EVALUATION

The complete system was tested under multiple daily scenarios. Usage/generation patterns were simulated to observe prediction reliability, switching efficiency, and user interaction. Edge cases like power cut conditions and SoC dropping below thresholds were tested. User feedback from teammates and early users highlighted satisfaction with suggestions and prediction accuracy. Test outcomes were used to fine-tune UI elements and control logic thresholds.

4.3 SUMMARY OF THE CHAPTER

This chapter provides a comprehensive breakdown of the proposed energy-saving and management system, detailing its key components from the Android interface and predictive machine learning backend to ESP-based power source switching and relay control. A systematic methodology was followed, combining design analysis, development, and rigorous testing to build a user-friendly, reliable system. Results from integration and testing phases confirm that the system aligns with its goal of enhancing energy efficiency, enabling smart automation, and offering resilience during power outages in Indian households.



CHAPTER-V

RESULTS AND DISCUSSIONS

This chapter outlines the performance and outcomes of the Android-based energy-saving and management system developed for Indian households. The system aims to provide users with a cost-effective and intelligent solution to manage home energy consumption, optimize appliance usage, monitor renewable energy generation, and respond to power cuts using machine learning predictions. The project integrates weather data, real-time monitoring, and smart suggestions through a user-friendly mobile app. The results demonstrate accurate energy usage predictions, effective smart scheduling of appliances, and dynamic control of power sources (solar, wind, battery, grid) with seamless user interaction. Comparison with existing commercial and DIY systems highlights the strengths of this approach in terms of customizability, local control, and cost efficiency.

5.1 OUTPUT

5.1.1 ENERGY MANAGEMENT INTERFACE

The Android application provides a clean and interactive interface built using Jetpack Compose. It integrates multiple components to give a complete view of the user's energy scenario.

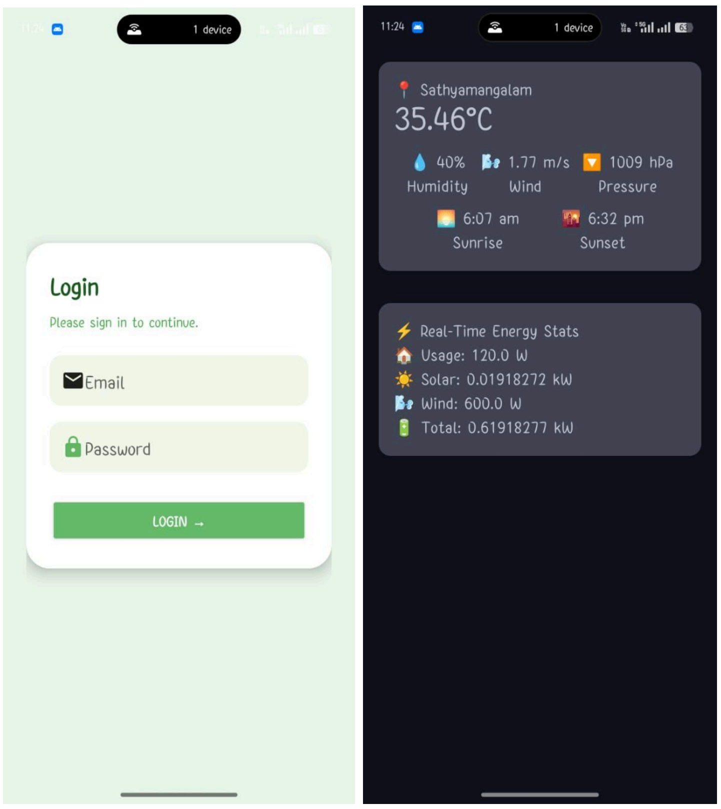
- **WEATHER AND PREDICTION DISPLAY**: The top section shows live weather data for the default location (Sathyamangalam), along with predicted energy usage and renewable generation for the day based on ML models.

- **REAL-TIME USAGE AND GENERATION**: The app simulates live data from solar, wind, and home usage CSVs, updating every 10 seconds to reflect real-time values.

- **SMART SUGGESTIONS SECTION**: Based on the predicted peak solar/wind output and usage trends, the app suggests optimal times for appliance usage (e.g., "Use washing machine at 2 PM when solar is highest").

- **BATTERY STATUS AND POWER SOURCE**: The interface shows current power source (e.g., battery, solar, or grid) and battery state of charge (SoC) with real-time switching logic.

Figure 3: UI DESIGN – HOME SCREEN OVERVIEW



Sathyamangalam
35.46°C
40% Humidity
1.77 m/s Wind
1009 hPa Pressure
6:07 am Sunrise
6:32 pm Sunset

Real-Time Energy Stats
Usage: 120.0 W
Solar: 0.01918272 kW
Wind: 600.0 W
Total: 0.61918277 kW

5.1.2 SMART ENERGY CONTROL FUNCTIONALITY

The system enables users to manage their energy intelligently using machine learning predictions and real-time feedback.

- **ML PREDICTIONS FROM FLASK SERVER**: Usage, solar, and wind predictions are generated using RandomForest models hosted on a local Flask server. The Android app sends sample feature rows and displays predictions in-app.

- **APPLIANCE USAGE SUGGESTIONS**: The system calculates ideal operation windows for non-critical appliances based on predicted solar and wind peaks, ensuring maximum use of green energy.

- **DYNAMIC POWER SWITCHING**: Based on battery SoC and grid availability, the system switches intelligently between battery, grid, or solar sources.

5.1.3 PREDICTION AND BACKEND INTEGRATION

The app connects to an ML model backend and dynamically updates based on dummy or real sensor data.

- **USAGE PREDICTION INPUTS**: The RandomForest model uses 27 input features from CSV including weather, previous usage, and time-based parameters to forecast next-hour energy consumption.

- **RENEWABLE GENERATION PREDICTION**: Separate models handle solar and wind generation forecasts based on weather inputs and panel/turbine specifications.

- **RETROFIT API CONNECTION**: The app uses Retrofit to send feature rows to the server and display predictions without UI lag.

5.1.4 NETWORK CONNECTIVITY AND PERFORMANCE

The system maintains smooth operation with efficient model calls and responsive UI behavior.

- **REAL-TIME UPDATES**: CSV-based simulated values refresh every 10 seconds to mimic sensor-based systems, ensuring a real-time feel.

- **LOCAL HOSTED ML SERVER**: Running the Flask model server on the same Wi-Fi ensures minimal latency, typically under one second.

- **RELIABILITY UNDER POWER CUT SCENARIOS**: The app logic reserves battery power in advance based on power cut forecasts scraped from news/RSS feeds.

5.2 COMPARISON WITH EXISTING SOLUTIONS

5.2.1 COMPARISON WITH COMMERCIAL ENERGY MANAGEMENT SYSTEMS

This project is compared with available commercial energy management and smart inverter platforms such as EcoNet, Tata Power Solar Monitoring, and Tesla Powerwall.

Feature	Our Android App	EcoNet (Rheem)	Tata Solar App	Tesla Powerwall
Prediction & Suggestions	Yes	No	Partial	Yes
Local Control	Yes	No	Cloud-Only	Cloud-Only
Customizability	High	Low	Low	Medium
Cost	Very Low	High	Medium	Very High

TABLE 1: COMPARISON WITH COMMERCIAL ENERGY SYSTEMS

5.2.2 FEATURE COMPARISON WITH SIMILAR DIY PROJECTS

Feature	Our Project	DIY Solar Logger	DIY Smart Inverter	Smart Pi Monitor
ML-Based Prediction	Yes	No	No	Optional
Battery & Source Logic	Yes	No	Yes	No
Android App UI	Yes	No	Yes	Partial
Power Cut Intelligence	Yes	No	No	No
Ease of Use	High	Low	Medium	Medium

Table 2: DIY PROJECT FEATURE COMPARISON

5.3 SIGNIFICANCE, STRENGTHS, AND LIMITATIONS

5.3.1 STRENGTHS

- **COST EFFECTIVE**: Uses only basic hardware (ESP, battery, sensors) and free tools (Flask, Colab, Android Studio).

- **MODULAR DESIGN**: ML, control logic, and UI are modular, allowing upgrades without rewriting the whole system.

- **USER FRIENDLY**: Clean app layout with real-time feedback, ML-driven smart tips, and no cloud dependency.

- **PRIVACY AND RELIABILITY**: Local-only processing ensures data privacy and continuous operation even during internet failure.

5.3.2 LIMITATIONS

- **LIMITED SENSOR INPUT**: Real hardware integration not yet implemented, relying on dummy CSV data.

- **PREDICTION SCALABILITY**: ML models may need retraining for different homes or cities with different usage patterns.

- **VOICE CONTROL NOT INCLUDED**: Currently excluded as per project scope; could be added in future for accessibility.

5.4 COST-BENEFIT ANALYSIS

5.4.1 COST SAVINGS

- **Hardware Components**: Low-cost microcontroller, relays, and optional solar/battery equipment.
- **No Cloud Charges**: Entirely local, removing the need for cloud APIs, subscriptions, or server hosting.
- **Open Source Tools**: Utilizes free tools like Android Studio, Python, Colab, and Retrofit.

5.4.2 BENEFIT EVALUATION

- **SMART USAGE**: Predictive analytics reduce waste and improve energy efficiency.
- **FUTURE EXPANDABILITY**: Modular ML and UI design allows integration of sensors, automation relays, or IoT platforms.
- **EDUCATIONAL VALUE**: Provides a hands-on learning platform in ML, Android, and energy systems.

CHAPTER VI

CONCLUSIONS & SUGGESTIONS FOR FUTURE WORK

This project aimed to develop an intelligent energy-saving and management system for Indian households using machine learning and real-time data integration. The solution focused on optimizing energy usage, predicting renewable generation (solar and wind), and ensuring resilience during power cuts through smart battery management. A user-friendly Android application was built to display current energy data, weather conditions, future predictions, and smart usage suggestions.

6.1 CONCLUSION

The system successfully achieved its primary objectives by:

- Predicting next-day energy usage and renewable generation using trained ML models.
- Recommending optimal appliance usage times based on predicted surplus energy.
- Managing battery charging and discharging dynamically using SoC (State of Charge), forecasted generation, and grid status.
- Simulating realistic energy usage and generation using CSV-based dummy datasets in the app.
- Providing live weather updates and a modular, real-time UI on Android using Jetpack Compose.

The application demonstrated reliable functionality in testing environments using dummy data and local Flask servers for predictions. While accuracy of ML predictions was acceptable for prototype-level implementation, improvements can be made in model training using real-time sensor data and more diverse conditions.

This project shows that affordable, intelligent energy management systems are feasible using open-source tools and machine learning. It supports sustainability, cost savings, and resilience — especially in regions with frequent power outages.

6.2 SUGGESTIONS FOR FUTURE WORK

Several improvements can enhance the system's accuracy, flexibility, and real-world applicability:

- **Real Sensor Integration**: Replace dummy CSV data with real-time input from smart meters and renewable generation sensors for more accurate predictions.

- **More Accurate ML Models**: Train models on real Indian household data, including seasonal and regional variation, to improve forecasting performance.

- **Power Cut Alert Integration**: Enhance power cut forecasting by scraping live sources or using SMS/email alerts from electricity boards.

- **Remote Server Deployment**: Host the ML model on a remote cloud server to allow 24/7 prediction access without needing a local Flask server.

- **User Feedback System**: Add in-app feedback like notifications or visual indicators to show current source (grid/battery) and suggest user actions.

- **Smart Scheduling**: Automate appliance operation (e.g., water heaters, washing machines) based on predicted energy surplus using smart switches.

- **Energy Usage Analytics**: Provide graphical history of usage, generation, and battery performance for user insights and further optimization.

In conclusion, the project lays a solid foundation for a smart, adaptive energy management system tailored to Indian homes. With further development, it has strong potential for real-world deployment, contributing to sustainable living and energy cost reduction.

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APPENDICES

BILL OF MATERIALS :

S.No	Components	Cost	Quantity
1	BreadBoard	60	1
2	ESP8266 Wi-Fi Module	400	1
3	Voltage sensor	130	1
4	Jumper Wires	50	1
5	Current sensor	120	1
	Total	960	

INDIVIDUAL CONTRIBUTION

This section highlights the contributions made by each member of the project team towards the successful implementation of the **Smart Energy-Saving and Management System Using Machine Learning**. Each member contributed significantly to their respective modules, combining software development, machine learning, and hardware integration to build a comprehensive energy management solution tailored for Indian households.

DINESH KARTHICK D(7376221EE111)

Contribution:

DINESH KARTHICK D was primarily responsible for the electrical integration, backend logic, and full system coordination of the energy management platform. His major focus was on the development of real-time decision-making algorithms for dynamic energy source switching between solar, battery, and grid. He designed and implemented a smart battery management system using State of Charge (SoC), enabling the system to decide when to charge or discharge the battery based on predicted usage, renewable generation, and possible power outages.

He also worked on simulating realistic sensor data by parsing usage, solar, and wind CSV datasets, refreshing them every 10 seconds within the Android application. This enabled a near real-time visual representation of energy flow and consumption. In addition, he set up the backend Flask server to receive input data and return machine learning predictions, acting as the bridge between the Android app and the ML model. Debugging API integration issues, improving backend performance, and ensuring modularity across app components were also part of his responsibilities.

MAIYARASI P(7376221SE24)

Contribution:

MAIYARASI P led the machine learning model development for the prediction modules of the project. She collected and processed historical energy usage and generation data, performed data cleaning, feature engineering, and trained various models including Random Forest to accurately forecast next-day home energy consumption, solar power generation, and small wind turbine output based on weather parameters.

Her work was critical in developing logic for smart appliance usage suggestions by identifying peak renewable generation periods. She implemented model evaluation metrics to validate performance and handled model serialization using .pkl files for Flask API integration. She also contributed to creating backup logic using news scraping and RSS feeds to anticipate possible power cuts, enhancing system resilience. Her models formed the intelligence layer of the app, helping users make cost-efficient and energy-conscious decisions.

JAISRI M(7376221SE117)

Contribution:

JAISRI M was in charge of the Android application frontend and app-level backend integration. Using Jetpack Compose in Kotlin, she designed a clean, responsive UI divided into key sections such as weather information, real-time energy consumption, expected usage/generation, battery state, and appliance usage suggestions. Her design emphasized usability and clarity, making the app accessible to users unfamiliar with technical energy data.

She implemented Retrofit to connect the app with the Flask backend, used ViewModel and LiveData for efficient data handling, and ensured smooth rendering of dynamic data refreshed every 10 seconds. She handled asynchronous requests, loading indicators, and error handling mechanisms to make the app reliable. In addition, she integrated the OpenWeatherMap API to fetch live weather data and used it in sync with ML inputs. Her work ensured that users received an informative, aesthetically pleasing, and real-time energy overview directly on their mobile devices.