INTELLIGENT ENERGY RE-ROUTING IN PHOTOVOLTAIC POWERED HOMES USING ML

Major project submitted in the partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY
in
CSE (DATA SCIENCE)

by

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TKR COLLEGE OF ENGINEERING &TECHOLOGY
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DECLARATION BY THE CANDIDATES

We, **Mr. Gundoju Sai Vishwak** bearing Hall Ticket Number: **21K91A6747**, **Mr. Akula Sai Madhan**, bearing Hall Ticket Number: **21K91A6704, Ms. Busa Harini** bearing Hall Ticket Number: **21K91A6723, Mr. Annapureddy Manikanta Reddy** bearing Hall Ticket Number: **21K91A6706,** hereby declare that the minor project report titled **INTELLIGENT ENERGY RE-ROUTING IN PHOTOVOLATIC POWERED HOMES USING ML** under the guidance of ***Mr. K SREENIVASA REDDY, ASSISTANT PROFESSOR*** in Department of Computer Science & Engineering (Data Science) is submitted in partial fulfillment of the requirements for the award of the degree of ***Bachelor of Technology in CSE(Data Science)***.

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CSE (DATA SCIENCE)

CERTIFICATE

This is to certify that the project report entitled **"INTELLIGENT ENERGY RE-ROUTING IN PHOTOVOLATIC POWERED HOMES USING ML"**, being submitted by **Mr. Gundoju Sai Vishwak**, bearing **Roll.No: 21K91A6747, Mr. Akula Sai Madhan**, bearing **Roll.No: 21K91A6704, Ms. Busa Harini**, bearing **Roll.No: 21K91A6733** and **Mr. Annapureddy Manikanta Reddy**, bearing **Roll.No: 21K91A6706** in partial fulfillment of requirements for the award of degree of **Bachelor of Technology in *CSE(Data Science)***, to the TKR College of Engineering & Technology is a record of bonafide work carried out by them under my guidance and supervision.

Signature of the Guide	Signature of the HOD
K. Sreenivasa Reddy	Dr. V. Krishna
Assistant Professor	Professor

ACKNOWLEDGEMENT

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ABSTRACT

The growing prevalence of photovoltaic (PV) systems in smart homes thus requires sophisticated energy management techniques that will use energy optimally while reducing grid dependence. This paper presents an intelligent energy optimization framework that is integrated with various machine learning (ML) models to make weather forecasts and predict energy demand within Photovoltaic-powered smart homes with battery storage. The system enables dynamic energy source allocations based on real-time analyses of solar generation, battery status, and forecasted demand to ensure efficiency and sustainability in energy use. It adopts a strategic approach of utilizing battery management, charging with excess solar energy, and reserving the stored energy for low solar radiation periods. At the same time, it switches between solar, battery, and grid power in order to minimize energy wastage, and therefore, reduce the dependence on the grid as well as carbon emissions. This work demonstrates the capability of ML-driven energy systems to improve smart home resilience, thus supporting sustainable and self-sufficient energy practices.

Index Terms-- Photovoltaic Systems, Smart Homes, Intelligent Energy Optimization, Machine Learning, Grid resilience, Battery storage, Energy demand forecasting.

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1. INTRODUCTION

1.1 MOTIVATION

The rapid adoption of renewable energy technologies, particularly photovoltaic (PV) systems, has driven a growing need for intelligent energy management solutions in residential settings. Smart homes equipped with PV solar panels and battery storage hold immense potential for reducing energy costs, minimizing dependence on conventional grid electricity, and promoting environmental sustainability. However, the unpredictable nature of solar energy generation due to weather variability and fluctuating household energy demands poses significant challenges to achieving optimal energy utilization. Addressing these challenges requires advanced energy management systems that can dynamically adapt to changing conditions. By leveraging cutting-edge machine learning models and integrating real-time energy monitoring, intelligent energy management systems can maximize the efficiency of renewable energy usage, supporting energy-efficient and self-sufficient homes.

1.2 PROBLEM STATEMENT

Traditional energy management systems in smart homes often lack the capability to efficiently handle the variability in solar energy generation and household energy demands. Existing solutions frequently rely on static energy allocation methods, resulting in suboptimal energy utilization and unnecessary reliance on grid electricity. Furthermore, these systems fail to incorporate advanced weather forecasting and demand prediction models, limiting their ability to adapt dynamically to changing conditions. There is a need for an intelligent energy management system that can seamlessly integrate PV panels, battery storage, and grid power to optimize energy allocation. Such a system must provide real-time insights, enable strategic energy routing, and support sustainable energy practices while ensuring scalability and reliability for diverse household environments.

1.4 LIMITATIONS OF EXISTING SYSTEM

Existing energy management systems for smart solar homes face several limitations:

- **Static Energy Allocation**: Many systems employ predefined energy routing strategies that do not adapt to real-time changes in energy generation and demand.
- **Lack of Predictive Models**: Current solutions do not utilize advanced weather forecasting or energy demand prediction models, limiting their ability to optimize energy usage.
- **Inefficient Battery Management**: Battery charging and discharging strategies in most systems are inefficient, leading to energy wastage and reduced battery lifespan.
- **Over-reliance on Grid Electricity**: Poor energy utilization often results in unnecessary dependence on grid power, increasing costs and reducing system efficiency.
- **Limited Scalability**: Existing systems are often tailored to specific use cases, lacking the flexibility to adapt to varying household energy needs and configurations.

1.5 PROPOSED SYSTEM

The proposed Intelligent Energy Management System (IEMS) offers a comprehensive solution to overcome the limitations of existing energy management systems. By leveraging advanced machine learning models and integrating real-time energy monitoring, the system is designed to provide a smarter, more efficient approach to energy utilization in residential settings. It addresses the challenges posed by the variability in solar energy generation and fluctuating household energy demands, ensuring optimal energy allocation and minimal wastage. Specifically tailored for smart homes equipped with photovoltaic (PV) panels and battery storage, the IEMS combines predictive analytics, data-driven decision-making, and user-friendly interfaces to deliver a seamless and adaptive energy management experience. By focusing on sustainability, reliability, and scalability, the system empowers households to maximize the benefits of renewable energy while reducing dependence on conventional grid power. Key functionalities include:

- **Dynamic Energy Routing**: The system analyzes real-time data on solar energy generation, battery status, and energy demand to allocate energy seamlessly between PV panels, battery storage, and the grid.
- **Weather and Demand Prediction**: Advanced machine learning models predict solar energy availability and household energy demands, enabling proactive energy allocation.

- **Strategic Battery Management**: Batteries are efficiently charged during periods of surplus solar energy and discharged during low solar availability to minimize grid dependency.
- **Real-time Monitoring and Insights**: Users can access detailed energy production, consumption, and storage data through an intuitive dashboard.
- **Scalability and Flexibility**: The system is adaptable to diverse household configurations, supporting integration with IoT devices and smart home automation setups.

This system provides a robust and scalable solution to achieve energy-efficient and self-sufficient homes, promoting sustainability and reducing carbon footprints.

2. LITERATURE SURVEYS

2.1 REVIEW OF LITERATURE

The development of intelligent home energy management systems (HEMS) is driven by advancements in machine learning, optimization models, and dynamic control systems, all of which contribute to improved energy efficiency and adaptability in modern households. However, the effectiveness of these systems is often constrained by the quality of data they rely on, highlighting the importance of integrating high-resolution data from diverse sources, including real-time environmental inputs such as weather conditions and user-specific energy consumption patterns.

The inclusion of renewable energy sources, particularly solar power, along with battery storage systems, has demonstrated significant potential in enhancing the sustainability and cost-efficiency of energy management frameworks. These systems enable households to reduce dependence on grid electricity while maintaining personalized energy consumption that aligns with user preferences and fluctuating environmental conditions. Furthermore, open access to standardized datasets and improved data-sharing protocols would facilitate rigorous benchmarking and enable comparative analysis of different energy management techniques across diverse residential environments.

Despite these advancements, existing models often lack the ability to seamlessly adapt to evolving household needs and environmental dynamics, underscoring the need for future research to focus on developing resilient, user-centric models. Such models should integrate effectively with existing smart home technologies to deliver real-time, personalized energy solutions that dynamically adjust to changing conditions, ensuring both sustainability and operational efficiency.

LITERATURE SURVEY – 01

Title: A Hybrid Approach for Home Energy Management With Imitation Learning and Online Optimization.

Author(s): Shuhua Gao, Raiyan bin Zulkifli Lee, Zhenhao Huang(Member IEEE), Cheng Xiang, Ming Yu, Published in IEEE on 3, March, 2024

Description:

This study presents a hybrid home energy management system designed for solar-equipped households, combining imitation learning (IL) and online optimization to achieve enhanced energy efficiency. The system employs deep neural networks (DNNs) to manage shiftable household loads while utilizing mixed-integer linear programming (MILP) for optimizing adjustable ones. By incorporating IL, the approach significantly reduces training time and improves energy allocation, achieving better cost efficiency and lower grid dependency compared to traditional static methods. The system is particularly notable for its ability to dynamically adapt to real-time conditions, demonstrating potential as a sustainable and scalable energy solution.

Merits:

- Successfully integrates IL for faster training compared to RL.
- Effective in reducing household electricity costs by leveraging solar energy and dynamic pricing.
- Demonstrates scalability across various building sizes with minimal performance loss.

Demerits:

- Limited consideration of user-specific comfort requirements.
- Complexity increases with additional appliances and larger energy demands.
- Relies on accurate real-time data for optimal performance, which may require substantial investment in sensors and data collection.

LITERATURE SURVEY – 02

Title: A Multistage Home Energy Management System With Residential Photovoltaic Penetration

Author(s): Fengji Luo, Gianluca Ranzi, Can Wan, Zhao Xu (Member IEEE), Zhao Yang Dong(Member IEEE), Published in IEEE on 20 September 2018

Description:

This paper introduces a multistage Home Energy Management System (HEMS) designed to optimize residential energy usage in homes with high rooftop photovoltaic (PV) penetration. The system employs a comprehensive approach that includes energy forecasting, day-ahead scheduling, and real-time adjustments to dynamically manage energy allocation. It incorporates an adaptive thermal model, enabling efficient operation of HVAC systems while balancing energy supply and demand. By integrating these components, the HEMS ensures optimal utilization of solar energy, reduces reliance on grid power, and enhances overall energy efficiency for sustainable household management.

Merits:

- Introduces a structured three-stage HEMS for improved scheduling and operational efficiency.
- Employs an Artificial Neural Network (ANN) for accurate short-term PV and load forecasting.
- Incorporates an adaptive thermal model to enhance HVAC system scheduling.

Demerits:

- Limited consideration of non-thermal household appliances.
- Relies heavily on forecasting accuracy, leading to potential performance issues with inaccurate data.
- Computational complexity in real-time model adjustments.

LITERATURE SURVEY – 03

Title: A Novel Single-Stage Single-Phase Reconfigurable Inverter Topology for a Solar Powered Hybrid AC/DC Home

Author(s): Nikhil Sasidharan, Jai Govind Singh, Published in IEEE on 22 December 2016

Description:

This paper introduces a reconfigurable single-stage inverter specifically designed for hybrid AC/DC solar homes. The innovative inverter supports DC/DC, DC/AC, and grid-tie operations within a single converter, offering a compact and efficient solution for energy management. By integrating these functions, the system minimizes power loss, reduces cost and size, and improves power quality, making it ideal for modern solar-powered households. Comprehensive simulations and hardware testing validate the inverter's performance, highlighting its potential to play a significant role in smart grid applications and sustainable energy systems.

Merits:

- Provides a flexible, single-stage conversion to reduce conversion losses.
- Supports hybrid AC/DC loads, improving efficiency in energy distribution within homes.
- Reduces harmonic distortion by isolating DC loads to DC supply, enhancing power quality.

Demerits:

- Requires specific hardware configurations (e.g., inductor-based design) for optimal performance.
- Sensitive to variations in solar radiation, necessitating careful control logic adjustments.
- Limited focus on scalability for larger grid-tied systems.

LITERATURE SURVEY – 04

Title: A Shrinking Horizon Model Predictive Controller for Daily Scheduling of Home Energy Management Systems

Author(s): Ali Esmaeel Nezhad, Abolfazl Rahimnejad (Member IEEE), Pedro H. J. Nardelli, Stephen Andrew Gadsden, Subham Sahoo, Published in IEEE on 10 March 2022

Description:

This study presents a Shrinking Horizon Model Predictive Controller (SH-MPC) for the efficient daily scheduling of residential energy consumption, seamlessly integrating photovoltaic (PV) panels and battery storage. The proposed approach aims to minimize electricity costs by optimizing the operation of household appliances through predictive scheduling informed by meteorological forecasts and electricity market data. By dynamically adjusting to changing conditions, the SH-MPC enhances energy efficiency, maximizes the utilization of solar power, and reduces reliance on grid energy, contributing to a more sustainable and cost-effective energy management strategy for modern households.

Merits:

- Reduces electricity costs for homeowners with PV and battery storage.
- Provides flexibility through real-time energy management.
- Evaluates both Time-of-Use (TOU) and Real-Time Pricing (RTP) tariffs.

Demerits:

- Computationally intensive due to Mixed-Integer Linear Programming (MILP).
- High dependence on accurate meteorological and price data.
- Primarily applicable to residential settings.

LITERATURE SURVEY – 05

Title: An Intelligent Home Energy Management System to Improve Demand Response

Author(s): Yusuf Ozturk, Datchanamoorthy Senthilkumar, Sunil Kumar, Gordon Lee, Published in IEEE on 15 April 2013

Description:

This paper presents an integrated framework combining Demand Response (DR) and Time-of-Use (TOU) pricing to optimize residential electricity consumption. The proposed solution includes a decision-support system capable of forecasting household energy usage and dynamically scheduling appliance operations. By considering user-defined constraints and preferences, the system ensures both energy efficiency and user comfort. Additionally, it enhances participation in DR programs through intelligent smart appliance control, enabling households to adapt their energy usage patterns to pricing signals, reduce electricity costs, and contribute to grid stability and sustainability.

Merits:

- Comprehensive forecasting of electricity demand based on user lifestyle.
- Dynamic appliance scheduling improves energy efficiency and user comfort.
- Promotes continuous interaction between customers and utility companies for effective DR.

Demerits:

- Primarily applicable to residential settings, limiting broader implementation.
- Requires user engagement for optimal scheduling preferences.
- Accuracy of demand predictions can be affected by unexpected user behavior.
- Integration with existing systems may present communication challenges.

LITERATURE SURVEY – 06

Title: Deep Reinforcement Learning for Real-Time Energy Management in Smart Home

Author(s): Guixi Wei, Ming Chi, Zhi-Wei Liu, Mingfeng Ge, Chaojie Li, Xianggang Liu, Published in IEEE on 10 March 2023

Description:

This paper introduces a real-time energy management algorithm utilizing deep reinforcement learning (DRL) with proximal policy optimization (PPO) to optimize appliance scheduling in smart homes. The proposed approach efficiently manages rooftop photovoltaic systems, energy storage, and smart appliances, ensuring seamless energy distribution. By dynamically adapting to real-time energy demands and supply conditions, the algorithm minimizes energy costs while maintaining user comfort and convenience. This innovative system demonstrates significant potential for enhancing energy efficiency, reducing grid reliance, and promoting sustainability in modern smart home environments.

Merits:

- Incorporates both discrete and continuous action control for diverse appliance types.
- Uses PPO, which enhances training efficiency and robustness.
- Adapts to real-time changes in temperature, electricity price, and solar irradiation.

Demerits:

- Limited to real-time management, potentially complex for large-scale deployments.
- Requires extensive historical data for effective training.
- Model accuracy may decline with unpredictable user behavior and environmental changes.

LITERATURE SURVEY – 07

Title: Peak Reduction and Long-Term Load Forecasting for Large Residential Communities Including Smart Homes with Energy Storage

Author(s): Liang Yu (Member IEEE), Weiwei Xie, Di Xie, Yulong Zou, Dengyin Zhang, Zhixin Sun, Linghua Zhang, Yue Zhang, Published in IEEE on 10 March 2023

Description:

This paper addresses the challenge of minimizing energy costs in smart homes by introducing an innovative approach that does not rely on a thermal dynamics model. Utilizing a deep deterministic policy gradient (DDPG) algorithm, the study designs a solution to efficiently manage HVAC systems and energy storage systems (ESS) for optimal cost reduction. Operating on real-time observations, the algorithm eliminates the need for prior parameter knowledge, ensuring adaptability and simplicity. This method balances cost efficiency and user comfort, demonstrating potential for practical applications in smart home energy management.

Merits:

- Provides a robust solution that adapts to uncertainties in parameters like renewable energy output.
- Demonstrates significant energy savings (8.10%–15.21%) compared to baselines, without compromising thermal comfort.
- Showcases the algorithm's resilience and effectiveness in real-world scenarios with variable data inputs.

Demerits:

- Does not integrate a comprehensive thermal dynamics model, which may limit adaptability in more complex environments.
- The reliance on DDPG may impose higher computational demands, affecting efficiency.
- Potential scalability issues for residential buildings with diverse energy requirements.

LITERATURE SURVEY – 08

Title: Optimization of Stand Alone Solar Home System with Battery

Author(s): Isdawimah, Nuha Nadhiroh, A. Damar Aji, Published in IEEE on 27 December 2021

Description:

This paper investigates error optimization in the design of stand-alone solar home systems with battery storage, concentrating on critical factors such as photovoltaic (PV) module selection, battery sizing, and system losses. The study aims to enhance system performance and reliability by reducing errors in these key components. A 100 Wp prototype was developed and validated, with real-time monitoring conducted using LabVIEW software, achieving an impressive 97.2% accuracy in performance. The findings offer valuable insights for improving the design and efficiency of solar home systems in real-world applications.

Merits:

- Comprehensive analysis of solar home system components (PV, battery, cables, protection systems).
- Validates design with a real-world prototype and high accuracy (97.2%) in monitoring.
- Uses LabVIEW for efficient, real-time parameter monitoring.

Demerits:

- Prototype capacity (100 Wp) may limit scalability and applicability for larger systems.
- Limited discussion on cost optimization.
- Relies on specific environmental data, which may affect accuracy in different conditions.

LITERATURE SURVEY – 09

Title: Optimization-based home energy management in the presence of solar energy and storage

Author(s): Sattar Mohammadi, Mahmoud Momtazpour, Esmaeil Sanaei (Member IEEE), Published in IEEE on 25 December 2021

Description:

This paper introduces a real-time energy management system designed to optimize appliance scheduling and energy storage in smart homes. The system utilizes a combination of solar power and grid electricity to minimize household energy costs. It features an Integer Linear Programming-based Home Energy Management (ILPHEM) optimization engine, which efficiently handles dynamic electricity prices, schedules appliances, and manages storage in real time. By continuously adjusting to changing energy conditions, the system ensures cost efficiency, sustainability, and improved energy utilization, offering a practical solution for modern smart home environments.

Merits:

- Reduces household energy costs by 20% compared to conventional approaches.
- Efficiently integrates solar energy with grid electricity to optimize energy use.
- Provides real-time management and decision-making for cost savings.

Demerits:

- Requires precise, real-time data for effective optimization.
- Dependent on adequate solar and storage infrastructure.
- Complexity may limit scalability in certain environments.

LITERATURE SURVEY – 10

Title: Smart Solar Home System with Solar Forecasting

Author(s): Anusha Manur, Maitreyee Marathe, Ashray Manur, Abhishek Ramachandra, Shamsundar Subbarao, Giri Venkataramanan, Published in IEEE on 04 January 2020

Description:

This study explores the challenges of solar energy utilization in Solar Home Systems (SHSs), which face significant daily and seasonal fluctuations in both solar irradiance and load usage. To address these challenges, the paper proposes a smart solar home system that incorporates an advanced forecasting methodology to optimize battery utilization and enhance overall energy efficiency. The proposed system dynamically adjusts to variations in solar energy availability and consumption patterns. The study also evaluates field data collected from deployed smart solar home systems, demonstrating the effectiveness of the forecasting technique in real-world applications.

Merits:

- Enhances energy optimization in SHSs by incorporating battery utilization into solar forecasting.
- Addresses the limitations of conventional forecasting methods applied to larger systems.
- Real-world deployment and evaluation provide practical insights into system effectiveness.

Demerits:

- Requires accurate weather data and battery usage forecasting.
- Limited computing power in SHSs may restrict optimization potential.
- Seasonal solar variation can still impact overall effectiveness.

LITERATURE SURVEY – 11

Title: Federated Reinforcement Learning for Energy Management of Multiple Smart Homes with Distributed Energy Resources

Author(s): Sangyoon Lee, Dae-Hyun Choi, Published in IEEE on 03 November 2020

Description:

This article introduces a federated reinforcement learning (FRL) framework for energy management across multiple smart homes, each equipped with appliances, solar systems, and energy storage. The framework features local home energy management systems (LHEMSs) that operate within each home and a global server (GS) that aggregates local models to form a global model. This process enhances convergence speed, improves the optimization of energy consumption, and reduces energy costs while considering user preferences. The proposed approach provides a scalable solution to efficiently manage distributed energy resources in modern smart homes.

Merits:

- Offers a distributed approach that preserves data privacy and reduces communication overhead.
- Demonstrates significant improvement in convergence speed and energy consumption management compared to conventional methods.
- Validated through simulations across heterogeneous smart home environments, ensuring effective scheduling of appliances.

Demerits:

- Potential complexity in implementation due to the need for local model updates.
- Performance may vary depending on the diversity of appliances and user preferences across different homes.

LITERATURE SURVEY – 12

Title: Real-Time Energy Management for Smart Homes

Author(s): Subho Paul, Narayana Prasad Padhy (Member IEEE), Published in IEEE on 31 August 2020

Description:

This paper proposes a multi-objective optimization portfolio for real-time energy management in smart homes equipped with battery-associated rooftop solar panels, lighting loads, air conditioners, and other smart appliances. The framework aims to address two critical objectives: the minimization of monetary energy costs and the reduction of total dissatisfaction arising from restrictions in power consumption. To achieve these goals, the paper employs a mixed-integer convex nonlinear programming approach, providing an efficient method to balance cost-effectiveness with user comfort while optimizing energy usage in smart homes.

Merits:

- Presents a novel multi-objective real-time energy management optimization framework.
- Uses current data without needing probabilistic estimation for renewable generation, energy price, and load demand.
- Demonstrates superiority over traditional greedy algorithms through practical case studies.

Demerits:

- Requires accurate real-time data, which may increase operational complexity.
- Results based on specific scenarios may require customization for varied household patterns.
- Does not account for historical data, potentially limiting the adaptability of the optimization.

3. REQUIREMENT ANALYSIS

3.1 FUNCTIONAL REQUIREMENTS

The functional requirements define the essential capabilities that the **Intelligent Energy Management System** must include to efficiently manage energy in smart homes. The key functionalities include:

- **Energy Source Selection**: The system must dynamically select the most efficient energy source (solar, battery, grid) based on real-time energy availability, household demand, and environmental conditions.
- **Energy Routing and Allocation**: It should allocate energy from available sources (solar panels, batteries, or the grid) to meet the varying energy demand of the household, ensuring minimal wastage and optimal energy use.
- **Weather Forecast Integration**: The system must integrate weather forecasts to predict solar energy generation and adjust energy management strategies accordingly.
- **Battery Management**: The system should control battery charging and discharging, prioritizing solar energy storage during surplus generation and ensuring optimal battery lifespan by managing charge cycles efficiently.
- **Real-Time Energy Monitoring**: Users must be able to monitor energy consumption, solar generation, and battery status in real-time, with visual indicators and alerts for critical energy-related events.
- **User Dashboard**: A user-friendly dashboard should allow users to track energy usage, receive notifications, and access insights about their energy consumption patterns and potential savings.
- **Data Logging and Analysis**: The system should log all energy data for historical analysis, helping users evaluate their energy consumption trends and identify opportunities for further optimization.
- **Mobile and Web Interface**: The system should be accessible via both mobile apps and web platforms, ensuring that users can manage their energy resources from anywhere.

3.2 NON-FUNCTIONAL REQUIREMENTS

Non-functional requirements define the system's operational characteristics, focusing on performance, reliability, and scalability. These include:

- **Scalability**: The system must support a large number of users and energy devices across various household configurations. It should scale efficiently to accommodate growing energy demands and integration of additional smart devices.
- **Real-Time Performance**: The system should process and update energy routing decisions and weather forecasts in real-time, ensuring that users experience minimal delay in energy source switching and monitoring.
- **Accuracy**: Predictions related to energy consumption, solar generation, and battery management must be highly accurate, with low deviation from actual conditions to ensure optimal decision-making.
- **Security**: The system must securely handle user data, including energy consumption, device statuses, and personal information, with encryption for data storage and transmission.
- **Reliability**: The system must operate continuously without interruption, ensuring high availability and reliability, particularly during peak usage hours or during energy-critical situations.
- **Usability**: The system should be easy to use, with intuitive interfaces that allow non-technical users to manage their energy efficiently. Clear visual indicators, straightforward navigation, and simple configuration options are essential.
- **Maintainability**: The system should be modular, allowing for easy updates, integration of new features, and maintenance without significant system downtime. This ensures long-term functionality as new energy technologies emerge.
- **Cross-Platform Compatibility**: The system should be fully compatible across various devices and platforms, including smartphones, tablets, and desktop computers, offering users a consistent experience.
- **Integration with External Systems**: The system should integrate seamlessly with smart home devices, IoT sensors, and cloud-based platforms, allowing for continuous data collection and analysis across multiple devices.

4. DESIGN

4.1 DFD AND UML DIAGRAMS

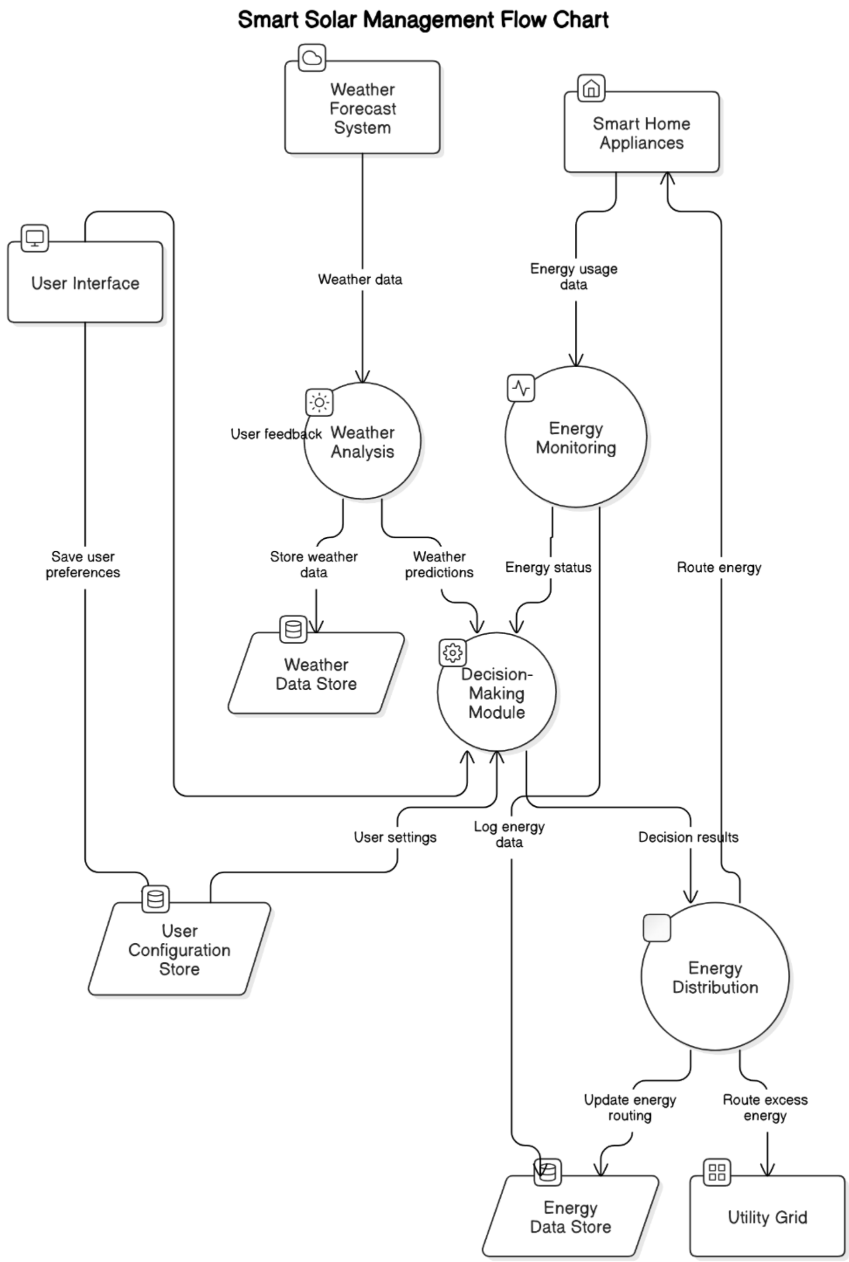

Fig. 4.1 Data Flow Diagram

4.2 USE-CASE DIAGRAM

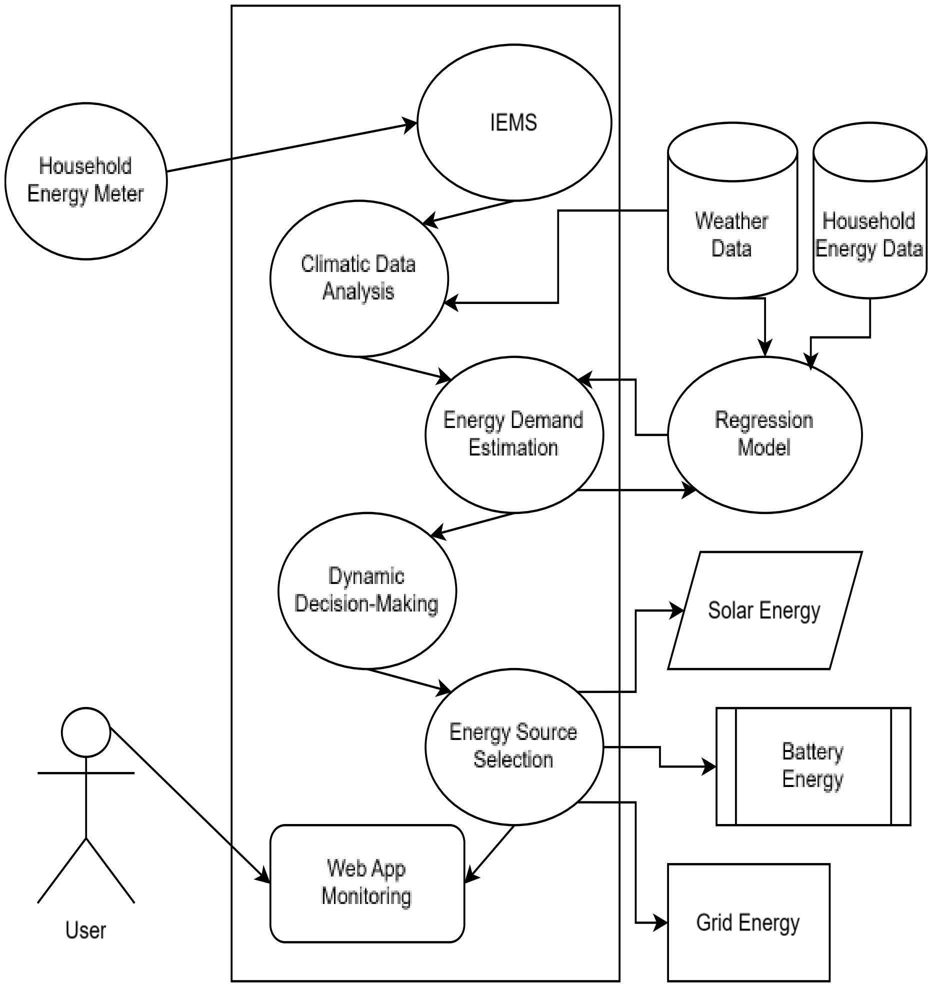

Fig. 4.2 Use Case Diagram

4.3 RELATIONSHIP (ER) DIAGRAM

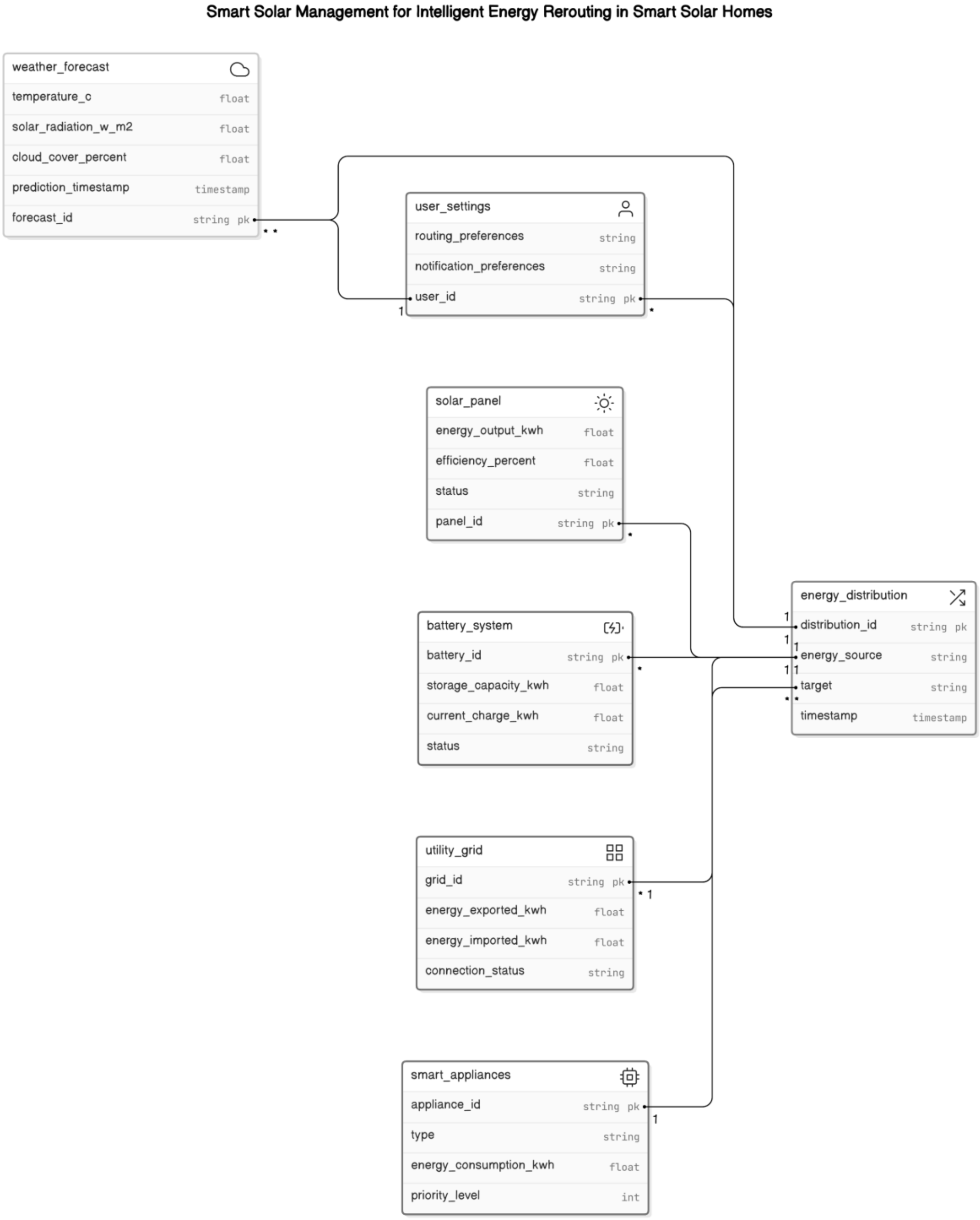

Fig. 4.3 Relationship design

4.4 ARCHITECTURE DIAGRAM

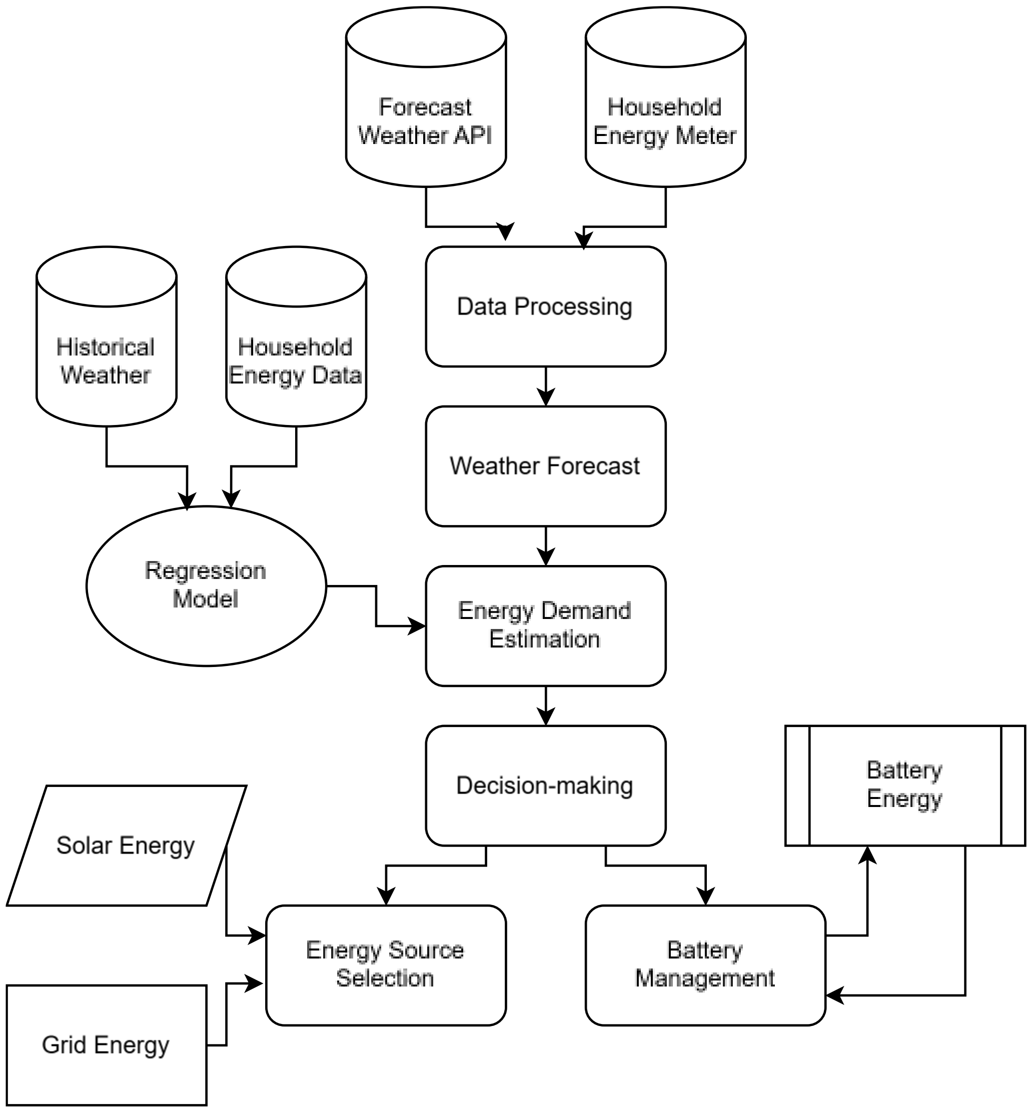

Fig. 4.4 Architecture Diagram

5. CODING

5.1 PSEUDO CODE:

app.py

```
from flask import Flask, render_template, request, jsonify
import requests
import datetime
import math, os
from dotenv import load_dotenv
load_dotenv()
LAT = float(os.getenv("LATITUDE", 17.375))  # Default to Hyderabad if not set
LON = float(os.getenv("LONGITUDE", 78.474))
app = Flask(__name__)
I0 = 1367  # Extraterrestrial Solar Radiation (W/m²)
def solar_zenith_angle(lat, lon, timestamp):
    dt = datetime.datetime.fromtimestamp(timestamp)
    day_of_year = dt.timetuple().tm_yday
    declination = 23.45 * math.sin(math.radians((360/365) * (day_of_year - 81)))
    hour_angle = (dt.hour - 12) * 15  # 15 degrees per hour
    lat_rad = math.radians(lat)
    decl_rad = math.radians(declination)
    hour_rad = math.radians(hour_angle)
    cos_theta_z = math.sin(lat_rad) * math.sin(decl_rad) + math.cos(lat_rad) * math.cos(decl_rad) * math.cos(hour_rad)
    theta_z = math.degrees(math.acos(max(min(cos_theta_z, 1), -1)))
    return theta_z
@app.route("/api/weather", methods=["GET"])
def fetch_weather():
    response = requests.get(url)
    if response.status_code != 200:
        return jsonify({"error": "Failed to fetch weather data"}), 500
    data = response.json()
    weather = []
    for forecast in data['list']:
        timestamp = forecast['dt']
        temp = forecast["main"]["temp"]
        humidity = forecast["main"]["humidity"]
        wind_speed = forecast["wind"]["speed"]
        precipitation = forecast.get("rain", {}).get("3h", 0)  # Rain in last 3 hours (default 0)
        cloud_cover = forecast['clouds']['all']
        theta_z = solar_zenith_angle(LAT, LON, timestamp)
        GHI_0 = I0 * max(0, math.cos(math.radians(theta_z)))
        GHI = GHI_0 * (1 - 0.75 * (cloud_cover / 100) ** 3)
        weather.append({
            "datetime": datetime.datetime.fromtimestamp(timestamp).strftime('%Y-%m-%d %H:%M:%S'),
            "temperature": temp,
            "humidity": humidity,
            "wind_speed": wind_speed,
            "precipitation": precipitation,
            "cloud_cover": cloud_cover,
            "theta_z": theta_z,
            "irradiance": GHI
        })
    return jsonify(weather)
@app.route("/")
def home():
    return render_template("index.html")
@app.route("/dashboard")
def dashboard():
    return render_template("dashboard.html")
```

```python
@app.route("/reports")
def reports():
    return render_template("reports.html")
@app.route("/forecasts")
def forecasts():
    return render_template("forecasts.html");
@app.route("/status")
def status():
    return render_template("status.html")
if __name__ == "__main__":
    app.run(debug=True)
```

index.html:

```html
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>Solaris</title>
    <link rel="stylesheet" href="style.css">
</head>
<body>
    <header>
        <nav class="navbar">
            <div class="logo">Solaris</div>
            <ul class="nav-links">
                <li><a href="#home">Home</a></li>
                <li><a href="#dashboards">Dashboards</a></li>
                <li><a href="#reports">Reports</a></li>
                <li><a href="#forecasts">Forecasts</a></li>
                <li><a href="#settings">Settings</a></li>
                <li><a href="#login">Login</a> / <a href="#signup">Signup</a></li>
            </ul>
        </nav>
    </header>
    <section class="welcome" id="home">
        <div class="welcome-content">
            <h2>Welcome to Solaris</h2>
            <p>Your gateway to intuitive dashboards, predictive forecasts, and insightful reports to optimize your
workflow.</p>
            <button onclick="scrollToModules()">Explore Solaris</button>
        </div>
    </section>
    <section class="modules">
        <div class="module">
            <img src="images/bg2.jpg" alt="Reports">
            <h3>Reports</h3>
            <p>Generate detailed reports to understand your system’s performance and make informed decisions
efficiently.</p>
        </div>
        <div class="module">
            <img src="images/bg3.jpg" alt="Forecasts">
            <h3>Forecasts</h3>
            <p>Use predictive analytics to anticipate challenges and opportunities, ensuring proactive solutions for your
operations.</p>
        </div>
        <div class="module">
            <img src="images/bg4.jpg" alt="Settings">
            <h3>Settings</h3>
            <p>Customize your experience with user-friendly settings tailored to your needs and preferences.</p>
        </div>
    </section>
```

```html
    <footer>
        <div class="footer-column">
            <h4>Solaris</h4>
            <p>Your trusted platform for optimizing workflows and staying ahead with predictive insights.</p>
        </div>
        <div class="footer-column">
            <h4>Links</h4>
            <ul>
                <li><a href="#home">Home</a></li>
                <li><a href="#dashboards">Dashboards</a></li>
                <li><a href="#reports">Reports</a></li>
                <li><a href="#forecasts">Forecasts</a></li>
                <li><a href="#settings">Settings</a></li>
            </ul>
        </div>
        <div class="footer-column">
            <h4>Account</h4>
            <ul>
                <li><a href="#profile">Profile</a></li>
                <li><a href="#logout">Logout</a></li>
                <li><a href="#login">Login</a></li>
                <li><a href="#signup">Signup</a></li>
            </ul>
        </div>
    </footer>
    <script>
        function scrollToModules() {
            document.querySelector('.modules').scrollIntoView({ behavior: 'smooth' });
        }
    </script>
</body>
</html>
```

style.css:

```css
body {
    margin: 0;
    font-family: Arial, sans-serif;
    color: #333;
    background-color: #fff;
}
.navbar {
    display: flex;
    justify-content: space-between;
    align-items: center;
    background-color: #000;
    padding: 10px 20px;
}
.navbar .logo {
    color: #fff;
    font-size: 1.5em;
    font-weight: bold;
}
.nav-links {
    list-style: none;
    display: flex;
    gap: 15px;
}
.nav-links a {
    color: #fff;
    text-decoration: none;
    font-size: 1em;
}
```

```css
.welcome {
  height: 100vh;
  background: url('images/bg1.jpg') no-repeat center center/cover;
  display: flex;
  justify-content: center;
  align-items: center;
  position: relative;
  color: #fff;
}
.welcome::before {
  content: '';
  position: absolute;
  top: 0;
  left: 0;
  width: 100%;
  height: 100%;
  background: rgba(0, 0, 0, 0.5);
  z-index: 1;
}
.welcome-content {
  position: relative;
  z-index: 2;
  text-align: center;
}
.welcome button {
  padding: 10px 20px;
  background-color: #000;
  color: #fff;
  border: none;
  font-size: 1em;
  cursor: pointer;
}
.modules {
  display: flex;
  justify-content: space-around;
  padding: 50px 20px;
  gap: 20px;
}
.module {
  text-align: center;
  max-width: 300px;
  border: 2px solid #ccc; /* Light gray border */
  border-radius: 8px; /* Rounded corners */
  padding: 15px; /* Space inside the border */
  background-color: #fff; /* White background */
  box-shadow: 0 4px 6px rgba(0, 0, 0, 0.1); /* Optional shadow for depth */
}
.module img {
  width: 100%;
  height: 200px;
  border-radius: 8px;
}
.module h3 {
  margin: 10px 0;
}
.module p {
  font-size: 1em;
  color: #666;
}
```

6. IMPLEMENTATION and RESULTS

6.1 EXPLANATION OF KEY FUNCTIONS

The **Intelligent Energy Rerouting System for Smart Solar Homes** implements several key functions across its modules:

Weather Forecasting and Solar Irradiance Prediction Module:

- Integration with Open-Meteo API to fetch real-time weather data (temperature, humidity, cloud cover)
- Calculation of solar irradiance from weather parameters
- Prediction of solar energy availability for the next 5 days in 3-hour intervals

Energy Demand Prediction Module:

- Historical energy consumption data processing
- Random Forest Regression model to forecast future energy demand
- Identification of peak energy consumption periods for optimized decision-making

Energy Routing and Decision-Making Module:

- Dynamic decision-making engine to optimize energy usage
- Evaluation of energy source options (solar, battery, or grid) based on predicted demand and weather conditions
- Intelligent selection of the most cost-effective and sustainable energy source

Battery Management Module:

- Monitoring battery metrics (voltage, current, state of charge, discharge rate)
- Determination of battery charging/discharging status based on demand and solar availability
- Prevention of battery overcharging and deep discharging for extended battery life

Dashboard and Reporting Module:

- Real-time visualization of energy production, battery status, weather conditions, and cost savings
- Generation of comprehensive energy usage and performance reports
- Interactive and user-friendly interface for monitoring system status

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6.2 METHOD OF IMPLEMENTATION

Frontend Implementation:

- HTML5 and CSS3 for designing static pages.
- Clean and responsive design to ensure user-friendly navigation
- JavaScript to add interactivity and manage user requests dynamically

Backend Implementation:

- Flask framework to serve HTML pages and manage API requests
- RESTful API development to handle data processing and API communication
- API integration to fetch real-time weather data and dynamically update dashboards

Weather Data and Solar Irradiance Integration:

- Open-Meteo API integration for real-time weather data retrieval
- Calculation of solar irradiance based on weather parameters and geographic location
- Dynamic display of weather forecasts and irradiance predictions on the forecasts page

Model Integration and Decision Engine:

- Random Forest Regression model implemented using scikit-learn for energy demand forecasting
- Decision engine logic to determine the optimal energy source based on predicted demand and available solar energy
- Battery charge management algorithm to ensure optimal battery usage and lifespan

Dashboard and Report Integration:

- Real-time data binding between Flask APIs and HTML elements for dynamic updates
- Graphical representation of system metrics using interactive visual elements
- Generation of downloadable performance reports based on historical data

6.3 TECHNOLOGIES USED

Frontend Technologies:

- HTML5/CSS3 for page structure and design
- JavaScript for interactivity and dynamic content updates
- Bootstrap for responsive UI design

Backend Technologies:

- Python 3.8+ for backend development
- Flask framework for API development and serving HTML pages
- RESTful API architecture for data communication

Machine Learning Technologies:

- Scikit-learn for Random Forest Regression model implementation
- NumPy and Pandas for data manipulation and preprocessing

API and Data Integration:

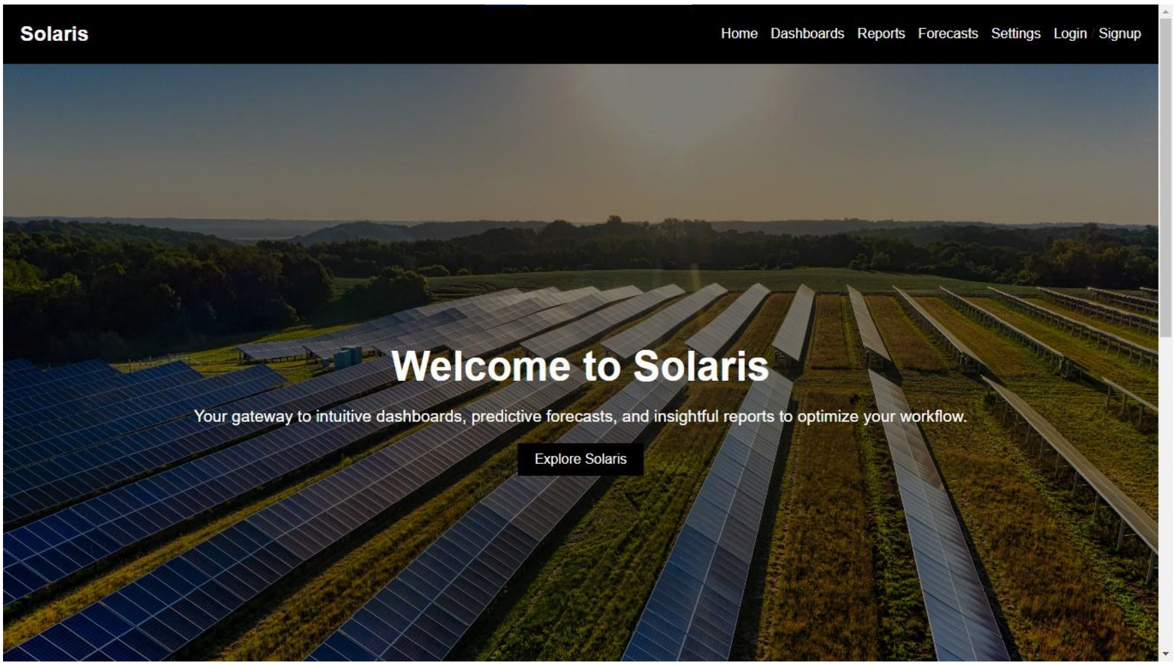
- Open-Meteo API for real-time weather data retrieval
- Flask integration for weather API calls and data processing

Development Tools:

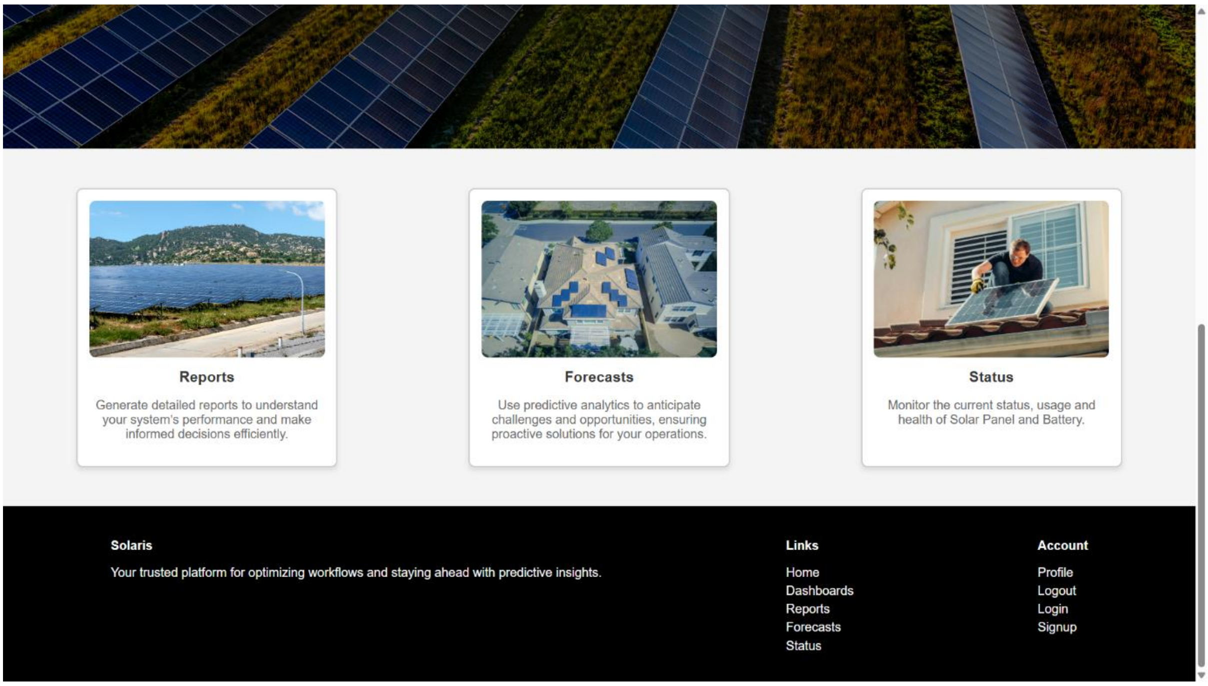
- Visual Studio Code for development
- GitHub for version control
- Postman for API testing
- Jupyter Notebook for model training and development

7. SCREENSHOTS

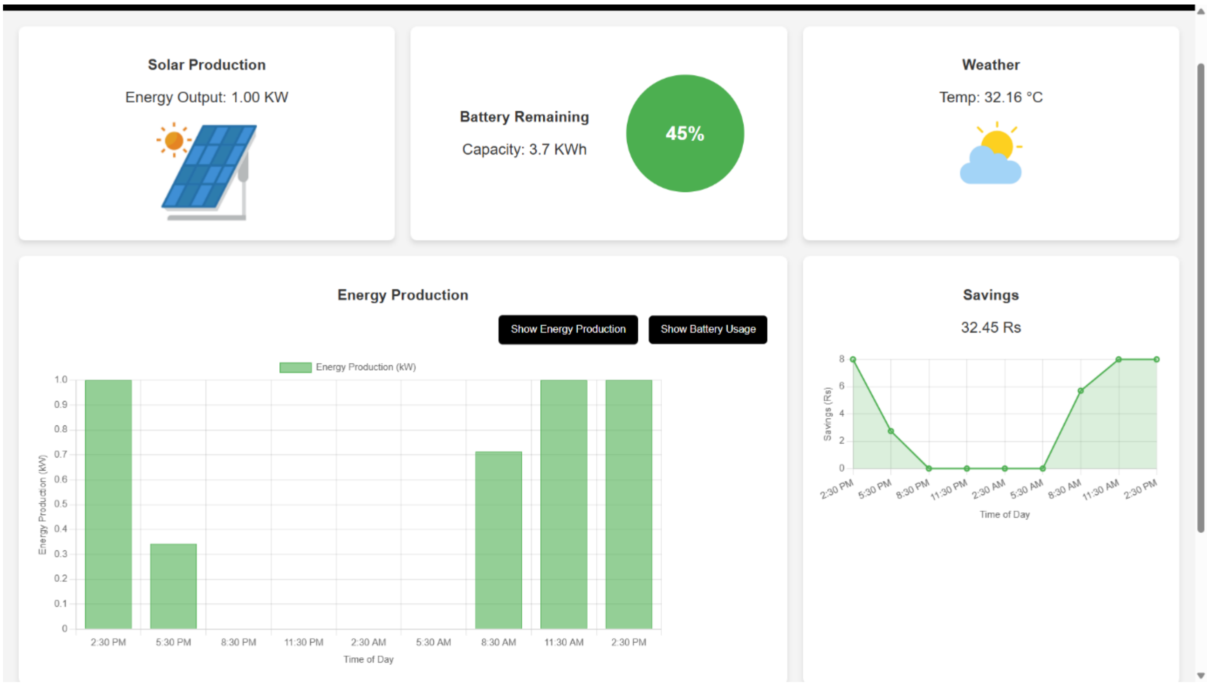
7.1 HOME PAGE:



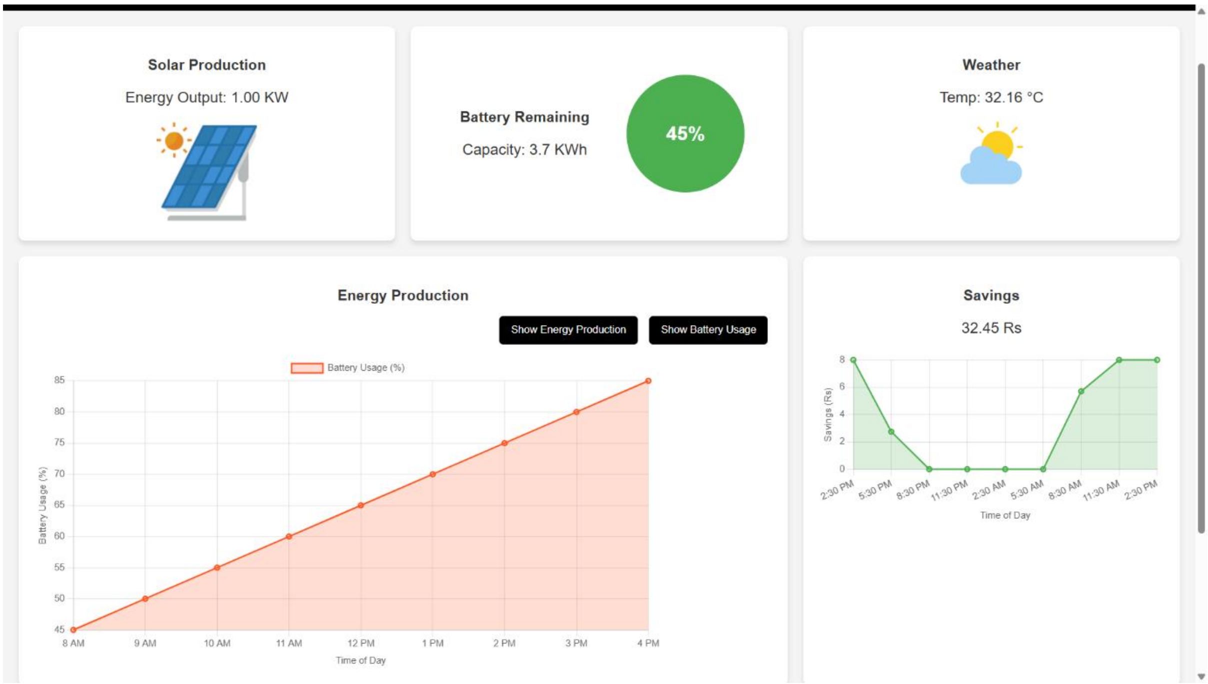
7.2 OVERVIEW:



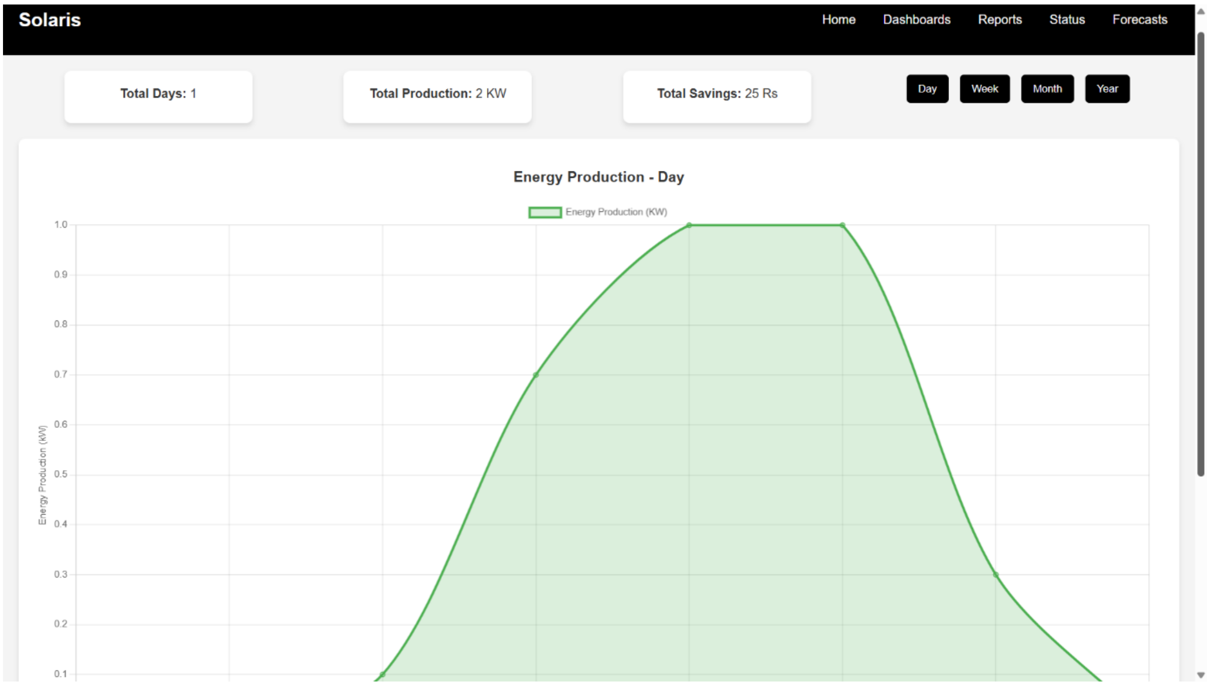
7.3 ENERGY PRODUCTION DASHBOARD:



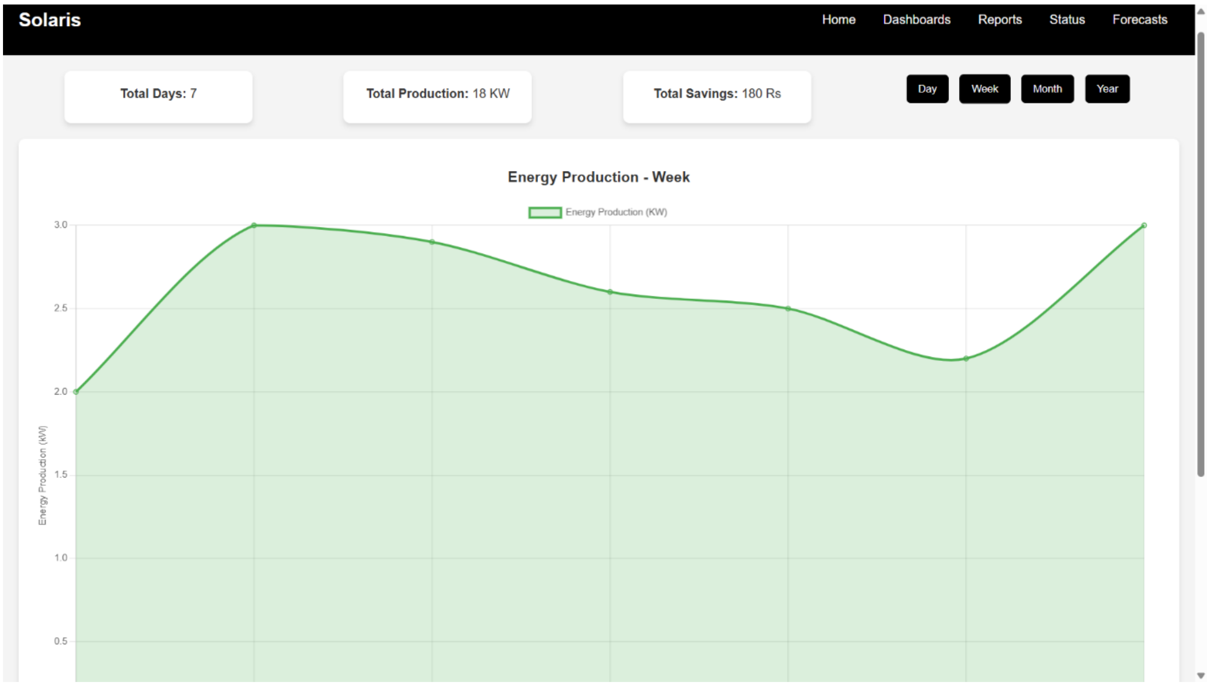
7.4 BATTERY USAGE DASHBOARD:



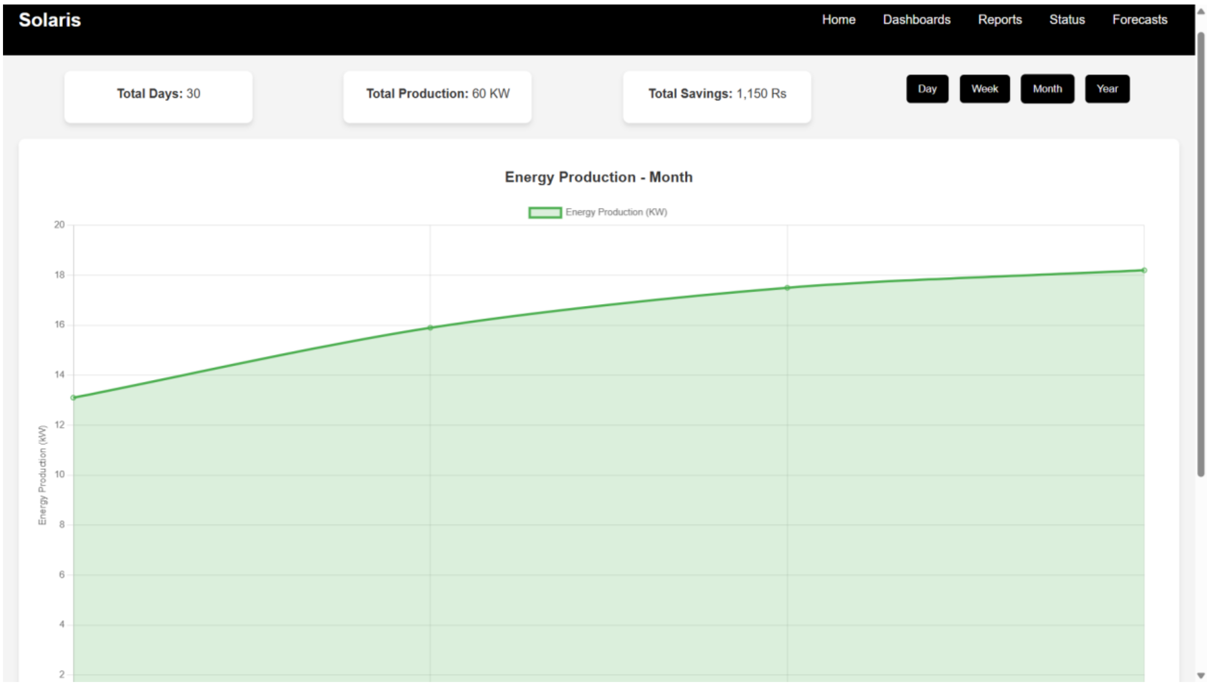
7.5 DAILY REPORT:



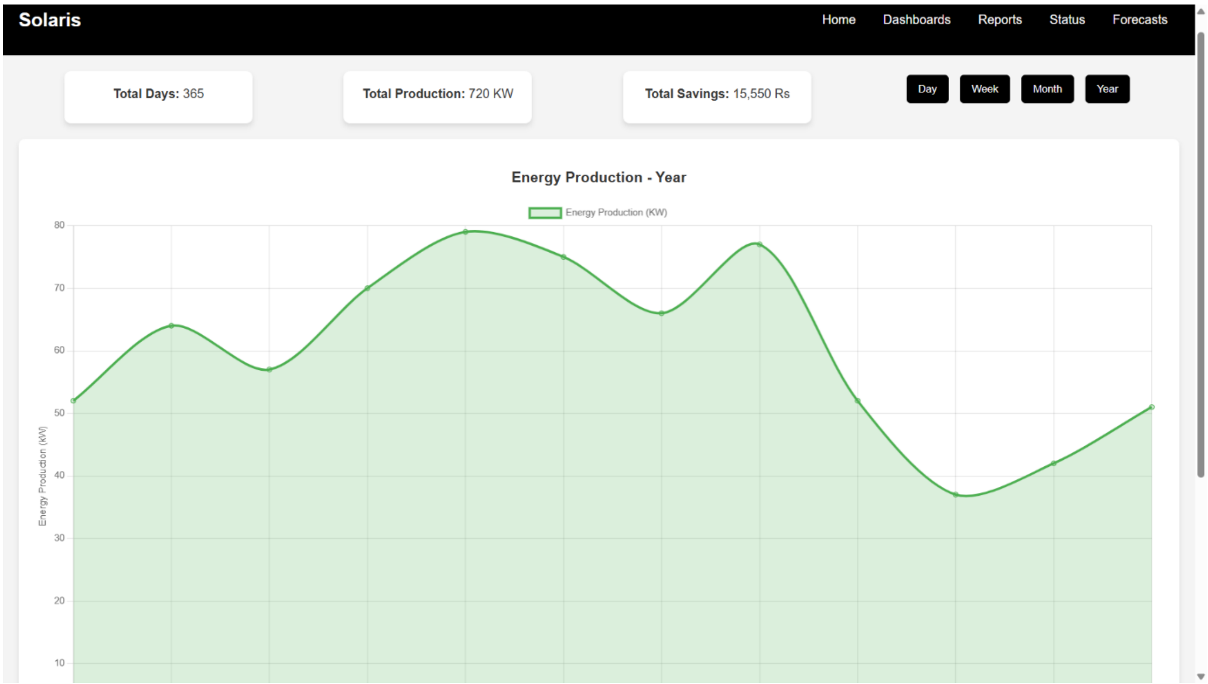
7.6 WEEKLY REPORT:



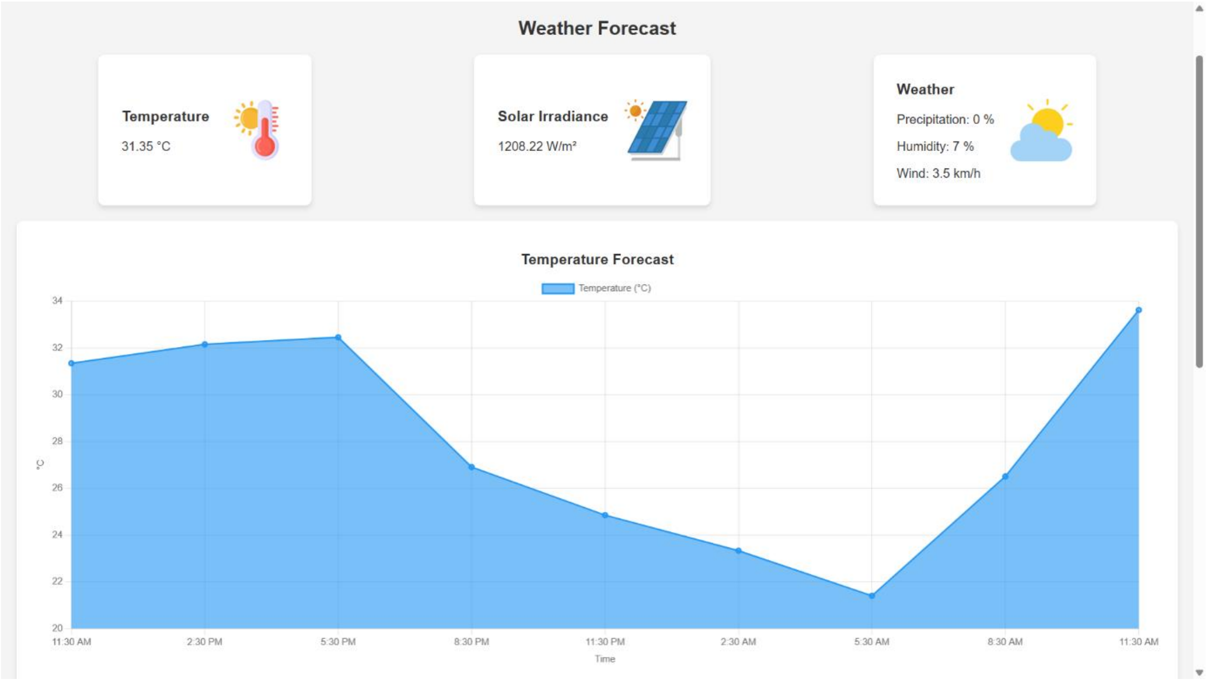
7.7 MONTHLY REPORT:



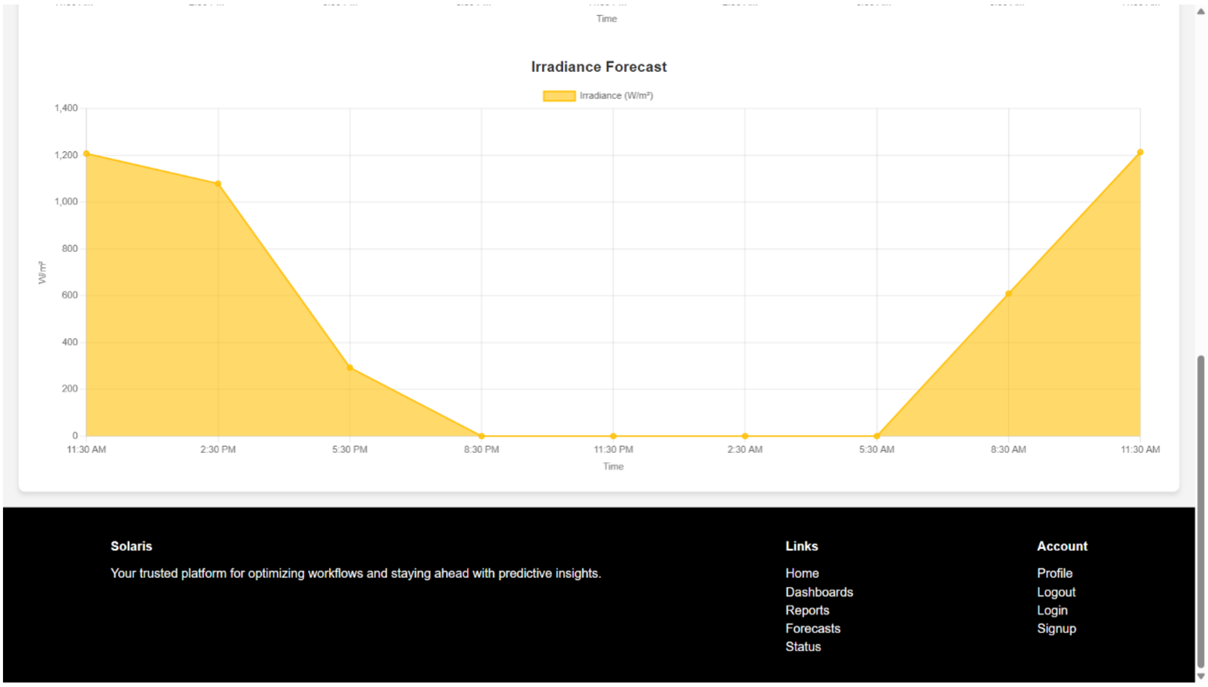
7.8 YEARLY REPORT:



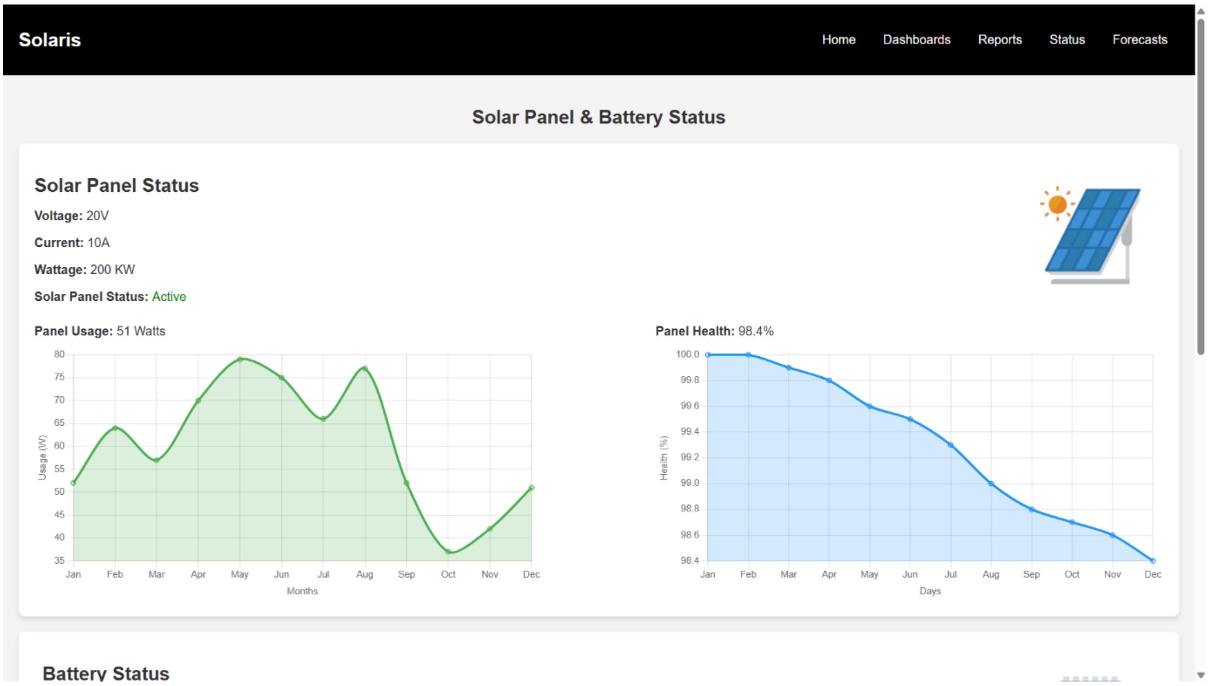
7.9 TEMPERATURE FORECAST:



7.10 IRRADIANCE FORECAST:



7.11 SOLAR PANEL STATUS:



7.12 BATTERY STATUS:

8. TESTING AND VALIDATION

8.1 DESIGN OF TEST CASES AND SCENARIOS

The design of test cases and scenarios for the Intelligent Energy Rerouting in Smart Solar Homes project is structured to cover a wide range of functionalities and edge cases. This ensures that the system performs optimally under different conditions and meets performance, security, and usability standards. The test cases focus on validating core functions such as energy prediction, decision-making, and dashboard visualization. The test scenarios are categorized into functional, performance, security, and usability tests to ensure a holistic evaluation.

Test Cases:

Test case ID	Test case name	Pre-condition	Test case description	Expected result	Actual result	Pass/Fail	Action
1.	Weather Data Fetch	None	The system fetches weather data from the API	Weather data is retrieved and stored successfully	PASS	No action	NA
2.	Energy Demand Prediction	Weather data fetched	System predicts energy demand using historical data	Energy demand prediction is accurate	PASS	No action	NA
3.	Decision Engine	Weather and demand data	System selects optimal energy source (solar, battery, grid)	Optimal energy source is selected	PASS	No action	NA
4.	Battery Management	Energy source selected	System monitors battery charge/discharge based on energy source usage	Battery is managed efficiently	PASS	No action	NA
5.	Dashboard Display	Data available	System updates dashboards with energy, battery, and weather data	Dashboard displays updated metrics correctly	PASS	No action	NA
6.	Report Generation	Data available	System generates detailed production and energy usage reports	Reports are generated and displayed successfully	PASS	No action	NA

7.	Error Handling	API/Data error	System detects and handles errors in API calls or data processing	Error is logged and notified without system failure	PASS	No action	NA
8.	User Interaction	Dashboard loaded	User navigates through different dashboard pages and views reports	Smooth navigation and data interaction	PASS	No action	NA

8.2 VALIDATION

The validation of the Intelligent Energy Rerouting in Smart Solar Homes project ensures that the system operates as expected and meets all functional and non-functional requirements. The validation process includes rigorous testing of individual components, system interactions, and end-to-end workflows to confirm system reliability, performance, and security.

Unit Testing

Unit testing validates individual functions and modules such as weather data retrieval, energy demand prediction, and decision-making logic. Each unit was tested independently to identify and address any functional inconsistencies early in the development cycle, ensuring a robust and error-free codebase.

Integration Testing

Integration testing ensures that all system modules—weather data API, ML model, and decision engine—communicate and work together effectively. This phase involves validating the flow of data between modules and verifying that system interactions function as intended, ensuring seamless integration of the system components.

System Testing

System testing was performed to evaluate the complete functionality of the application in a real-world scenario. This phase validated that all modules operate together, covering functional, performance, and security aspects. The goal was to ensure that the system behaves correctly under normal and extreme conditions.

8.3 VALIDATION CONCLUSION

The testing and validation phases of the Intelligent Energy Rerouting in Smart Solar Homes project have demonstrated that the system meets all specified requirements and performs efficiently in real-world scenarios. Through rigorous unit, integration, and system testing, the system has proven its reliability, accuracy, and scalability. Data accuracy, dashboard interactivity, and decision-making efficiency have been thoroughly validated, ensuring seamless energy management. User Acceptance Testing (UAT) has confirmed that the system meets user expectations and delivers an intuitive experience. With successful validation, the system is ready for deployment, promising improved energy efficiency and cost savings in smart solar homes.

9. CONCLUSION

The "**Intelligent Energy Optimization in Smart Photovoltaic-Powered Homes**" project represents a paradigm shift in energy management for the contemporary smart home. The smart algorithm through which machine learning is implemented-Random Forest Regression-for energy demand predictions based on forecast weather data from the meteorological department APIs in real-time and thus reducing dependence on the grid while increasing the use of solar energy and battery storage-forms the apt complement for the set of skills that the project provides towards improving energy efficiency and cost-saving while lessening the carbon footprint of the residential areas.

The project evidently addresses various hurdles to energy sustainability. It takes into account the ever-changing energy requirements due to constant changes in the environment. In implementing dynamic energy resource management by the system, a wonderful collaborative approach would be in evidence-meeting the demands of resilience, being efficient and environmentally friendly. The monitoring of solar generation, battery status, and energy consumption through web applications allows for greater user interaction, offering insights about system performance. Thus, this effort provides an initial step to a sustainable energy system, which may be further translated to become a scalable and widely applicable feature in the field of community-level energy management and grid integration.

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