A Project Report

on

Hybrid Energy inspired DC Micro-grid System using Machine Learning

Submitted to the
Savitribai Phule Pune University, Pune
In partial fulfilment for the award of the Degree of
Bachelor of Engineering in Computer Engineering

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SAVITRIBAI PHULE PUNE UNIVERSITY
2023-24

CERTIFICATE

This is to certify that the project report entitled

"Hybrid Energy inspired DC Micro-grid System using Machine Learning"

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are bonafide students of this institute and the work has been carried out by him under the supervision of **Dr. B. S. Tarle** and it is approved for the fulfillment of the requirement of Savitribai Phule Pune University, for the award of degree of **Bachelor of Engineering**, Computer Engineering.

Dr. B. S. Tarle		Dr. S. R. Devane
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Place:- Nashik
Date:-

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Abstract

Our project idea aims at the creation of a smart grid management system for hybrid energy power-plants (integration of renewable and conventional sources) using machine learning, where the energy generation can be controlled as per the estimated power demand (based on historical readings) as well as the real time demand, to ensure that there is minimum wastage of the electrical energy. Renewable sources like solar and wind can power the grid while the load demand is low and as per the increase in the power demand, the conventional steam generators' power output can be regulated by controlling the amount of steam generated using a programmable burner flame controlling unit which we will try to integrate in our project as part of our future scope.

Keywords - Energy Demand Forecasting, Hybrid Energy Controller, Energy Management System, Internet of Things, Machine Learning.

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Chapter 1

Hybrid Energy inspired DC Micro-grid System using Machine Learning

1.1 Introduction

A smart grid is an electrical grid which includes various operations and energy measures including: advanced metering infrastructure, smart distribution boards, load control switches, energy efficient resources.

Artificial Intelligence can be integrated with smart grids, to facilitate energy demand forecasting and output prediction, to ensure minimal wastage of electricity. Also, renewable energy sources, having an intermittent nature can be integrated in such a system.

Hence, our project is aimed at building an energy management system software, to use machine learning to control and regulate renewable and non-renewable energy modules in a DC micro-grid system, to minimize outages and maximize the output of the system by efficient use of energy demand forecasting.

1.2 Problem Statement

We must gradually shift our focus to integrating non-polluting renewable energy sources with the conventional grid system to harvest renewable energy economically, while ensuring minimal wastage of electricity generated conventionally.

In traditional thermal power-plants, the demand and generation of electricity is matched using a manual process - the grid operators convey the power demand of the users (using their meter readings) to the power-plant operators, who in turn control the power output of the plants. This process causes time delays and wastage of electrical energy. Hence, a smart hybrid energy management system is necessary to override the communication latencies for minimum wastage of electricity while controlling the integration of various energy sources.

1.3 Motivation

Sustainability of any country leads to its growth over a long term. Thus, we must shift gradually towards the use of renewable energy as making a drastic shift might be costly. This implies that Hybrid Power Plants will play a vital role in the power industry in coming years. This is what motivated us to build a hybrid DC micro-grid, in fulfillment of the final year project.

Also, most smart grid projects focus on controlling the management of the energy that is already generated whereas our idea aims to automate the generation aspect in real time. If our system is deployed in thermal power-plants, we can minimize the wastage of electricity, while establishing profitable relationships with the electricity manufacturing companies by reducing their manual labor and time delays.

Thus, we intend to build an energy management system, for controlling the power output of the sources according to the energy demand of the users.

1.4 Current Statistics of Indian Power sector

Installed capacity of thermal power in India is 237.26 GW which accounts for 60 % of the total electricity generation in India. The rest of which is derived from non-renewable energy sources.

64 % of the consumers are located in rural areas, where there is an abundance of renewable energy from biomass, wind etc. Hence these resources can be integrated with the main grid to reduce the average cost per unit of electricity, which currently is ₹7/unit (average cost as of April '23). [11]

1.5 Objectives of Work

The Objectives of the project work are as follows:

1. Predict the power output generated by renewable energy generators, using illumination and wind-speed sensors.
2. Predict load demand of the users in the grid using their previous power usage readings, according to their observed behaviour, by measuring the voltage drop and line current at their end.
3. Switch and regulate the energy sources based on the load / consumption of the users as per the estimates. For uncertain demands, make use of a battery backup module.
4. Work on securing a wireless setup of the system from cyber attacks as a part of future scope.

1.6 Project Scope

1. Assembling the entire wired setup of the DC micro-grid and executing the switching and regulation of the sources as well as the backup energy sources (battery) according to the load demand.
2. Training multiple Machine Learning and Deep Learning models to estimate the power generation and forecast the load demand.
3. Building our own dataset consisting of sensor readings, to measure the illumination, wind speed and other parameters relevant to our energy sources.
4. To try obtaining as good an accuracy at the predictions as mentioned in our base paper, by the author, work and investigate more on improving the accuracy using newer techniques like Ensemble Learning.
5. Building a wireless micro-grid and securing it against data manipulation attacks, as future scope.

Chapter 2

Literature Survey

2.1 Overview

The base paper [1] suggests the use of a two-stage machine learning based energy dispatch management system for hybrid power plants (HPPs) , designed to control renewable energy sources, reserve and backup energy sources. The first stage aims to forecast the power output of renewable energy sources, as well as the load demand. The second stage aims to coordinate the energy output of the reserve and backup sources to achieve the required objective.

The second paper [2] discusses about distributed energy resources (DERs) being largely interconnected to electrical power grids, causing significant impact to the operation of traditional centralized generation power plants and the dispatch control centers. Further, the authors introduced the use of a simplified LSTM algorithm to forecast one day-ahead solar power generation, elaborating on data processing, model fitting, cross validation, metrics evaluation, hyper-parameters tuning and the results showing as average RMSE of 0.512 which offers quite a promising solution for short-term solar power forecasting applications. The authors made use of raw data collected from Photo Voltaic (PV) systems to train a model using a long short term memory approach to forecast one day-ahead solar power generation.

The third paper [3] deals with a residential hybrid thermal grid-connected home energy system, including a fuel-cell and a battery as Energy Storage System (ESS). A day-ahead scheduling algorithm for managing different resources is developed to generate an efficient look-up table that determines an optimal operation schedule for the distributed energy resources at each time interval, so that the operation cost of a smart house is minimized. We plan to use a similar approach for our project and will try to include additional functionalities of controlling conventional power generation.

[4] Suggests an energy management system for HPPs powered by PV and diesel batteries. [5] Suggests the use of hourly scheduling of energy sources.

2.2 Limitations

1. The gaps which we identified in the base paper [1] were that all of the model training and testing was done using simulated datasets and not on any actual grid / micro-grid system.
2. The second paper [2] made use of raw data collected from PV systems to train a model using a long short term memory approach to forecast one day-ahead solar power generation but did not explore other renewable energy sources.

2.3 Current Market Survey

INDIA

Presently, in India, power grids are manually controlled. However, there are numerous pilot projects, some of which have been completed and some undergoing development, under the National Smart Grid Mission, established by the Government of India, since 2015. Below are the Smart Grid pilot projects sanctioned by the Ministry of Power, completed in India.

Sr No.	Location	Functionalities Adopted
1.	PED, Puducherry	Advanced Metering Infrastructure
2.	IIT Kanpur	Renewable Integration
3.	UHBVN, Haryana	Outage Management
4.	UGVCL, Gujarat	Outage Management
5	HPSEB, Himachal Pradesh	Power Quality Measurement
6	AVVNL, Ajmer	Advanced Metering Infrastructure
7	APDCL, Assam	Distributed Generation
8	WBSEDCL, West Bengal	Advanced Metering Infrastructure
9	SGKC, Manesar	Micro-Grid / Distributed Generation, EV with Charging Infra, Home Energy Management, Cyber Security and Training Infrastructure
10	TSSPDCL, Telangana	Advanced Metering Infrastructure
11	TSECL, Tripura	Advanced Metering Infrastructure
12	CESC, Mysore	Micro-Grid

Table 2.1: Smart Grid Pilot Projects in India

GLOBAL

Smart Grid market size was valued at USD 31.5 billion in 2022 and is expected to grow up to USD 108.238 billion by 2032, at an annual growth rate of 14.70%. Countries having established smart grids are : the U.S.A., Canada, Germany, France, the UK, Italy, Spain, China, Japan, India, Australia, South Korea, and Brazil.

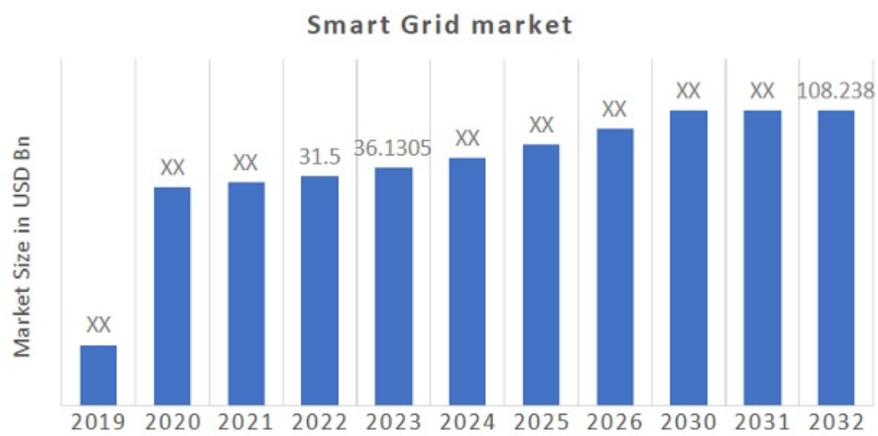

Figure 2.1: Smart Grid Global market size [7]

TECHNOLOGICAL INSIGHTS

Smart grids can either be wired or wireless (transferring information over a distance without electrical conducting wires). A reliable, secure, and low-latency bi-directional communication infrastructure is required between the intelligent electronic devices and the control center to implement wireless communication in a substation. Wireless technology ensures cost savings and secure data transmission compared to wired technology. This technology offers utility support by offering high bandwidth, covering a large area, and optimizing complex logistics and production processes. [7]

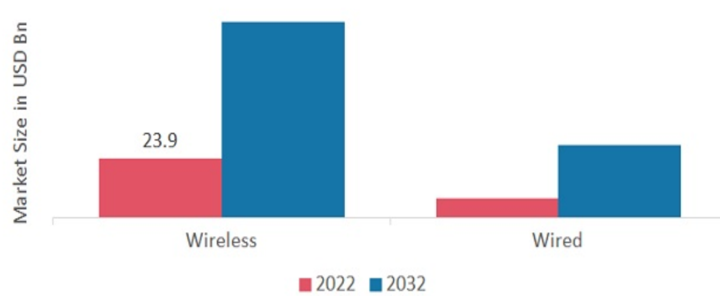

Figure 2.2: Wired vs Wireless Grid market size [7]

Companies leading the smart grid market are - IBM Corporation (US), Schneider Electric (France), Open Systems International (US), Oracle Corporation (US), Wipro Ltd (India).

Chapter 3

Design Details

3.1 PHASE 1: Requirement Analysis

3.1.1 Software Requirements

Operating System - Linux
The proposed system is designed to work on Linux operating systems as all distributions of Linux come with Python installed out of the box. Also, as mentioned in our future scope, working on securing a wireless model requires the use of security and forensics tools, which are free to install and use, on the Linux platform.

3.1.2 Minimum Hardware Requirement

- **Microprocessor** - Intel Core i5 / i7 (= 6th gen)
- **RAM** - 4 GB or more (on AWS Virtual Machine)

3.1.3 Functional Requirements

System Features

We aim to offer our users, an energy management system which will :
1. Predict the power output generated by renewable energy generators.
2. Predict load demand of the users in the grid using historical power usage readings.
3. Switch and regulate the energy sources based on the load / consumption of the users in real time.

Database Management System (DBMS)

We will be aggregating the sensor readings - illumination, wind speed, using a Raspberry Pi Pico and pushing them onto the cloud storage, in the form of JSON. On cloud, this data will be stored as CSV files, hence our databases will actually be datasets along with trained models as pickle files.

3.1.4 External Interface Requirements

User Interfaces

1. An intuitive and easy to interpret dashboard showing the integration of energy sources.

Software Interfaces

The proposed system will be a set of Python scripts, which will estimate the load power consumed by the users as well as the output power of the powerplants and generate a control sequence to control the switching and regulation of all the sources. The system will be deployable on local as well as remote machines. The admin of the system (electricity board users) will be able to modify the scripts to change the parameters of the machine learning as well as switching phases.

Hardware Interfaces

The proposed system will be executed in the form of a prototype, simulating an actual DC micro-grid.

Hardware Components

- Raspberry Pi Pico W
- Solar Panel, Charge Controller and Lead Acid Battery
- DC Adaptor, Motor, Relay
- For future modules - RF Transceivers, Wireless Network Adaptor, Steam generator and steam burner flame controller.

Communication Interfaces

For training of the machine learning models, to control the system, we will require computers having 8 GB RAM and 32 GB of storage, running Linux operating systems to ensure security and responsiveness. These requirements will be harnessed through the use of remote virtual machines, on the AWS EC2. Our trained model will be deployed on a virtual machine hosted on AWS EC2. For our prototype, a single 8 GB RAM and 32 GB storage space VM will be enough.

Network and Communication Protocols

- **IEEE 802.11 (WiFi)** :
  Wireless Fidelity, is widely used to enable wireless internet access in various devices, including smartphones, laptops, and IoT devices. It operates using the IEEE 802.11 family of protocols, which define the standards for wireless communication. We will make use of this protocol to transfer data to and from the Raspberry Pi module and the AWS virtual instances.

- **SSH (Secure Shell)** :
  It is a network protocol that allows secure remote access to and control of devices and servers over an encrypted connection, using strong encryption and authentication methods.

3.1.5 Non-Functional Requirements

Software Quality Attributes

1. **Reliability** : As the models will be trained to fit the data just correctly, the system will give reliable estimates.
2. **Portability** : Accessible from anywhere, as the dashboard will be hosted on cloud.
3. **Usability** : User friendly dashboard.

Operational and Maintenance Considerations

For maintenance of the trained model and prevention of corruption of the files, we will schedule cronjobs for repeatedly training the model at regular intervals.

Scalability and Performance

The proposed system is designed, considering a DC microgrid; hence, for the machine learning part, we will make use of only virtual machines for the training purpose and serving of the dashboard module. As the system scales, we can integrate multiple remote virtual machines for the training and serving purpose. Hence, our system is scalable, considering the fact that we are using Apache Spark for distributed machine learning and a lightweight, responsive dashboard library - Dash.

Security Considerations

As part of security, we hope to secure the physical setup of our project from external threats like fire and water. Also, as detailed in the scope of this document, we will work on securing our system against man in the middle attacks.

Security and Access Control Constraints

We will ensure that the virtual instance can only be accessed by authorized persons, through SSH, by storing the private keys required to login, in hidden files, which will be password protected.

Version Control and Source Code Management

We will make use of Git and GitHub to manage the versions of our source code, to allow the recovery of previous versions, if desired.

3.2 PHASE 2: ANALYSIS PHASE

3.2.1 Technologies Used

Programming Languages and Technologies

- **Python 3** - It is a high-level, general-purpose programming language.
- **Apache Kafka** - It is a distributed event store and stream-processing platform.
- **Apache Spark** - It is an open-source analytics engine for large-scale data processing.

Development Tools and Environments

- **JupyterLab** - It is a web-based interactive computing platform.
- **AWS EC2** - Virtual machines on the Elastic Cloud Compute platform will enable us to deploy trained models and host the dashboard software.
- **Colab** - To speed up the training process using GPUs offered by Google's web notebooks.

Software Frameworks and Libraries

- **Pandas** - Open source data analysis and manipulation tool, using Python.
- **Scikit-Learn** - Library for implementing machine learning in Python.
- **Confluent-Kafka** - Library for using Kafka's publish-subscribe model using Python.
- **PySpark** - Library for distributed machine learning for big data, using Spark, in Python.
- **Dash** - Library for building dashboards using Python.

3.3 PHASE 3: DESIGNING PHASE

3.3.1 System Architecture Diagram

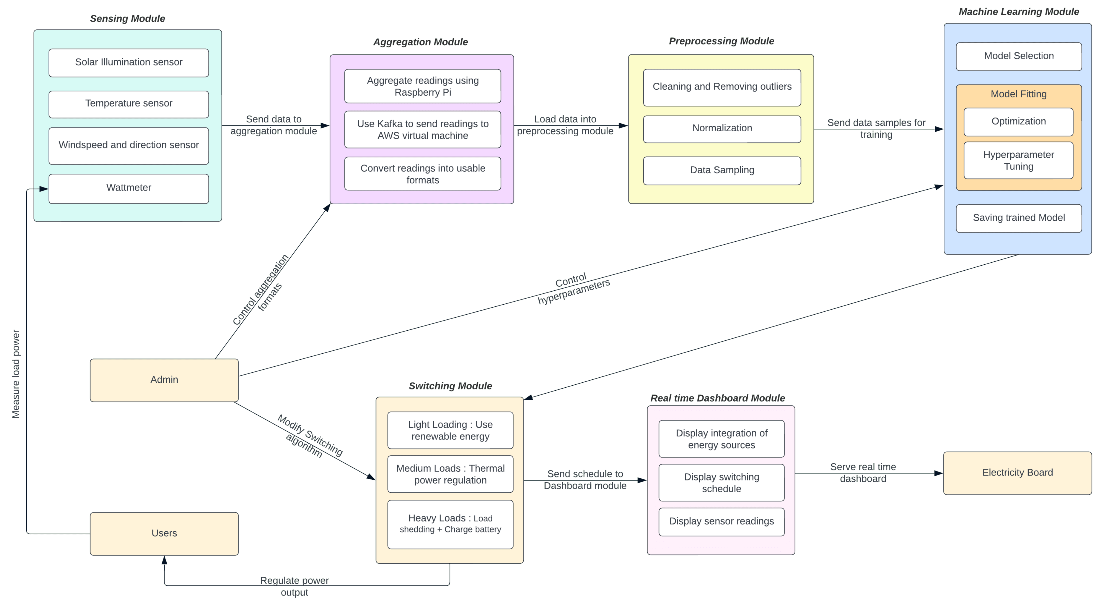

Figure 3.1: System Modules Overview

3.3.2 Data Flow Diagrams

Data Flow Diagram 0

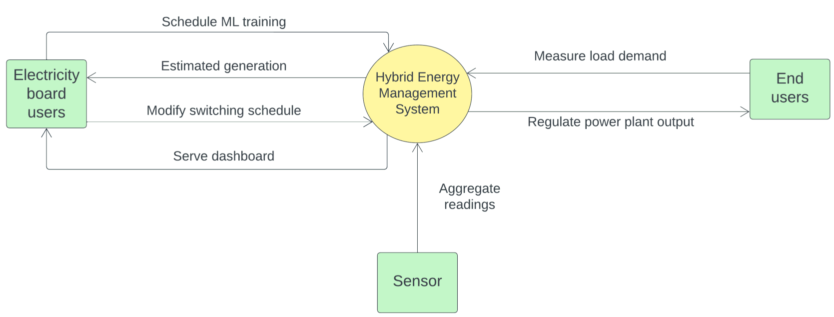

Figure 3.2: DFD Level 0

Data Flow Diagram 1

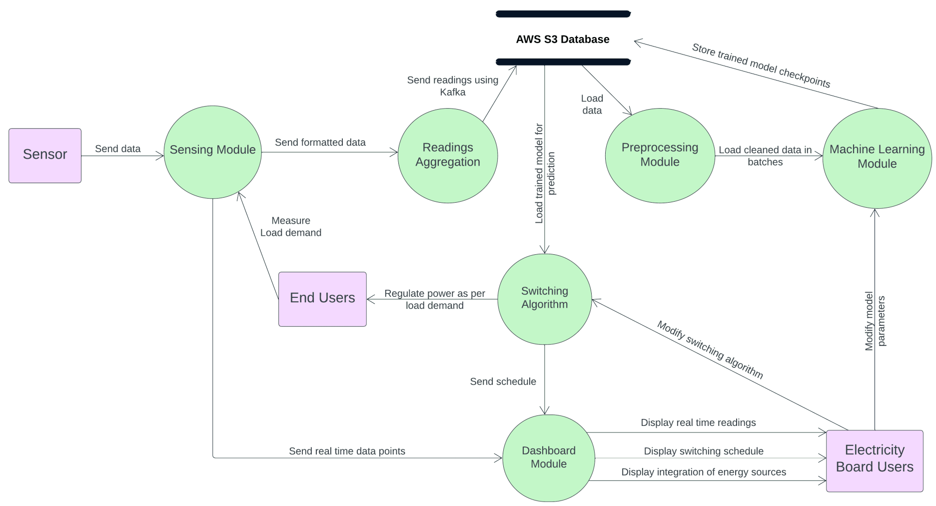

Figure 3.3: DFD Level 1

3.3.3 E-R Diagram

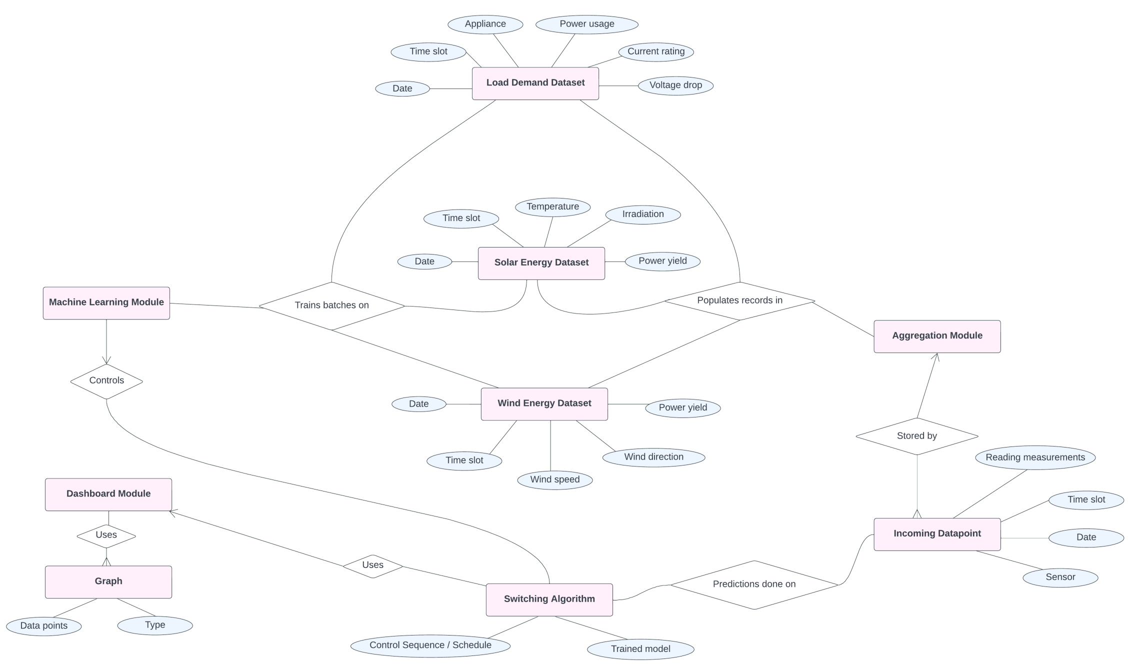

Figure 3.4: ER Diagram

3.3.4 Use Case Diagram

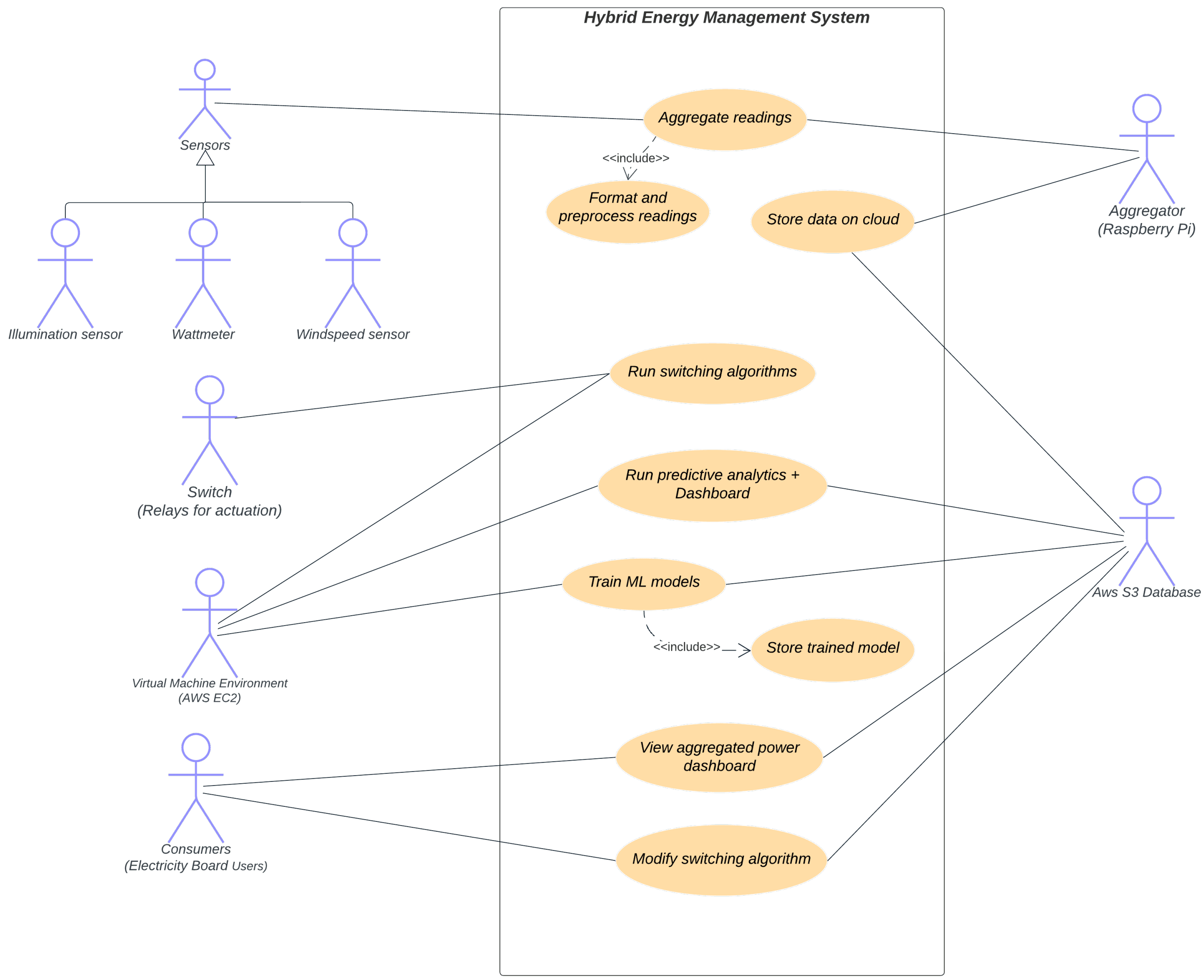

Figure 3.5: Use Case Diagram

The use cases of the system include -

- Sensors will send their reading to the aggregator which will push the readings on the cloud setup.
- The remote setup running on a virtual machine will run ML, predictive analytics, switching as well as dashboard scripts, which will be consumed by the users.
- The switching algorithm will generate a control sequence and control the flow and generation of electricity using relay modules.

3.3.5 Class Diagram

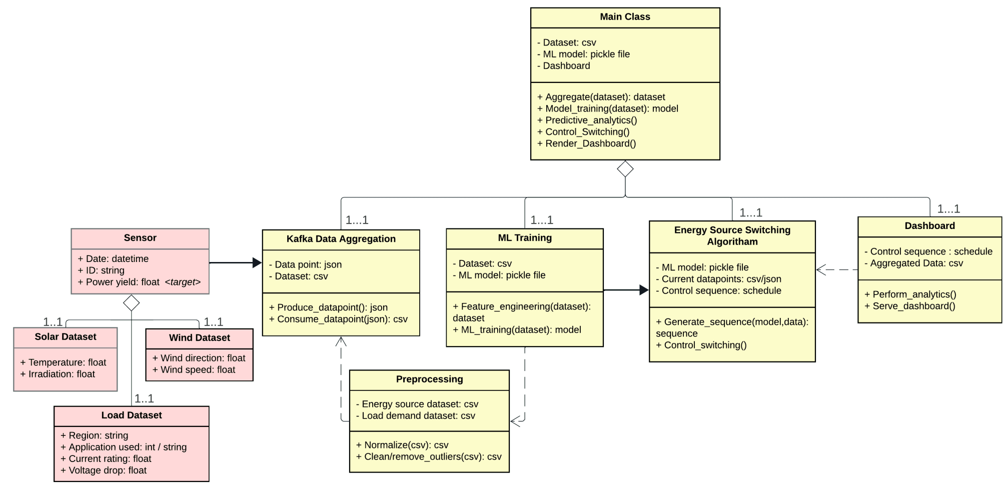

Figure 3.6: Class Diagram

3.3.6 Sequence Diagram

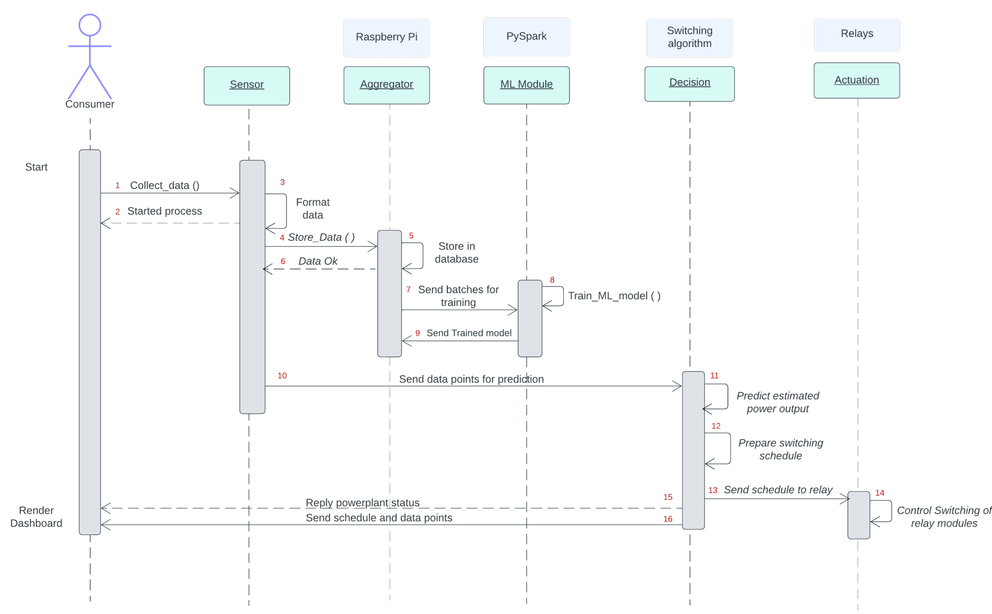

Figure 3.7: Sequence Diagram

3.3.7 State Diagram

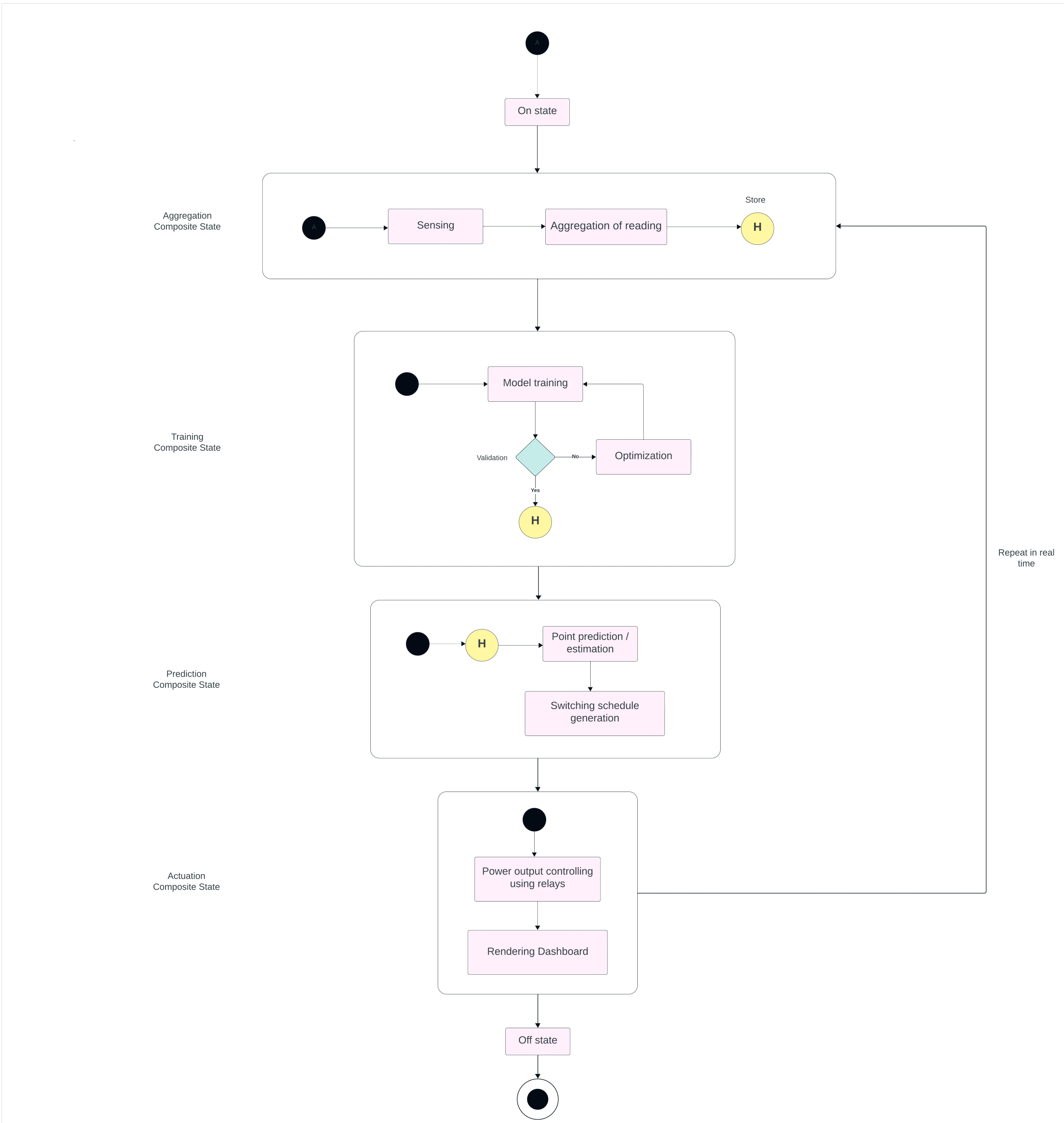

Figure 3.8: State Chart Diagram

3.3.8 Activity Diagram

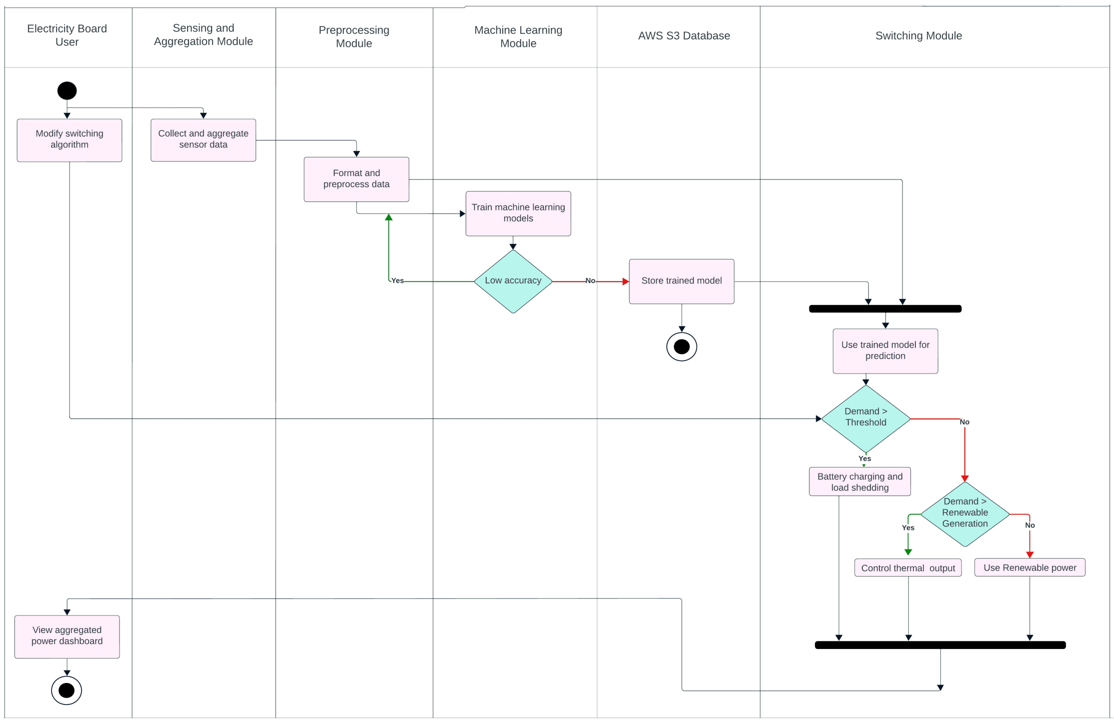

Figure 3.9: Activity Diagram

3.4 PHASE 4: PLANNING PHASE

3.4.1 Operating Environment

Our system will work in the physical setup of our DC microgrid, connected with the virtual machine instance running the machine learning scripts, via the Internet / WiFi hotspot.

3.4.2 Design Implementation

Hardware module

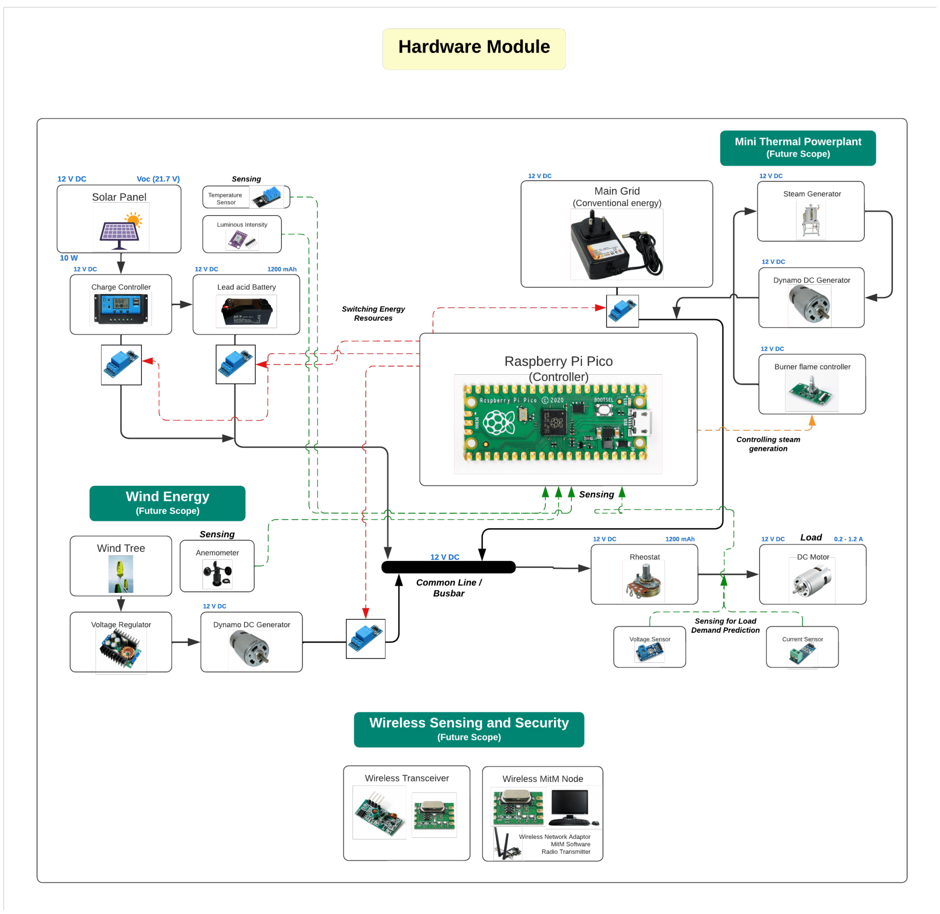

Figure 3.10: Hardware Module

1. **Mini Solar Energy Power Plant** : Comprising a 12V, 10W Solar Panel, a Charge Controller and a 1200 mAh Lead Acid Battery, this module will be responsible for

harvesting the solar energy and powering the microgrid. Also, we will deploy Luminous Intensity and Temperature Sensors to obtain readings in order to predict the power generation output.

2. **Main Grid** : As the conventional energy source in our project, we are going to make use of a stable 12 V DC connection using an Adaptor which will be connected to the Main Power Grid.

FUTURE SUB-MODULES :

3. **Mini Wind Energy Power Plant** : Comprising a Wind Tree Module, a 12 V Dynamo Generator and a Voltage Regulator, this module will be responsible for harvesting the wind energy. Also, we aim to deploy an Anemometer to obtain wind speed readings in order to predict the power generation output of the entire module.
4. **Mini Thermal Power Plant** : This module will consist of a Steam Generator, controlling a 12 V Dynamo, powered by a burner. We aim to deploy a Burner Flame Controlling Unit to control the power output of the thermal plant in real time.
5. **Wireless Sensing and Cyber Security Module** : This module will make use of Wireless Sensors (using Radio Frequency) instead of the above listed wired ones. To secure this wireless smart grid, we will try to execute data manipulation attacks on the wireless communication going on between the transmitter and the receiver and suggest possible security measures in opposition to the attacks.

Remote Machine Learning Module

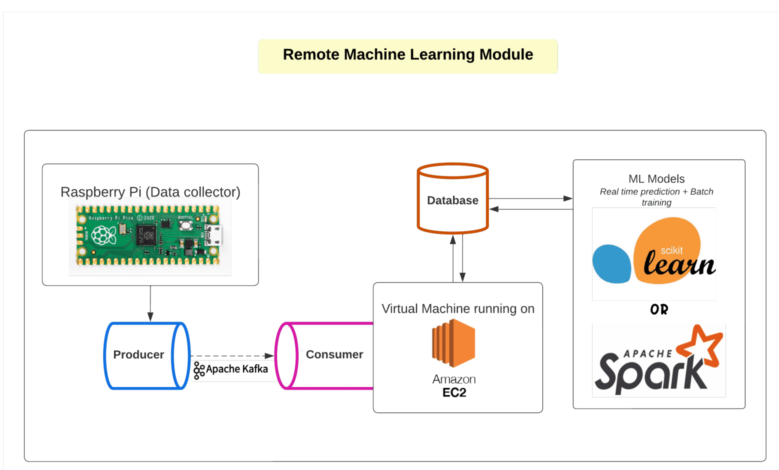

Figure 3.11: Remote Machine Learning Module

1. **Data Acquisition** : This module consists of a Raspberry Pi Pico which will obtain the sensor readings and control the actuation / management and switching of the mini power plant modules as the power load.
2. **Data Concentration** : The Raspberry Pi will stream the readings using Apache Kafka to a remote consumer program residing on an Amazon EC2 virtual machine, where all readings will be concentrated and machine learning programs will be executed.
3. **Machine Learning** : This module will consist of the batch training of the gathered data as well as real time prediction of the power generation estimates, load estimates to control the switching of the power plants in real time.

Dashboard Module

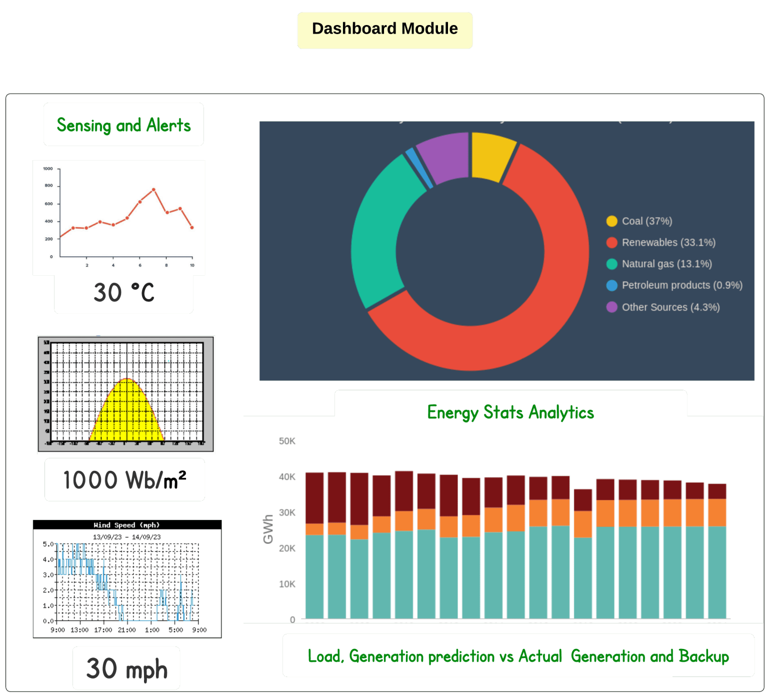

Figure 3.12: Dashboard Module

This module will consist of a real time dashboard to show the sensor readings over time and to give the users a visual representation of how the predicted load and generation estimates match with the actual power consumption and generation and how the switching of the energy sources is handled, to account for the minimum power wastage.

3.4.3 Risk Management

Risk Identification

The proposed system relies of third party hardware and libraries. Keeping this in mind, we have identified security risks that can most likely occur in the development stage.

Risk Mitigation, Monitoring and Management Matrix

Risk ID	Risk Name	Type	Impact (1-10)	Backup Plan
1	Hardware module / component failure.	Technical Risk	8	Keeping backup components at hand.
2	Remote Consumer (ML program) not reachable.	Operational Risk	5	Keep a local computer as a backup for remote machine learning.
3	Execution of the project in the real world would be challenging.	Business Risk	3	Communicate with stakeholders in the electricity department board, for real-world feasibility analysis.

Table 3.1: Risk Assessment Table

Overview of Risk Analysis

We have identified three risks in the development and execution phases of our project and rated their impact towards the completion of the project on a scale of 1 to 10, 1 being the lowest impact and 10 being the largest impact. Also, we have listed the strategies which we can employ to mitigate these identified risks.

3.4.4 Assumption and Dependencies

- **External Hardware Dependencies**
  The proposed system will make use of AWS hosted virtual machines. Hence, the owner of the hardware running the code will be a third party - AWS. Hence, the security of our data, beyond authentication mechanisms, is in the hands of AWS. To tackle any discrepancies arising due to this, we can make use of a local machine instead.

- **Software Dependencies**
  The proposed system will run on locally installed softwares - Kafka, Spark hence there will not be the use of any third party softwares unless we opt for remote versions of these softwares, to ease the process.
- **Data Source Dependencies**
  The proposed system will be making use of datasets procured from the IEEE Dataport. Hence, our system will rely on this data, aggregated by a third party.

3.4.5 Constraints of the Project

Time and Schedule Constraints

Regarding the schedule, the entire project can be implemented in a time frame of 2 months, starting - December 2023. Beyond which, we can work on fulfillment of the items we previously listed as part of our future scope.

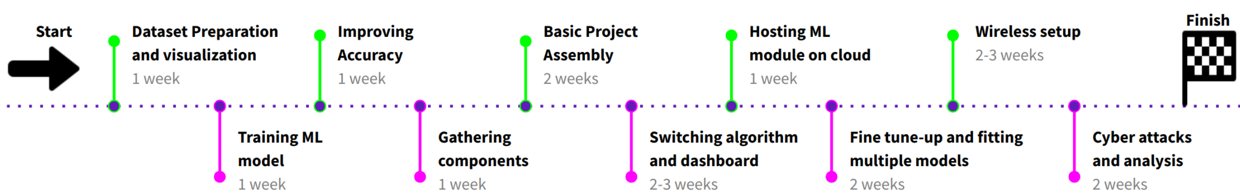

Figure 3.13: Project Schedule

Budget and Cost Constraints

We have limited the budget of our project to ₹10,000 to 15,000 considering the hardware cost of miniature prototype of the DC micro-grid along with the costs required to run the AWS virtual machines.

Regarding the software development cost of the project using the COCOMO model,

- $Effort\ Estimation\ (E) = a * (KLOC^b) = 3 * 0.8^1.12) \approx 2.144\ person\ months$
- $Development\ Time\ Estimation\ (D) = c * (E^d) = 2.5 * (2.144^{0.35}) \approx 2.55\ months$
- $Cost\ Estimation\ (C) = D * X = 2.55 * 40000\ (median\ salary) \approx$ ₹$1,02,000\ Lakh$

3.4.6 Testing and Quality Assurance

1. Regression Testing will be made use of, to ensure that new code changes or don't affect the existing functionalities.

2. To assess how the system performs under various conditions, like - high traffic asking to serve the dashboard, high rate of incoming sensor readings etc, we'll make use of Load and Performance Testing methods.
3. To protect our system from cyber attacks like data manipulation and denial of service attacks, we will make use of Security Testing, with tools which come installed on Kali Linux, out of the box.
4. Testing of the various cases of operation of the micro-grid system - light and heavy loading and how our system reacts to the cases.
5. Testing the performance of the system using different ML algorithms.

3.4.7 User Documentation

User Manual

To guide our users through the process of installing our system locally, instead of a virtual machine, we will prepare a detailed documentation, listing all the steps regarding the setup of the system as well as annotated source code so that the users can customize our system according to their requirements.

Troubleshooting and Problem-Solving

A troubleshooting guide will also be prepared for the users, in case they have any issues with the installation process, along with screenshots and visual aids.

Chapter 4

Conclusion

4.1 Conclusion

Hence, we have proposed a hybrid energy management system for DC micro-grids :

- Having a full fledged hybrid energy management system. To predict the power output of various energy resources .
- To have a system , to predict as well as sense real time load demand.
- To have a fully working real time Dashboard which will show the current readings as well as the process by which the energy sources will be switched and regulated.

4.2 Future Work

We are currently limiting our scope to building a wired microgrid setup. If feasible, we will work on building a wireless microgrid and study more on securing this wireless smart grid. We will try to execute data manipulation attacks on the wireless communication going on between the transmitter and the receiver and suggest possible security measures in opposition to the attacks. Also, we will try to integrate a steam generator and show the controlling of the thermal output using burner flame controlling knobs.

4.3 Advantages

- Aggregating various distributed energy sources together.
- Reducing the average cost of generation of electricity per unit.
- Ease the work of electricity board users, by automating the communication process.

4.4 Applications

- Control distributed hybrid energy systems for integration of generated electricity.
- Predicting time series behavioral data of users to obtain their estimated power requirement, which can be applied to sectors other than power and energy too.

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