A

MAJOR PROJECT REPORT

On

Electrical Network Modelling of NIT KKR using OpenDSS And Real Time Smart Meter Analysis

Submitted on partial fulfillment of award of

BACHELOR OF TECHNOLOGY

Degree

In

Electrical Engineering

Submitted to

DEPARTMENT OF ELECTRICAL ENGINEERING

2024-25

DEPARTMENT OF ELECTRICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
KURUKSHETRA
(Institute of National Importance)

Submitted By:

Shivansh Kumar Jha (12114138)
Kanhaiya Kumar (12114106)
Rishav Kumar Sah (12114119)
Aditya Raj Rana (12114117)

Guided By:

Dr. Pradeep Kumar
Assistant Professor
Department of Electrical Engineering
National Institute of Technology,
Kurukshetra

ABSTRACT

This report gives the results of a major project conducted at the Department of Electrical Engineering, National Institute of Technology, Kurukshetra, on Electrical Network Modelling of NIT Kurukshetra using OpenDSS and Real-Time Smart Meter Analysis. The project was intended to model and analyze the electrical distribution network of the NIT Kurukshetra campus with emphasis on enhancing monitoring, efficiency, and data-driven decision-making.

Guided by **Dr. Pradeep Kumar**, the project entailed creating a comprehensive simulation of the campus electrical grid using OpenDSS (Open Distribution System Simulator), an open-source industry-standard platform for power distribution system analysis. Concurrently, real-time smart meter data from different campus buildings and substations were gathered and analyzed to test the model and determine energy usage patterns.

The project made meaningful contributions to load distribution, voltage profiles, losses, and system performance across various operating conditions. It also presented the utilization of smart metering infrastructure at academic institutions for real-time energy monitoring and control. The integration of simulation with real-time data analysis provided a better understanding of the campus power system and presented opportunities for future optimization and smart grid integration.

This project not only enhanced the technical competence of the student in power system modeling and data analysis but also added significantly to the institution's initiative towards energy efficiency and digitalization. The practical experience with OpenDSS and smart meter data has provided a solid foundation for future research in smart grid technologies and advanced power systems

DECLARATION

We declare that this written submission represents our ideas in own words, and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented of fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Signature of Students:	**Signature of the supervisor:**
Shivansh Kumar Jha (12114138) Kanhaiya Kumar (12114106 Rishav Kumar Sah (12114119) Aditya Raj Rana (12114117)	Dr. Pradeep Kumar Assistant Professor Department of Electrical Engineering National Institute of Technology, Kurukshetra

CERTIFICATE

DEPARTMENT OF ELECTRICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY KURUKSHETRA
(Institute of National Importance)

This is to certify that the project report entitled "**Electrical Network Modelling Of NIT KKR Using OpenDSS And Real Time Smart Meter Analysis**" submitted by Shivansh Kumar Jha (12114138), Kanhaiya Kumar (12114106) , Rishav Kumar Sah (12114119) and Aditya Raj Rana (12114117)**,** in partial fulfillment of the requirements for the award of the Bachelor of Technology in Electrical Engineering and submitted to the Department of Electrical Engineering of National Institute of Technology Kurukshetra is an authentic record of our own work carried out during a period from July 2024 to April 2025 under the supervision of **Dr. Pradeep Kumar**, **Assistant Professor**, Department of Electrical Engineering, NIT Kurukshetra.

Shivansh Kumar Jha	Kanhaiya Kumar	Rishav Kumar Sah	Aditya Raj Rana
12114138	12114106	12114119	12114117

Guided by:
Dr. Pradeep Kumar
Assistant Professor
Department of Electrical Engineering
National Institute of Technology, Kurukshetra

PLAGIARISM DECLARATION

We understand that plagiarism is defined as any one or the combination of the following:

- Uncredited verbatim copying of individual sentences, paragraphs or illustrations (such as graphs, diagrams, etc.) from any source, published or unpublished including the Internet.

- Uncredited improper paraphrasing of pages or paragraph (changing a few words or phrases or rearranging the original sentence order).

- Credited verbatim copying of a major portion of a paper (or thesis chapter) without clear delineation of who did or wrote what (Source: IEEE, The Institute, and December 2004).

We have made sure that all the ideas, expressions, graphs, diagrams, etc. that are not a result of my work properly credited. Long phrases or sentences that had to be used for verbatim from published literature have been clearly identified using quotation marks. We affirm that no portion of my work can be considered as plagiarism and We take full responsibility if such complaint occurs. We understand fully well that guide of this thesis may not be in a position to check for the possibility of such incidents of plagiarism in this body of work.

1.Shivansh Kumar Jha (12114138)

2.Kanhaiya Kumar (12114106)

3.Rishav Kumar Sah (12114119)

4.Aditya Raj Rana (12114117)

ACKNOWLEDGEMENT

We would like to take this opportunity to thank all the people who have helped in the completion of this project. It is our immense pleasure to work under **Dr. Pradeep Kumar** (Assistant Professor), Department of Electrical Engineering, NIT Kurukshetra for project. We also thank sir for the constant guidance he has given us throughout the project.

We also thank for the constant support given by all the faculties of Electrical department, NIT Kurukshetra. We now thank NIT Kurukshetra for giving us the opportunity to present this valuable project report on "**Electrical Network Modelling Of NIT KKR Using OpenDSS And Real Time Smart Meter Analysis**".

Thanking you,

Shivansh Kumar Jha(12114138)
Kanhaiya Kumar (12114106)
Rishav Kumar Sah (12114119)
Aditya Raj Rana (12114117

CONTENTS

1. INTRODUCTION TO OPENDSS & NIT KKR MODEL

Electric power distribution is an essential component of delivering consistent energy supply throughout campuses, cities, and industries. For educational institutions like the National Institute of Technology Kurukshetra, the distribution grid has to distribute power effectively through a diverse set of consumers ranging from residential hostels to highly consuming laboratories. Conventional methods of power flow analysis tend to be inadequate in considering actual physical arrangements and space limitations. To overcome this, project employs *OpenDSS* (Open Distribution System Simulator) along with GIS-based coordinates to conduct a high-fidelity power flow analysis of the NIT-KKR campus distribution network.

This project fills the gap between theoretical knowledge and real-world application by constructing a fully navigable digital twin of the NIT-KKR distribution network. It investigates how OpenDSS can be applied outside academic simulations to address actual distribution planning issues. For example, it would be simple to extend the model to incorporate solar photovoltaic systems at every substation or model fault scenarios to develop protection schemes.

Need for Power Flow Analysis :

Power flow (or load flow) analysis is a fundamental task in power system engineering. It helps to determine:

- Voltages at various buses
- Currents in transmission lines and transformers
- Real and reactive power flows
- System total losses

Such analysis is crucial for system planning, load forecasting, contingency analysis, and decision-making regarding network expansion or upgrades. In a campus environment such as NIT-KKR, precise load flow studies can assist in the identification of under-loaded or overloaded feeders, possible voltage drop problems, and transformer placement efficiency.

1.1 OpenDSS : A Tool for Modern Power System Analysis

OpenDSS (Open Distribution System Simulator) is an open-source software developed by the Electric Power Research Institute for advanced simulation and analysis of electric power distribution systems.

It is widely used for :

- ❖ *Load Flow Analysis*: Steady-state voltage profiles, power flows, and losses.
- ❖ *Harmonic Studies*: Analysis of non-linear loads.
- ❖ *Time-Series Simulations*: Dynamic behavior over hours, days, or years.

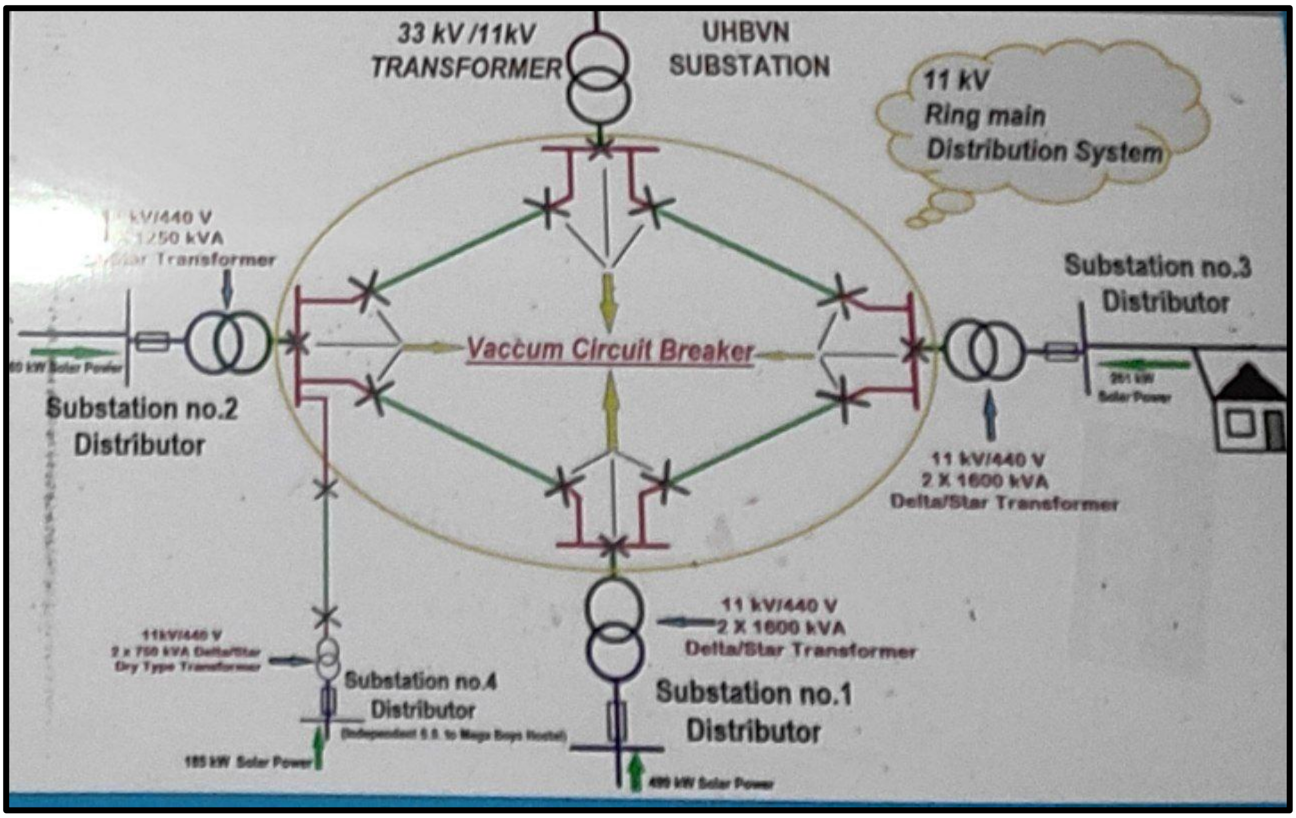
Why OpenDSS ?

- ❖ *Flexibility* : Supports radial, meshed and hybrid networks.
- ❖ *Scriptability* : Python integration for automation and custom analysis.
- ❖ *Cost*-Effective : Free for academic and research purposes.

1.2 NIT Kurukshetra Campus Power Distribution Model

The NIT Kurukshetra campus distribution system is modelled as a **ring structured network** with four substations connected to a central 11 kV main bus. The ring-structured is for increasing fault tolerance and ensure that alternate paths are available in case for an outage. The four key substations are modelled in this project. Each of them has :

a) A pair of transformers for redundancy and load sharing.
b) Dedicated feeders supplying loads like hostel, laboratories, or administrative buildings.



2. NIT KKR RING MAIN DISTRIBUTION SYSTEM ALONG WITH ITS COMPONENTS

The NIT KKR campus distribution scheme is simulated using a ring type network with four substations all connected to one central 11 kV main bus.

2.1 Key Components

A. Main Power Source

The main source is represented as a three-phase 11 kV voltage source located at NITK_MainBus. This emulates the grid supply received by the campus.

- 11 kV, 3-phase AC supply at NITK_MainBus
- Base Voltage : 11 kV(HV Side), 0.44 kV(LV Side)

Purpose : It acts as the sole incoming power source in the simulation. It ensures supply stability for the entire network.

The bus is the backbone of the ring system, from which all four substations derive their input power.

B. Substations & Transformers

- Four Substations(SUB1-SUB4) with dual transformers connected in parallel, which allows redundancy and improves load handling.
- Transformer Specifications :

Substation	kVA Rating	Impedance (Xhl %)	Connection
SUB1	2 * 1600	5.75	Wye – Wye
SUB2	2 * 1250	5.75	Wye – Wye
SUB3	2 * 1600	5.75	Wye – Wye
SUB4	2 * 750	5.75	Wye – Wye

Functional highlights of the transformers:

- Redundancy : Even if one transformer fails, the other continues supply.

- Wye – Wye connection : Simplifies grounding and helps in balance the neutral connections
- Impedance (5.75%) : Introduces realistic voltage drop.
- Step-down function : Transforms the 11 kV HV supply to 0.44 kV for load consumption.

C. Distribution Lines

The substations are tied together with resistive-only cables, having zero reactance. These depict underground or armored overhead cables commonly used in campus settings.

- Resistive Line : R_only (R = 0.02 ohm/km, X = 0)
- Line Lengths : 1 km each

Functional highlights of distribution lines:

- Forms the physical path for power flow across the ring.
- Simulates the voltage drop and losses during transmission.

These resistive-only configuration is valid for short distances.

D. Loads

The load voltage(LV) sides of the substations supply a diverse range of three-phase balanced loads.

- Balanced 3-phase loads at LV sides of substations.
- Load Types : Hostels, labs, canteen, gym, admin blocks.
- Load Data :

Substation	Load	kW	kVAR	Power Factor
SUB1-LV	Hostel-1	80	20	0.97
SUB1-LV	Hostel-2	90	15	0.98
SUB2-LV	Lab-1	120	40	0.95
SUB2-LV	Lab-2	100	35	0.94
SUB3-LV	Canteen	60	25	0.92
SUB3-LV	Gym	50	20	0.93
SUB4-LV	Admin	70	30	0.91
SUB4-LV	Block-C	75	25	0.95

- Balanced loads : Simplifies the simulation of three-phase currents.
- Inductive nature : Indicates the need for reactive power compensation and voltage control.
- Load diversity : Represents various functional areas of the campus :
    - Hostels : residential loads with steady consumption
    - Labs -: heavier and fluctuating load due to equipment
    - Canteen/Gym : medium-scale utility loads
    - Admin : moderate loads with computers, lights, HVAC etc.

These loads are connected in OpenDSS using the load element and are spread out geographically as per GIS mapping of the NIT campus.

2.2 Working principle of the Ring Main System

The Ring Main Unit(RMU) topology is crucial for reliable power supply, especially in institutions like NIT Kurukshetra. The system operates as follows:

i. Under normal conditions, power flows from the main bus to all substations via the shortest paths.

ii. In case of fault between two substations, that section can be isolated, and the power supply continues from the opposite direction in the ring.

iii. This minimizes downtime and ensures that no buildings or buildings or facility loses power during minor faults or maintenance operations.

Advantages over radial system :

- Redundancy : Single point faults do not affect the entire system.
- Load Balancing : Multiple paths allow better voltage control.
- Better Fault isolation : Only the faulty segment is taken offline

2.3 Single Line Diagram

The single line diagram of the NIT Kurukshetra ring main distribution has been designed for the connected loads, transformers and the substations with the main voltage supply at NITK_MainBus node[fig. above at page2]

3. OPENDSS CODE ARCHITECTURE : SYSTEMATIC DESIGN AND IMPLEMENTATION STRATEGY

The OpenDSS script models the NITK campus distribution system as a radial network with four substations, transformers, resistive lines, and loads. The code is structured into logical blocks:

a. Circuit Initialization : defined base parameters and the main source.
b. Substation & Transformers : configure HV-LV transformers.
c. Lines : connect substations with resistive lines.
d. Loads : attach campus facilities to LV buses.

3.1 Circuit Initialization

```
Clear
Set DefaultBaseFrequency=50

// --- Main Source ---
New Circuit.NITK_MainBus BasekV=11 pu=1.0 phases=3 bus1=NITK_MainBus
New Vsource.MainSource bus1=NITK_MainBus basekv=11 pu=1.0 phases=3 frequency=50
```

Circuit.NITK_MainBus :

- Central hub connecting all substations.
- BasekV = 11 : Nominal voltage (11 kV)
- Phases = 3 : 3-phase balanced system

Voltage.MainSource :

- Ideal voltage source representing the grid supply.
- pu = 1.0 : Per unit voltage (1.0 = 100% of base voltage).

3.2 Substations & Transformers

```
New Transformer.SUB3A buses=[SUB3_HV, SUB3_LV] phases=3 windings=2 xhl=5.75
~ kVs=[11,0.44] kVAs=[1600,1600] conns=[wye,wye]

New Transformer.SUB3B buses=[SUB3_HV, SUB3_LV] phases=3 windings=2 xhl=5.75
~ kVs=[11,0.44] kVAs=[1600,1600] conns=[wye,wye]
```

Key Parameters :

- buses : HV(11 kV) and LV(0.44 kV) buses.
- Xhl = 5.75% impedance for loss modelling.
- conns = [wye,wye] : Wye connections on both sides(neutral grounding).

Parallel transformers : SUB1A and SUB1B share load for redundancy and similar for other substations.

3.3 Lines between Substations

```
// --- Resistive LineCode (Only real power flow) ---
New LineCode.R_only nphases=3 baseFreq=50 r1=0.02 x1=0 r0=0.02 x0=0 units=km

// --- Lines Between Substations (1 km each) ---
New Line.SUB1_SUB2 bus1=SUB1_HV bus2=SUB2_HV phases=3 length=1 linecode=R_only
New Line.SUB2_SUB3 bus1=SUB2_HV bus2=SUB3_HV phases=3 length=1 linecode=R_only
New Line.SUB3_SUB4 bus1=SUB3_HV bus2=SUB4_HV phases=3 length=1 linecode=R_only
New Line.SUB4_MAIN bus1=SUB4_HV bus2=NITK_MainBus phases=3 length=1 linecode=R_only
```

3.4 Loads at LV Buses

```
// --- Loads at Transformer LV Sides ---
// SUB1 Loads
New Load.Hostel1 bus1=SUB1_LV phases=3 Conn=wye Model=1 kV=0.44 kW=80 kvar=20
New Load.Hostel2 bus1=SUB1_LV phases=3 Conn=wye Model=1 kV=0.44 kW=90 kvar=15

// SUB2 Loads
New Load.Lab1    bus1=SUB2_LV phases=3 Conn=wye Model=1 kV=0.44 kW=120 kvar=40
New Load.Lab2    bus1=SUB2_LV phases=3 Conn=wye Model=1 kV=0.44 kW=100 kvar=35

// SUB3 Loads
New Load.Canteen bus1=SUB3_LV phases=3 Conn=wye Model=1 kV=0.44 kW=60 kvar=25
New Load.Gym     bus1=SUB3_LV phases=3 Conn=wye Model=1 kV=0.44 kW=50 kvar=20

// SUB4 Loads
New Load.Admin   bus1=SUB4_LV phases=3 Conn=wye Model=1 kV=0.44 kW=70 kvar=30
New Load.BlockC  bus1=SUB4_LV phases=3 Conn=wye Model=1 kV=0.44 kW=75 kvar=25
```

Eight loads are being connected to LV side of the transformer with their active and reactive power demand.

3.5 Bus Coordinates & Visualization

```
// --- Load GIS Coordinates from CSV ---
Buscoords coordinates.csv
```

Bus coordinates (latitude & longitude) are being imported from the csv file.

3.6 Simulation Commands

```
// --- Voltage Base & Solve ---
Set Voltagebases=[11, 0.44]
CalcVoltageBases
Set Tolerance=0.0001
Set Maxiter=100
Solve

// --- Export Analysis Data ---
Export Voltages
Export Currents
Export Powers
Export Losses
```

Tolerance value is 0.0001 - to stop when voltage/power mismatches < 0.01%.

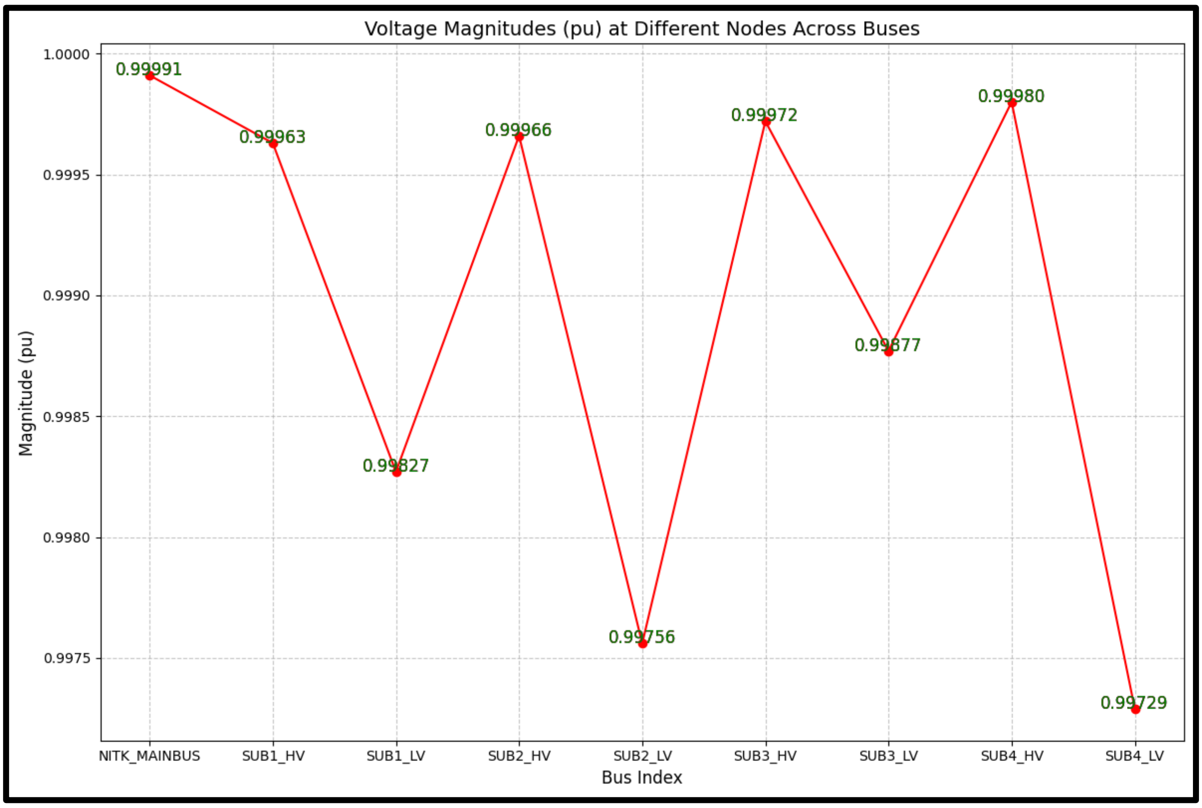
Then it generates the csv files of voltages, currents, active and reactive power, and losses for post processing and analysis using python.

4. ANALYSIS OF OPENDSS CODE OUTPUTS USING PYTHON

4.1 Voltage Analysis

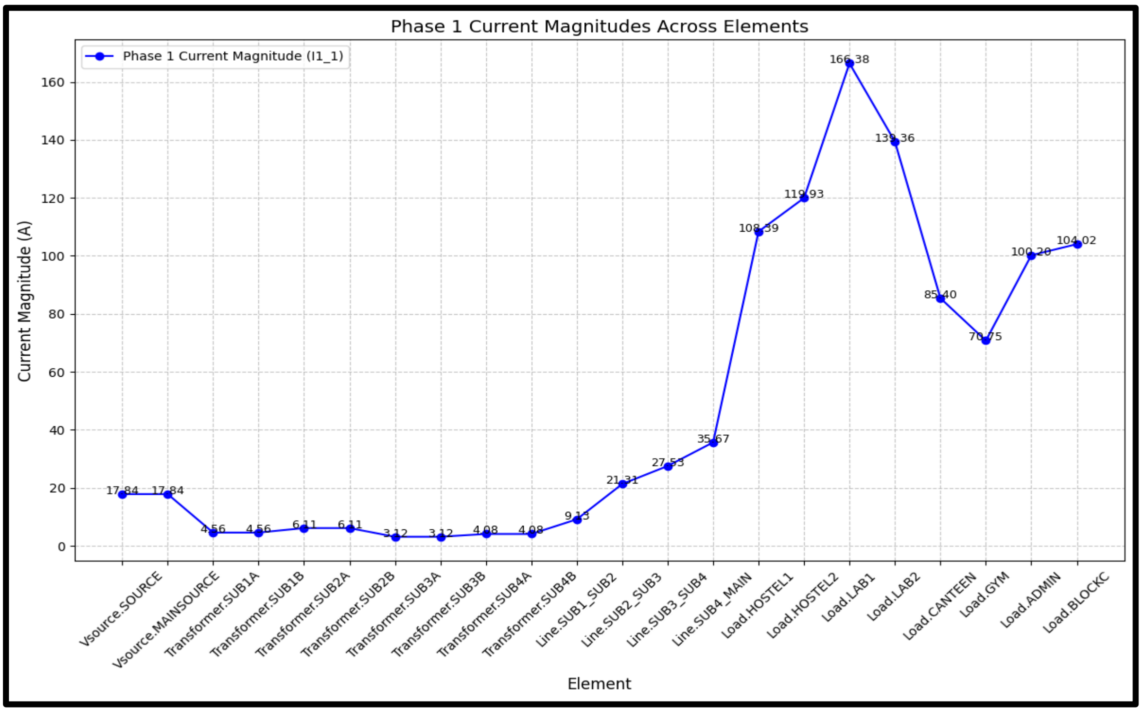
All buses maintain voltage magnitude close to 1.0 pu indicating stable voltage regulation across the network.

NITK_MainBus acts as the reference bus with near-ideal voltage(0.99991 pu).



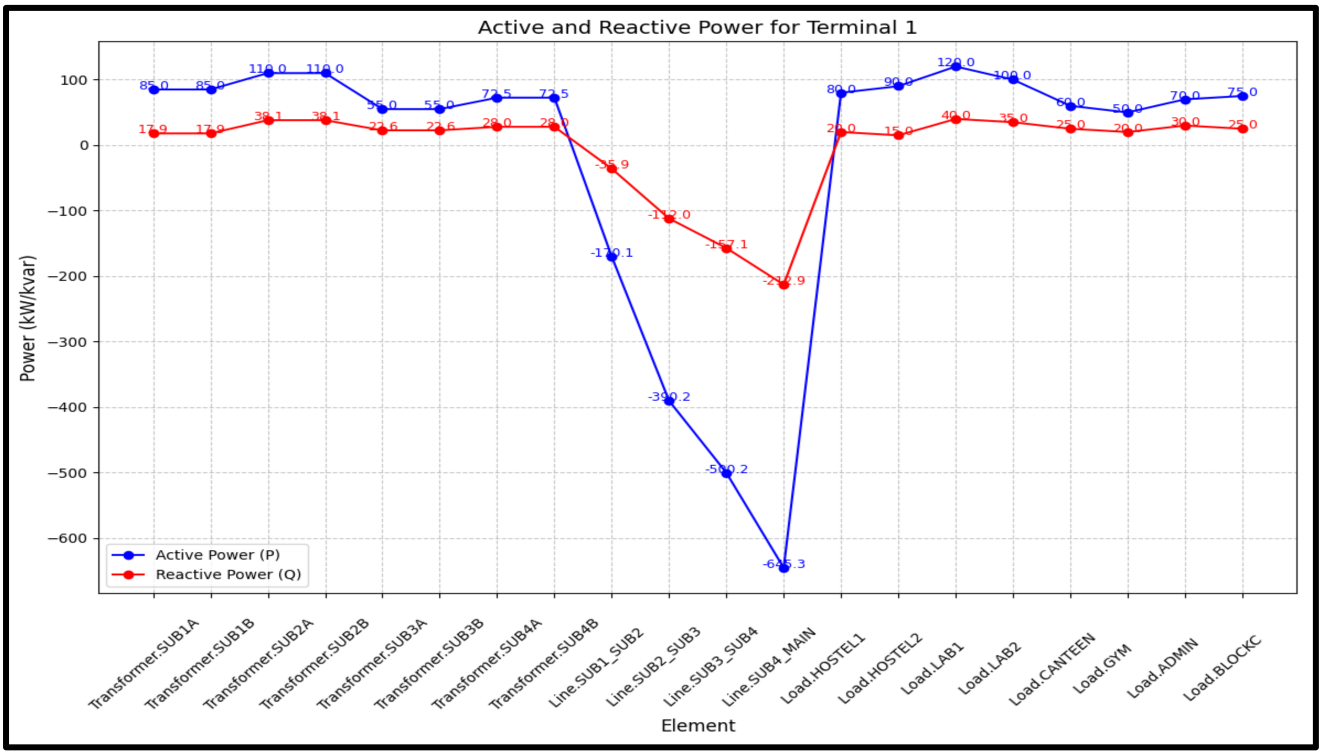
4.2 Current Distribution Analysis

Transformers and transmission lines carry lower currents compared to loads, indicating step-down supply and light initial distribution at each substation stage. Current increases progressively through the line segments, peaking at SUB4 to Main(106.99A), showing major load aggregation. Among all loads, Hostel2(166.38A), Lab1(133.63A) and Hostel1(110.93A) draw the highest currents, highlighting it as the primary power consumers. Administrative and utility areas like Gym(100.29A) and BlockC(104.02A) also exhibit high demand.



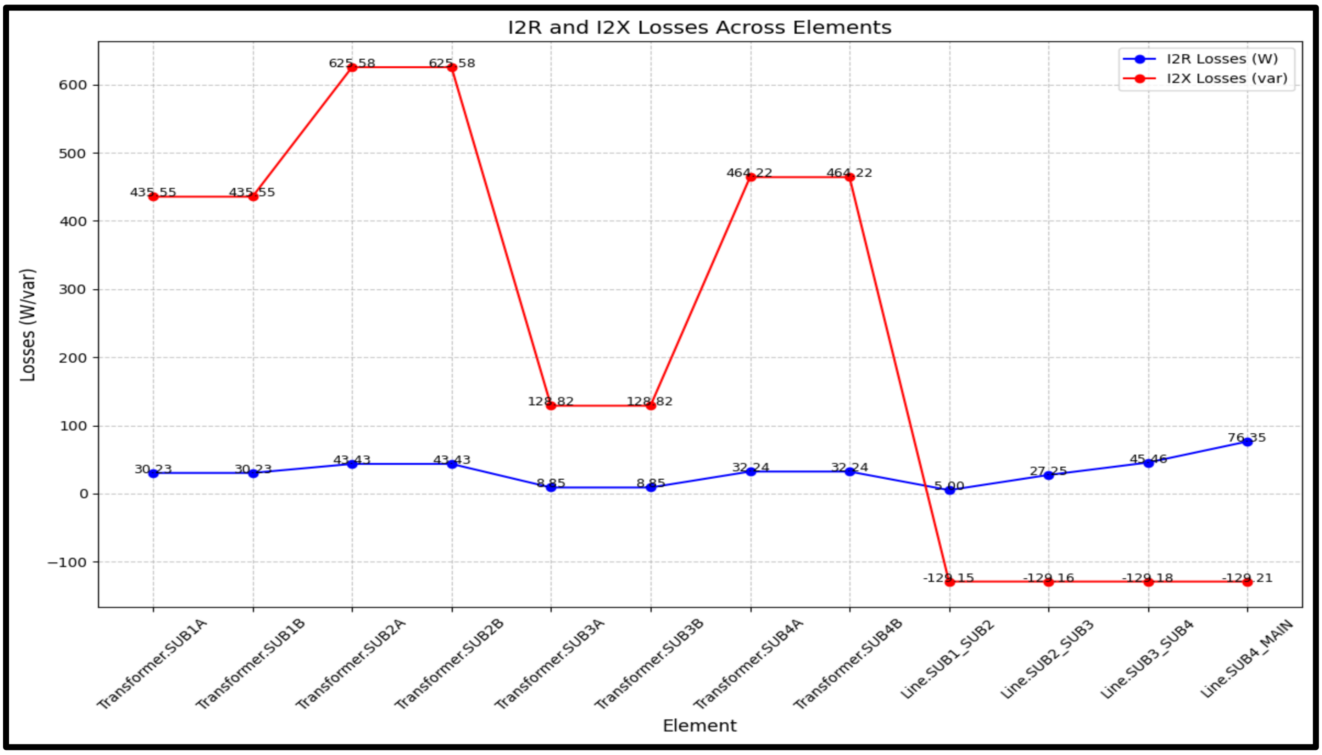
4.3 Active & Reactive Power Flow Analysis

In transformers, active power losses are minimal, indicating high efficiency. Negative P/Q values at Terminal 1signifies power flow direction from source to load. Lab1 and BlockC exhibit high P/Q ratios(~3:1), typical for mixed inductive/resistive loads.



4.4 Loss Analysis

In transformers, I²X (reactive) losses (625.58 var) dominate, stressing the need for capacitor banks.



5. IMPROVEMENTS & FUTURE PERSPECTIVES

5.1 Improvements

While the developed model provides a realistic and functional simulation of the campus distribution network, there are several areas that can be significantly improved to enhance accuracy, performance and efficiency.

A significant limitation of the current model lies in its reliance on presumed or theoretical load values for various types of buildings, including hostels, laboratories, cafeterias, gyms, and administrative blocks. These load values are derived from broad assumptions based on the function of the building, its area, and projected occupancy rates. In reality, load demands fluctuate based on the time of day, seasonal variations, and actual usage patterns. Therefore, it is essential to conduct thorough **load surveys** to gather accurate data on power consumption. The **installation of smart meters** at key load points can facilitate the recording of genuine power usage.

5.2 Future Perspectives

The present model of power flow developed based on OpenDSS and GIS-bundled coordinates is a monumental leap forward to realistic simulation of distribution networks. Yet, it leaves open avenues for further improvements and studies in the future. One of such directions could involve the integration of renewable sources of energy like wind turbines and solar PV. As distributed generation becomes more prevalent on campuses and in urban settings, simulating its effect on voltage profiles, harmonics, and reverse power flows will grow in importance.

The second significant area is the use of real-time data and smart metering infrastructure. Integrating the OpenDSS model with IoT devices and smart meters, it is possible to perform real-time simulations to simulate real load fluctuations, fault conditions, and equipment failure. Integration with SCADA systems will make it possible for dynamic monitoring and control features, transforming the model not only into a planning tool but also a tool for live operating decisions.

Moreover, machine learning algorithms can be employed to forecast peak load demand, fault probabilities, and system inefficiencies using historical and environmental data. This will assist in developing a more intelligent and resilient grid.

CONTENTS

1. INTRODUCTION

Growing need for efficient power distribution and consumption of sustainable energy, and monitoring and analyzing energy consumption has become essential for consumers, energy regulators, and utility providers. Smart meters, which measure energy consumption at regular intervals and send data for monitoring and billing, provide an unprecedented level of detail. Not only do these meters provide hourly or sub-hourly measurements but also advanced analytics and predictive modeling for enhancing energy efficiency.

This project offers a data visualization and analysis dashboard specifically crafted for the processing and interpretation of smart meter data. The ultimate aim is to take raw power usage logs—usually fragmented in multiple Excel spreadsheets and folders—and convert them into a coherent, informative representation that highlights trends in usage over time.

The dashboard is developed with Python and takes advantage of robust libraries like pandas for data manipulation, numpy for numerical computation, and matplotlib for plotting. Fundamentally, the project has a three-stage pipeline:

1. *Data Aggregation & Data Cleaning* – Collects, merges, formats and clean power consumption data from multiple Excel files into a consolidated dataset.
2. *Statistical Analysis* – Calculates descriptive statistics and organizes data temporally (by time of day, day of the week, and month) for deeper insights.
3. *Visualization* – Generates clear and informative charts to communicate energy consumption trends effectively.

Through these phases, the dashboard is able to determine consumption patterns, peak usage times, and seasonal changes, providing an overall energy profile for homes, businesses, or communities.

2. THREE – STAGE PIPELINE

2.1 Data Aggregation & Cleaning

Energy data is often stored across multiple files, especially when collected over long periods or from multiple locations. In this project, smart meter readings were originally provided in Excel (.xlsx) files housed in separate folders. Each folder corresponds to a different meter, property, or unit.

The script automates the process of:

- Navigating through these folders.
- Reading each Excel file.
- Combining files from the same folder into one CSV file.
- Merging all folder-level CSVs into a final, consolidated dataset called all_etaj_merged_data.csv.

Why This Is Important ?

This step is critical for two reasons:

1. *Data Usability* – Combining scattered files into a single source simplifies analysis and makes it possible to apply uniform preprocessing and filtering.
2. *Scalability* – As more data is collected over time, new files can be dropped into the existing folder structure, and the dashboard can regenerate the consolidated dataset automatically.

Using Python's glob module, all .xlsx files in a directory tree are located using pattern matching. The pandas.read_excel() function loads each file into a DataFrame. After cleaning and formatting (e.g., parsing timestamps, renaming columns), the data is appended and saved to disk using DataFrame.to_csv()).

Then after data aggregation and cleaning, descriptive statistics analysis are being done to get the related parameter and results.

Descriptive Statistics

Descriptive statistics are the foundation of any data analysis pipeline. Before diving into patterns or time-based trends, it’s important to understand the central tendencies and variability of the data.

This section of the dashboard computes:

- *Mean* – Indicates the average energy usage.
- *Minimum* – The lowest recorded consumption, which could point to periods of inactivity.
- *Maximum* – The highest recorded usage, potentially linked to heavy appliance use.

2.2 Statistical Analysis

Statistical analysis is being done on the basis of time, weekly and monthly basis. After getting the related graphs and charts, data are being analysed on the basis of result obtained.

2.2.1 Time-Based Analysis

This analysis categorizes each data point into a defined time period of the day, based on the hour in the timestamp:

- Midnight (00:00–04:00)
- Morning (04:00–08:00)
- Afternoon (08:00–16:00)
- Evening (16:00–20:00)
- Night (20:00–00:00)

This is implemented using pandas and conditional logic. For instance, the hour is extracted using pd.to_datetime(df['Timestamp']).dt.hour and mapped to a category.

Results Obtained

- *Minimum Time Analysis* : When during the day is energy usage at its lowest? Typically, early morning or late at night.
- *Maximum Time Analysis :* When does the highest demand occur? This align with evening routines, air conditioning, or heating usage.

By grouping and counting how often minimum and maximum readings occur in each period, the dashboard offers a glimpse into behavioural energy use.

2.2.2 Day-Wise Analysis

The project computes average power consumption for each day of the week using a simple aggregation:

df['Day'] = pd.to_datetime(df['Timestamp']).dt.day_name()

daily_avg = df.groupby('Day')['Power_Consumption_kWh'].mean()

This allows the identification of day-wise trends in energy consumption.

Benefits :

- *Operational Planning :* Businesses can optimize their operating hours.
- *Behavioural Insights :* Detects patterns like increased weekend usage (for residential) or weekday peaks (for commercial).

2.2.3 Month-Wise Analysis

Monthly averages provide insights into:

- Holiday-related spikes.
- Missing data detection, such as months with unusually low readings.

This is computed by extracting the month from the timestamp and grouping accordingly:

df['Month'] = pd.to_datetime(df['Timestamp']).dt.month_name()

monthly_avg = df.groupby('Month')['Power_Consumption_kWh'].mean()

2.3 Visualizations

Visualizations are critical to transforming raw or aggregated data into intuitive, easily understandable insights. In this dashboard, multiple types of visualizations are used to support decision-making by highlighting trends, identifying anomalies, and comparing energy usage across different timeframes. All visualizations are created using Python's matplotlib library, which allows precise control over layout, labeling, and aesthetics.

Below is a detailed breakdown of each type of visualization included in the project:

2.3.1 Descriptive Statistics Visualization

This chart gives users a snapshot of the range and distribution of their energy consumption values. It is typically the first visualization users encounter after data aggregation and helps set a baseline understanding of the data.

The bar chart includes three vertical bars, each representing:

- The mean consumption,
- The minimum consumption, and
- The maximum consumption.

Interpretation :

- Mean: Helps users understand typical daily consumption.
- Minimum: Identifies periods of inactivity or minimal usage.
- Maximum: Often points to periods of intense power draw, which could be a concern for load balancing or high billing rates.

	Mean Power Consumed	Minimum Power Consumed	Maximum Power Consumed
Building 1	6119.964508	92.0	33212.0
Building 2	6040.170555	381.0	31035.0
Building 3	6148.946767	0.0	38756.0
Building 4	6472.204133	0.0	42392.0
Building 5	6373.710451	0.0	42392.0

2.3.2 Time Period Analysis

This is done to understand how consumption patterns change over the course of a day, especially:

- When does energy consumption hit its lowest?
- When does it peak?

The analysis is split into two visualizations:

1. Minimum Consumption Time Period
2. Maximum Consumption Time Period

Minimum Time Period Bar Chart

This chart shows how often the minimum power consumption occurs in each time slot.

Maximum Time Period Bar Chart

Similarly, this chart counts how many times the maximum power consumption occurs during each period:

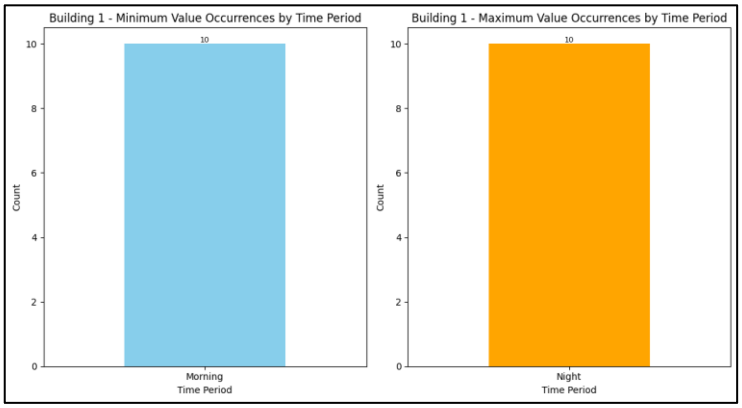
<u>Insights Gained :</u>

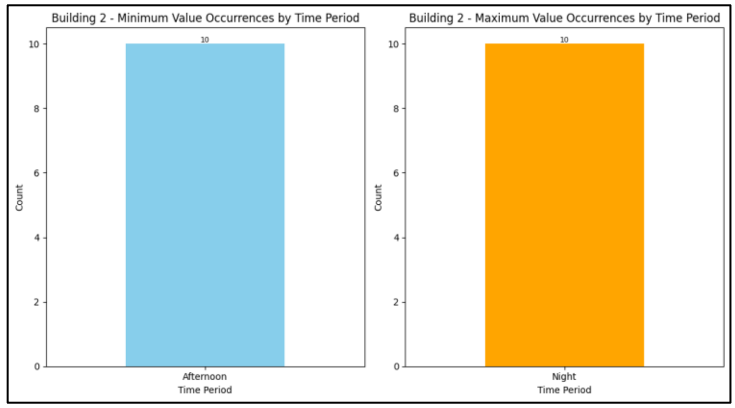
- Minimum consumption happens in the Morning, it indicates that occupants are not yet active (especially in residential settings).
- Maximum consumption consistently in the Midnight period may suggest overnight processes, such as heating/cooling or server operations, depending on the building type.

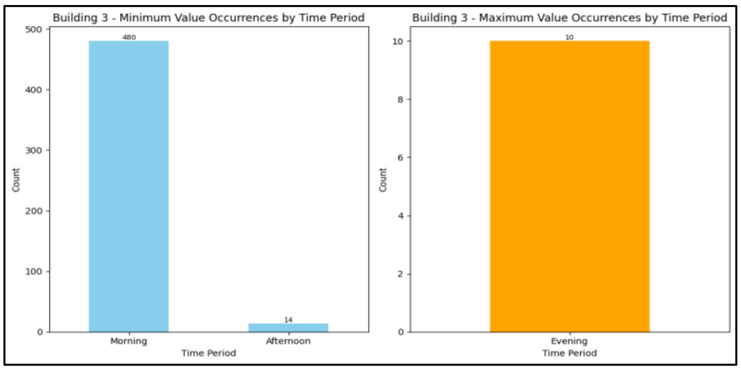
<u>Advanced Consideration :</u>

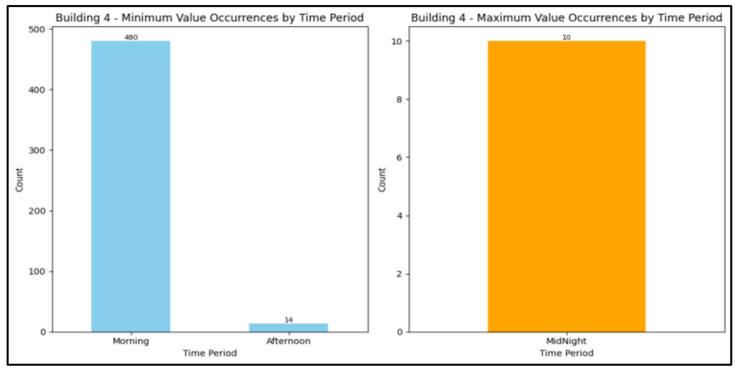
Charts can be enhanced with stacked bars to show differences between weekdays and weekends, or between different properties (if multiple meters are used). This will make the time-based patterns even more actionable.

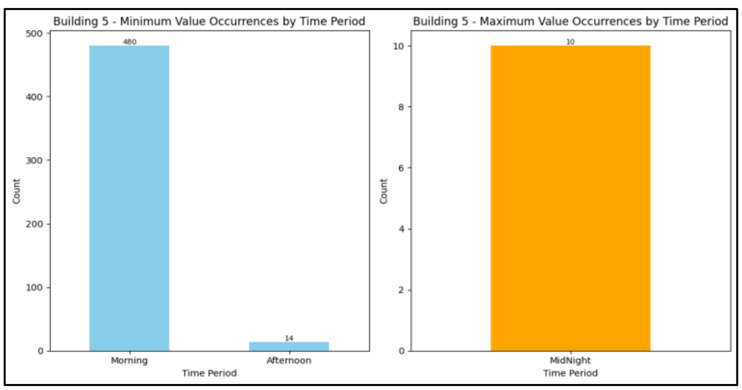
Minimum and Maximum Power consumption occurences for all buildings









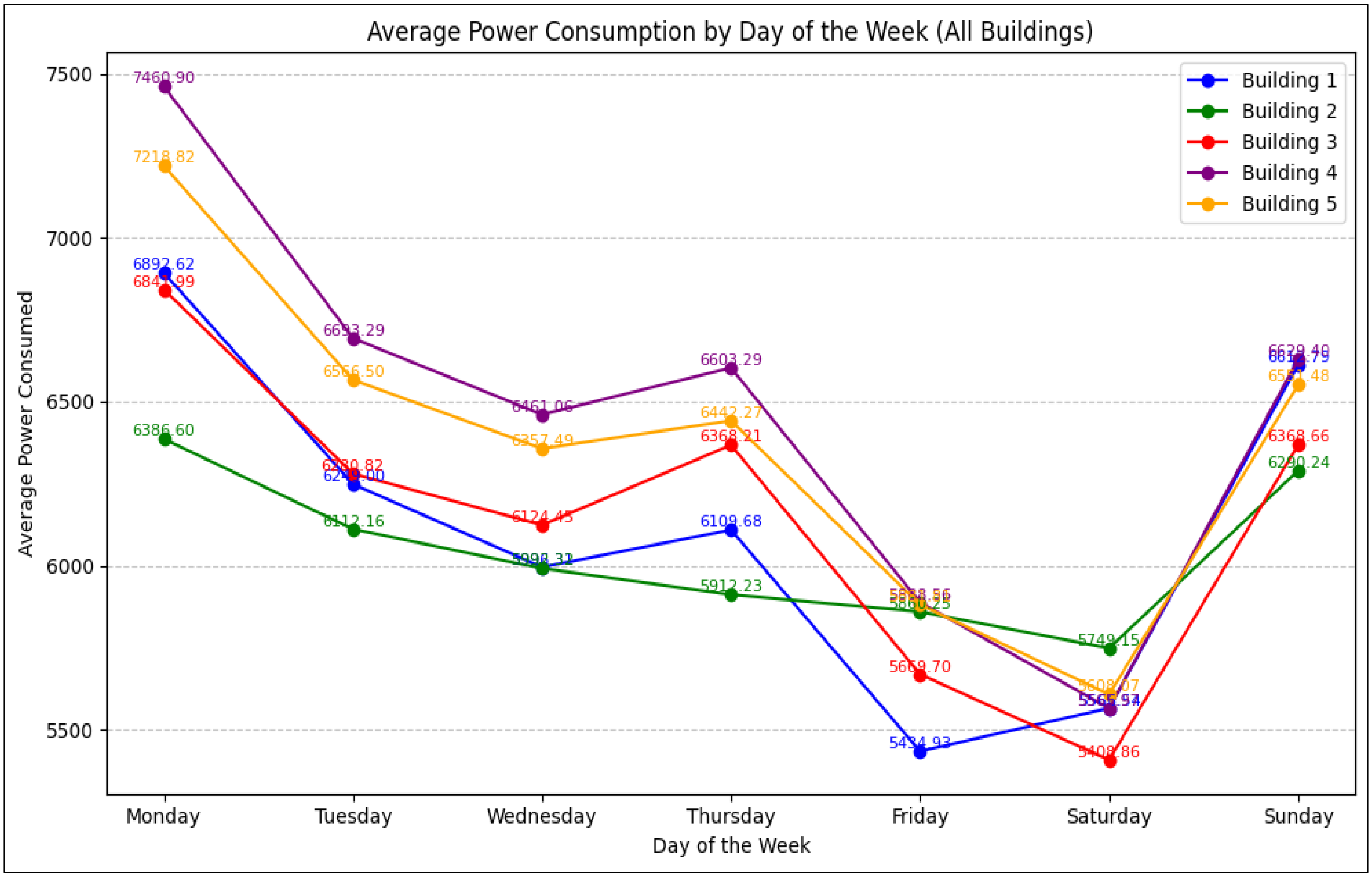


2.3.3 Day-Wise Analysis Visualization

This visualization maps the average power consumption across each day of the week (Monday through Sunday) to detect behavioral or operational cycles.

Analysis and Trends :

- A peak on Monday suggest high usage after a weekend shutdown (especially in industrial settings).
- Lower averages on Saturday and Sunday suggest reduced activity or absence, common in both commercial and residential properties.



By labeling data points and adding a rolling average line, one could track whether certain days consistently show higher usage month-over-month, which may signal a need for behavioral change or automation (e.g., delaying laundry or dishwashing to weekends).

2.3.4 Month-Wise Analysis Visualization

To detect seasonal trends and observe long-term energy patterns across the year.

Interpretation

- <u>Highest Average Power Consumption</u> : The highest average power consumption is observed in January, with a value of approximately 13,255.86 units. This could indicate increased energy usage during the winter season, possibly due to heating requirements.

- <u>Lowest Average Power Consumption</u> : The lowest average power consumption is observed in March, with a value of approximately 3,184.94 units. This reflects reduced energy usage during the transition from winter to spring.

➢ <u>Seasonal Trends</u> : Winter Months (December to February) : Higher power consumption is observed, particularly in January, likely due to heating needs. Summer Months (June to August) : Power consumption increases in August, possibly due to cooling requirements during peak summer.

➢ <u>Missing Data</u> : Data for May and June is missing, which impact the overall analysis and seasonal trends.

<u>Usefulness :</u>

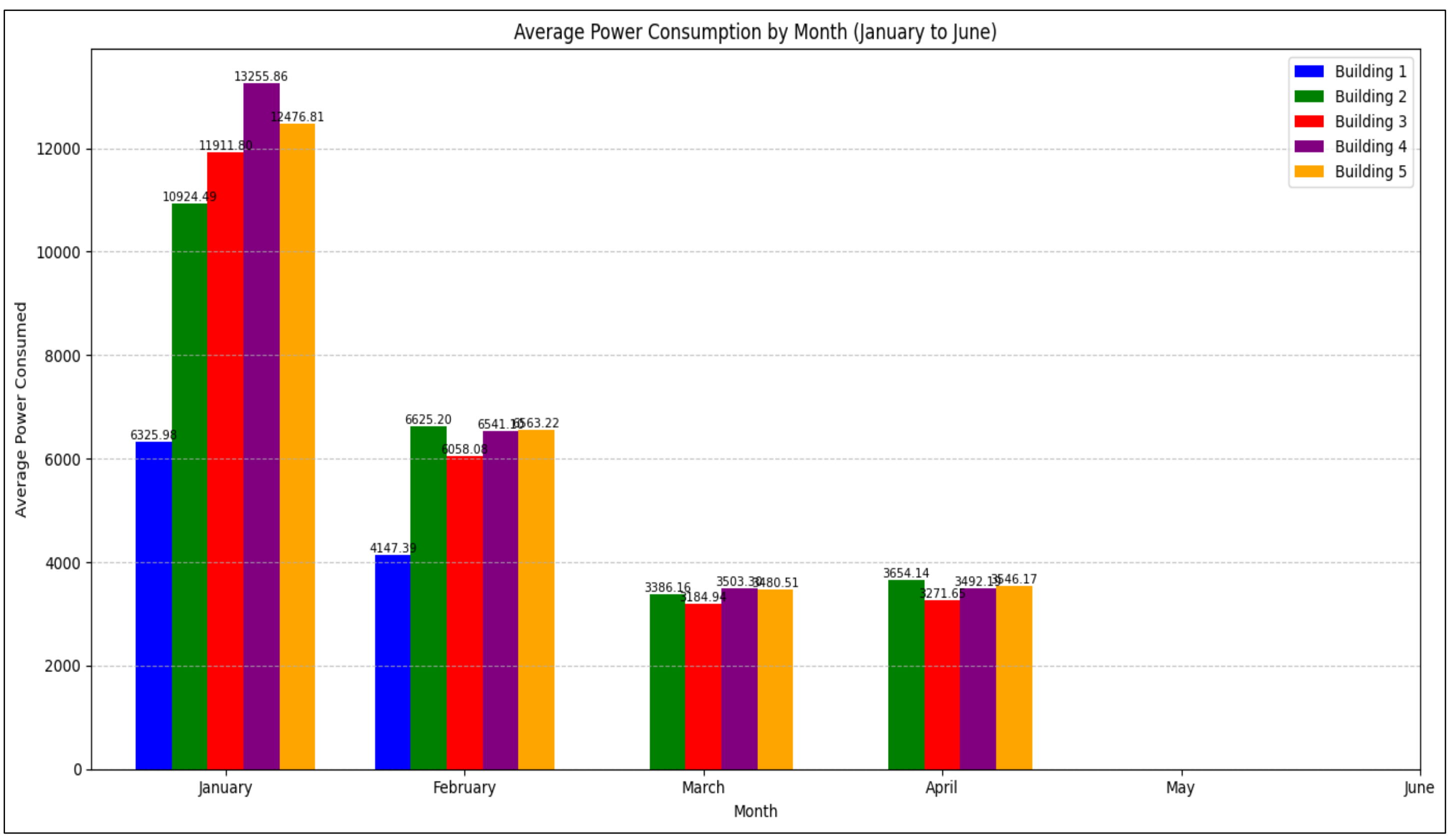
Utility companies could use this to:

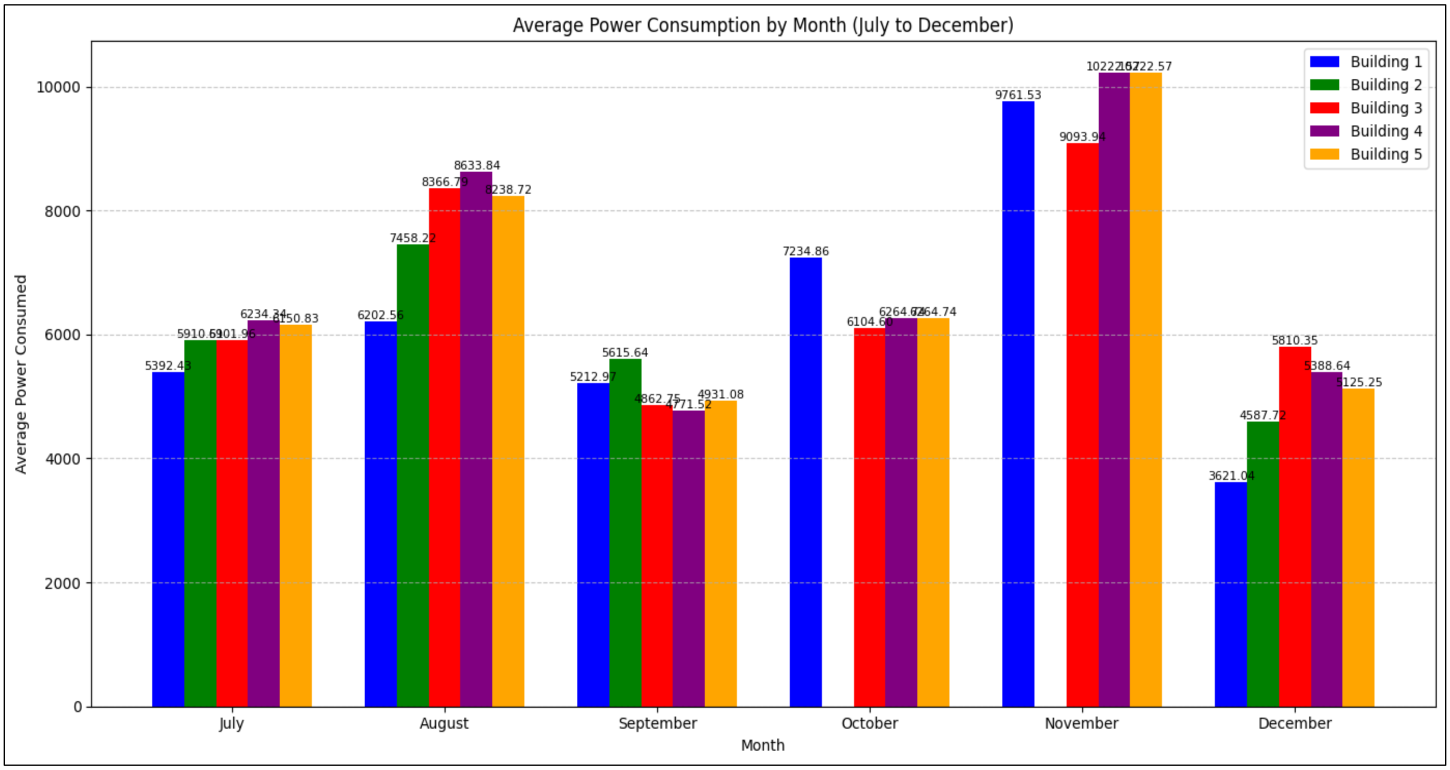
- Plan for peak demand months.
- Develop dynamic pricing strategies.
- Encourage energy savings through targeted awareness campaigns.

<u>Error and Outlier Handling</u>

If a month shows zero or unusually low consumption, it indicates:

- Missing data.
- Sensor or logging errors.





Visualization Best Practices Used :

To make the visualizations effective and interpretable, several best practices were followed:

- Axis Labeling: All charts include clear axis labels and units (kWh).
- Titles and Legends: Each chart has a descriptive title, and legends are used where multiple data series exist.
- Color Coding: Distinct and consistent colors help distinguish between data types (e.g., blue for low values, red for high).
- Gridlines: Light gridlines make it easier to track values across the plot.

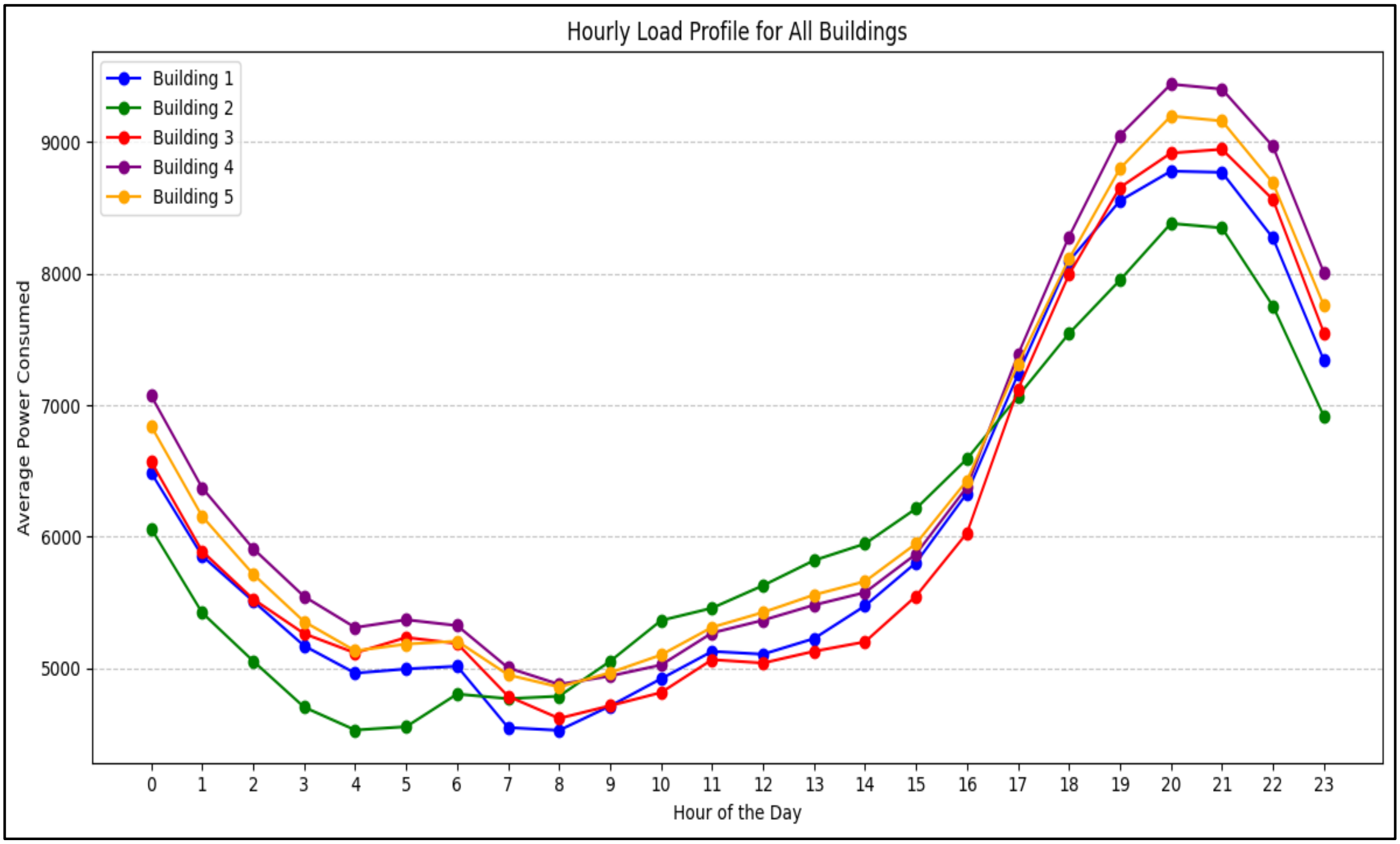
2.3.5 Hourly Load profile of all buildings

The hourly load profile provides insights into the average power consumption across all buildings for each hour of the day. Key observations include:

1. Peak Hours: The highest average power consumption occurs during the evening hours (18:00 - 20:00), indicating increased energy usage during this period.

2. Off-Peak Hours: The lowest average power consumption is observed during the early morning hours (2:00 - 5:00), reflecting reduced activity during these times.

3. Gradual Increase: Power consumption gradually increases from early morning to late evening, likely due to increased human activity and operational demands.



2.3.6 Different Factors associated with each buildings

Several factors are being determined with loads data obtained from the OpenDSS project. These factors are :

- Demand factor : Ratio of Maximum Demand to Connected Load. It indicates how much of the installed capacity is utilized during peak periods. A value closer to **1** signifies efficient use of infrastructure.

- Load Factor : Ratio of Average Load to Maximum Demand. It gives the consistency of energy use over time. A higher value (closer to **1**) implies stable demand, while a lower value indicates high variability.

1. **Labs and Hostels** exhibit low demand factor (0.32–0.42), indicating that only 32–42% of their connected load capacity is used during peak demand. This suggests oversizing of electrical infrastructure or sporadic equipment usage.

2. All **buildings** show very low load factor (0.15–0.19), meaning energy use is highly inconsistent. For example, the Canteen's Load Factor (0.15) highlights intense, short-duration peaks (e.g., meal hours) followed by prolonged low usage.

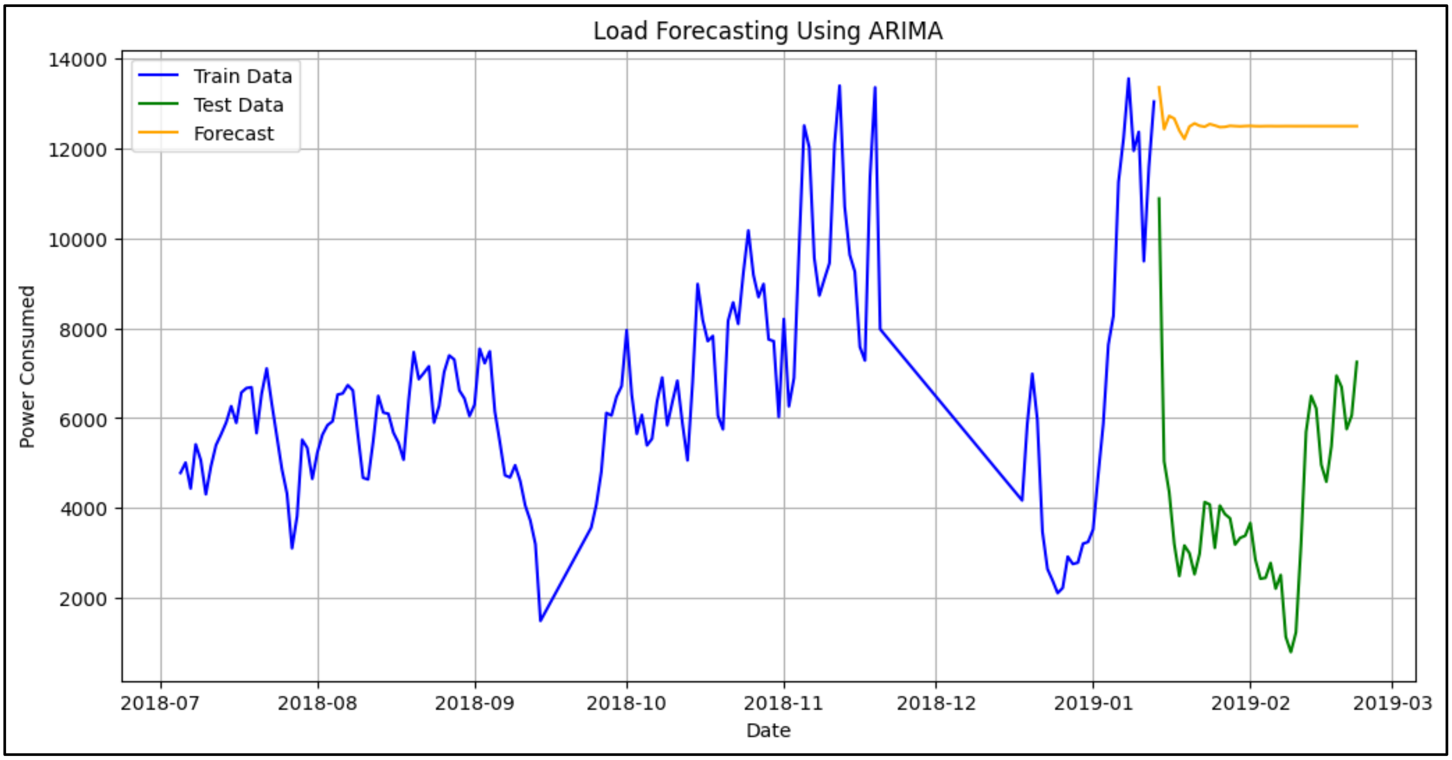
3. The **Canteen** has the highest demand factor (0.71) and a significant max demand (42.39 kW), indicating its role as a critical load during specific intervals. However, its low Load Factor (0.15) implies energy use is concentrated in brief, high-demand periods.

	Connected Load (kW)	Maximum Demand (kW)	Average Load (kW)	Demand Factor	Load Factor
Hostel1	80	33.21	6.12	0.42	0.18
Hostel2	90	31.04	6.04	0.34	0.19
Lab1	120	38.76	6.15	0.32	0.16
Lab2	100	42.39	6.47	0.42	0.15
Canteen	60	42.39	6.37	0.71	0.15

3. LOAD FORECASTING FOR BUILDINGS

To forecast daily power consumption, ARIMA model on resampled time-series data has been applied. The steps included:

- Preprocessing: Converted timestamps to datetime, set as index, and resampled to daily mean power consumption.
- Train-Test Split: Data was split 80/20 for training and testing respectively.
- Modelling: An ARIMA(5,1,0) model was fitted to the training data to capture autoregressive patterns and trends.
- Forecasting: Predictions were made over the test period and plotted alongside actual values for visual comparison.
- Evaluation: The model achieved a Mean Absolute Error (MAE) of {insert MAE here}, indicating reasonable predictive accuracy.



4. IMPROVEMENTS & FUTURE PERSPECTIVES

In order to further enrich energy analysis in depth and accuracy, future studies shall include reactive power measurement along with active power. Although the current dashboard targets only active (real) energy use, adding reactive power will facilitate the calculation of power factor, a vital performance metric for examining energy use efficiency. A low power factor suggests inefficient use of electrical power, resulting in increased losses and possible penalties from utilities, particularly in commercial and industrial applications. Through the examination of real and reactive power, we can more effectively evaluate electrical system performance, size equipment more precisely, and apply corrective actions such as capacitor banks to enhance power factor and minimize energy expenses.

Another major enhancement would be to have more precise and categorized load data for every building or unit. In this project, the loads are estimated based on assumed or generalized values, which can be far from actual usage patterns. A better way would be on-site energy audits or integration with building management systems (BMS) to collect detailed information about devices connected, their usage schedules, and peak demand profiles. This would allow for load-specific modelling, wherein lighting and HVAC loads, lab equipment, and other loads are separately analysed, thus enhancing the precision in demand forecasting, load flow analysis, and energy optimization planning.

CONCLUSION

The project successfully demonstrates the modeling and analysis of the electrical distribution network of NIT Kurukshetra using OpenDSS in conjunction with real-time smart meter analytics. Through a combination of simulation and data-driven approaches, the project evaluated voltage profiles, current distributions, power flows, and system losses with considerable precision. The implementation of OpenDSS enabled a scalable and adaptable framework for studying the network under varied scenarios, while Python-based visualization provided valuable insights into load behaviors and energy consumption patterns across the campus.

Furthermore, the integration of smart meter data enhanced the fidelity of simulations and supported the development of a comprehensive analytics dashboard. Load forecasting using ARIMA, hourly load profiling, and building-wise analysis underscored the effectiveness of statistical and machine learning techniques in energy planning.

This work lays a strong foundation for future enhancements like integrating renewable energy sources, incorporating reactive power metrics, and enabling live system monitoring using IoT and SCADA systems. It signifies a progressive step toward intelligent campus energy management and contributes to the broader vision of sustainable, data-driven smart grid technologies.

REFERENCES

1. Electric Power Research Institute (EPRI). OpenDSS Manual. https://sourceforge.net/projects/electricdss
2. Saadat, Hadi. Power System Analysis, McGraw-Hill Education, 2nd Edition, 2002.
3. Kundur, Prabha. Power System Stability and Control. McGraw-Hill, 1994.
4. Rafi, J.A. & Kothari, D.P. Power System Analysis, Pearson Education India, 2010.
5. Python Software Foundation. Python 3.10 Documentation. https://docs.python.org/3/
6. McKinney, Wes. Python for Data Analysis. O'Reilly Media, 2nd Edition, 2017.
7. IEEE Std 1547-2018. IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.
8. Glover, J.D., Sarma, M.S., Overbye, T.J. Power System Analysis and Design. Cengage Learning, 6th Edition, 2017.