Capacity Enhancement Planning of Renewable Energy in the State of Goa



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1.0 Introduction & Background of the Study



The State of Goa in July 2023 published its Clean Energy Roadmap 2050 (CER).

The State of Goa in July 2023 published its Clean Energy Roadmap 2050 (CER) [1]. The document describes various sectoral activities to be undertaken to achieve the net-zero emissions status by 2050, along with a 100% RE-based energy supply state. Among all sectors, electricity plays an important role in driving many different energy sectors as their functional input. Further, to facilitate the integration of renewable energy resources, it is necessary to solve the issues with high energy consumption and demand, along with the renewable potentials present by location and renewable energy integration in the existing power system network [2]. There is significant room for expansion with a current installed solar capacity of approximately 30 MW and a potential of over 1.2 GW from rooftop, ground-mounted, and floating solar sources. Without systems analysis, it is thus difficult to arrive at an optimal mix condition that can provide the least cost power supply condition while meeting various demand profiles.

Therefore, this project aims to analyze the state's power distribution network for RE capacity enhancement and further develop new RE policies. This report explores scenarios for integrating renewable energy (RE) into Goa's power network, identifying challenges, opportunities, and necessary interventions for successful adaptation.

With growing awareness of creating a cleaner and greener world, there has been a global policy trend towards setting net-zero targets in recent years [3]. India, like other countries, is also committed to achieving net-zero objectives within a set period [4]. Based on a variety of factors, such as energy accessibility, energy demand, local energy sources, infrastructure, legal frameworks, and socioeconomic conditions, the net-zero goals can be attained [5]. Currently, every Indian state is keen to adopt and put into practice various planning and management strategies. However, states with a higher population or energy-intensive industries may require tailored strategies to manage the energy transition while ensuring social equity and economic growth.

Goa is a state on the south-western coast of India, and has a fast-growing economy due to its large tourism industry. Goa has a population of 1.459 million residents, with the highest proportion of urban population, at 62.17% [6]. Goa's electricity demand is

primarily met through conventional energy sources such as coal, natural gas, and imported electricity [7].

Furthermore, efforts towards achieving the net-zero targets have already begun in some Indian states. Karnataka has been a frontrunner in renewable energy adoption. The state has a comprehensive solar policy aimed at promoting solar energy generation. It offers incentives such as subsidies, tax exemptions, and power purchase agreements (PPAs) to encourage solar power projects [8]. Gujarat has been a leader in solar power generation with its abundant sunlight. The state has implemented various policies and initiatives to promote solar energy, including subsidies, net metering, and incentives for rooftop solar installations [9]. Tamil Nadu has a significant focus on wind energy and has one of India's largest installed wind power capacities. The state offers incentives such as favorable tariffs and tax benefits to attract investment in wind energy projects [10]. Maharashtra has set ambitious renewable energy targets and aims to increase the share of renewable energy in its total energy mix. c [11]. Rajasthan has vast solar potential and has implemented various policies to harness this resource. To incentivize investment in solar generating installations, the state provides favorable tariffs, subsidies, and land distribution [12].

Andhra Pradesh has a strong focus on both solar and wind energy. The state offers incentives such as subsidies, tax exemptions, and land allotment for renewable energy projects. It also promotes the development of solar parks to attract investment [13]. Madhya Pradesh has set ambitious targets for the addition of renewable energy capacity. Incentives for solar and wind energy projects, including subsidies, tax exemptions, and land allocation [14] were made by the state. Uttar Pradesh has been focusing on solar energy development and aims to increase its solar power capacity. To encourage the production of solar energy, the state provides subsidies, tax breaks, and net metering facilities [15]. However, Goa has made some progress in renewable energy adoption, with a relatively low contribution in overall energy mix in compared to conventional sources. Challenges to renewable energy deployment in Goa includes land availability for large-scale solar or wind projects, intermittency of renewable energy sources, grid integration issues, and policy and regulatory barriers. Goa is subject to RPO (renewable purchase obligation) mandates set by the central government [16]. In the month of Oct. 2023. Govt. of India also notified revised RPO targets until 2030 which goes up to 43.3% from 29.9% as of now [17]. Different renewable energy sources will play a significant role in the RPO obligation fulfilment.

RPOs require electricity distribution companies (DISCOMs) and large consumers of electricity to procure a certain percentage of their power from renewable sources. Goa's Electricity Dept. may enter into PPAs power purchase agreements (PPA) with renewable energy developers for the purchase of electricity generated from renewable sources. The state likely adheres to environmental regulations and standards set by the central government

and state pollution control boards [18]. These regulations may include emissions standards for power plants, guidelines for environmental impact assessments of energy projects, and measures to mitigate environmental pollution. The government of Goa thus need to launch specific initiatives and schemes to promote renewable energy adoption, attract investment in the sector, and support the development of renewable energy infrastructure.

In order to address the challenges following the energy policies a comprehensive assessment of Goa's current energy profile, including sources of energy generation, consumption patterns, and existing infrastructure is required. Upgrade and modernize the electricity grid to accommodate increasing levels of renewable energy generation can further be decided. This may include investments in grid infrastructure, energy storage systems, smart grid technologies, and demand-side management programs to enhance RE penetration along with grid stability and reliability.

Power system modelling is a potential solution to enhance renewable energy accessibility and optimize the power generation at a minimum cost. It plays a crucial role by ensuring energy through resource planning, optimizing energy mix, infrastructure planning, policy formulation and economic analysis.



2.0 Rationale and Objectives of this study



Several sector-specific initiatives must be carried out in order to reach 100% renewable energy supply and net zero emissions by 2050.

The Clean Energy Roadmap 2050 (CER), which was released by the Goa of Goa in July 2023, outlines the several sector-specific initiatives that must be carried out in order to reach 100% renewable energy supply and net zero emissions by 2050. CER identified in a broad way the overall requirement of RE capacity addition and supply of power required in the State to make it 100% RE based by 2050. However, three major recommendations of the CER (Table 4 of the CER page-26) were to assess the technical means to utilize the full RE potential of the state while ensuring grid stability and system integration. The CER also highlighted the importance of planning of strengthening transmission and distribution network in the State to uptake RE. Further to understand the network augmentation required for absorbing higher RE supply a proper operational analysis of electrical power system along with RE potential assessment will be essential.

Thus, the major objectives of the project are to analyze the power distribution network of the State and conducting power system analysis for RE integration and augmentation in the State of Goa to enhance the overall share of RE in total electricity consumption to achieve the overall target of 100% RE share by 2050.

While implementing the CER, Goa also needs to pay attention towards faster identification of the location of the RE capacity addition and its use. As renewable energy potential is location specific, capacity addition requires such information with further details of network infrastructure in the area for seamless augmentation of RE in the network. One of the major objectives of this study is also to identify the location specific RE capacity addition potential in the State of Goa which will provide ample benefits to the concerned departments to identify and plan for RE capacity enhancement with immense granularity upto the distribution feeder level.

3.0 RE potential of Goa



Geographic Information System (GIS) mapping is leveraged and other tools are utilized to identify solar, wind, biomass, and tidal resources.

This section focuses on a comprehensive evaluation of the renewable energy (RE) potential in Goa. It leverages Geographic Information System (GIS) mapping and other tools to identify solar, wind, biomass, and tidal resources. This analysis sets the groundwork for scaling renewable capacity in the state and identify the location specific capacity addition plans.

3.1: Solar

The Solar Potential is calculated in terms of the following types, including Diffuse Horizontal Irradiation (DHI), Direct Normal Irradiation (DNI), and Global Horizontal Irradiation (GHI).

Diffuse Horizontal Irradiation

Diffuse horizontal irradiation refers to the solar radiation received from the sky

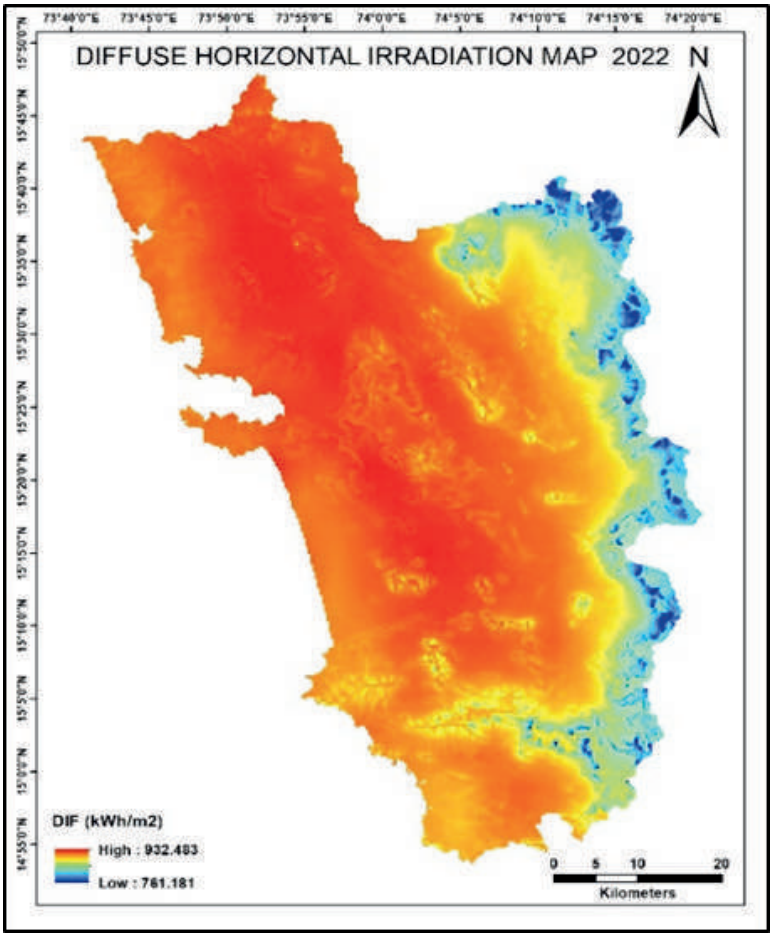


Figure 1: Diffuse horizontal irradiation map of Goa for the year 2022.

dome on a horizontal surface. Unlike direct normal irradiation, which comes directly from the sun, DHI is scattered and reflected by the atmosphere and clouds before reaching the Earth's surface. It includes both the diffuse radiation scattered by the atmosphere and the diffuse radiation reflected from the ground and surrounding surfaces. DHI is an important parameter in solar energy applications, especially in the design and performance evaluation of solar energy systems such as photovoltaic (PV) panels and solar thermal collectors. It influences these systems' overall energy production potential, as they can utilize both direct and diffuse sunlight to generate electricity or heat. Fig. 1 represents the diffuse horizontal irradiation map of Goa. The diffuse horizontal irradiation map ranges from 761. 18 (Lowest) to 932.48 (Highest) in kilowatt per hour per square meter as shown in Fig. 1.

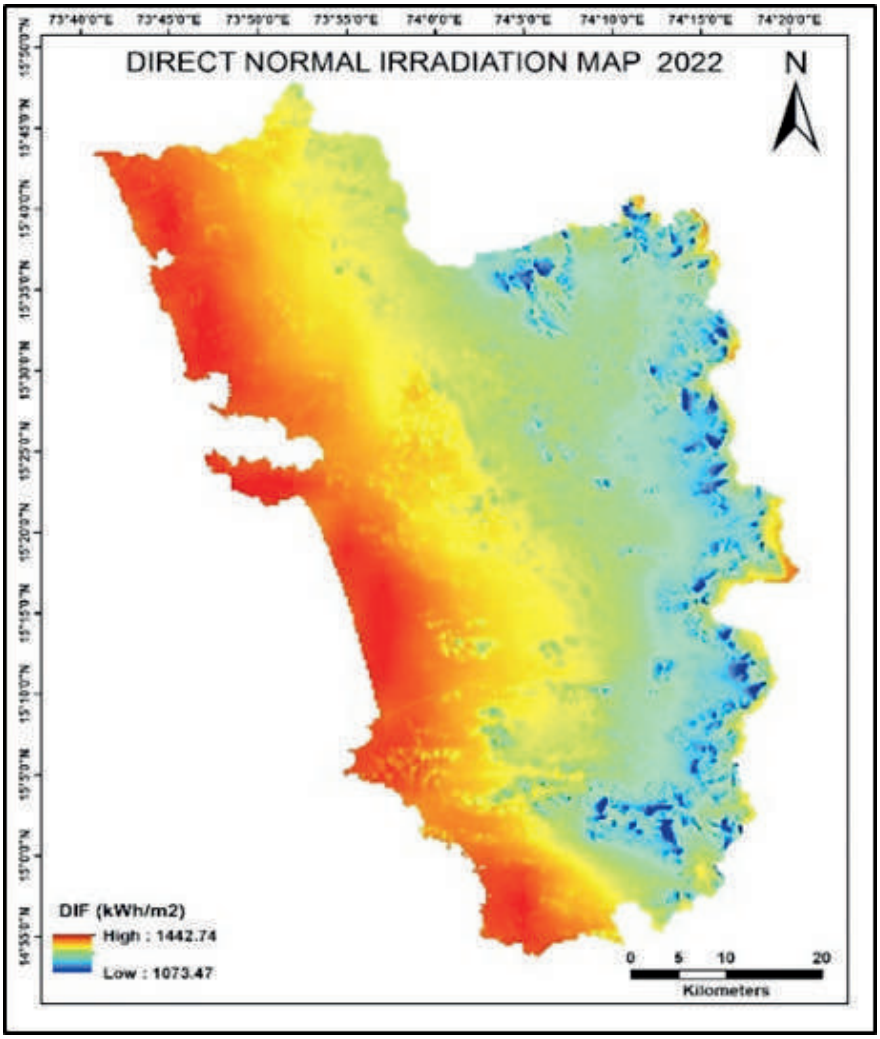


Figure 2: Diffuse horizontal irradiation map of Goa for the year 2022.

Direct Normal Irradiation

Direct normal irradiation refers to the solar radiation received from the direction of the sun on a surface that is perpendicular to the sun's rays. Unlike diffuse horizontal irradiation (DHI), which includes scattered and reflected sunlight, DNI specifically measures the direct solar radiation that reaches a surface without being scattered by the atmosphere or affected by shading. DNI is a key parameter in solar energy applications, particularly in concentrating solar power (CSP) systems and

and concentrating photovoltaic (CPV) systems, where mirrors or lenses are used to focus sunlight onto a small area to generate electricity or heat. Since DNI represents the intensity of sunlight directly from the sun, it is crucial for accurately predicting the performance and output of these systems. The direct normal irradiation map ranges from 1073.47 (Lowest) to 1442.74 (Highest) in kilowatt per hour per meter square as shown in Fig. 2.

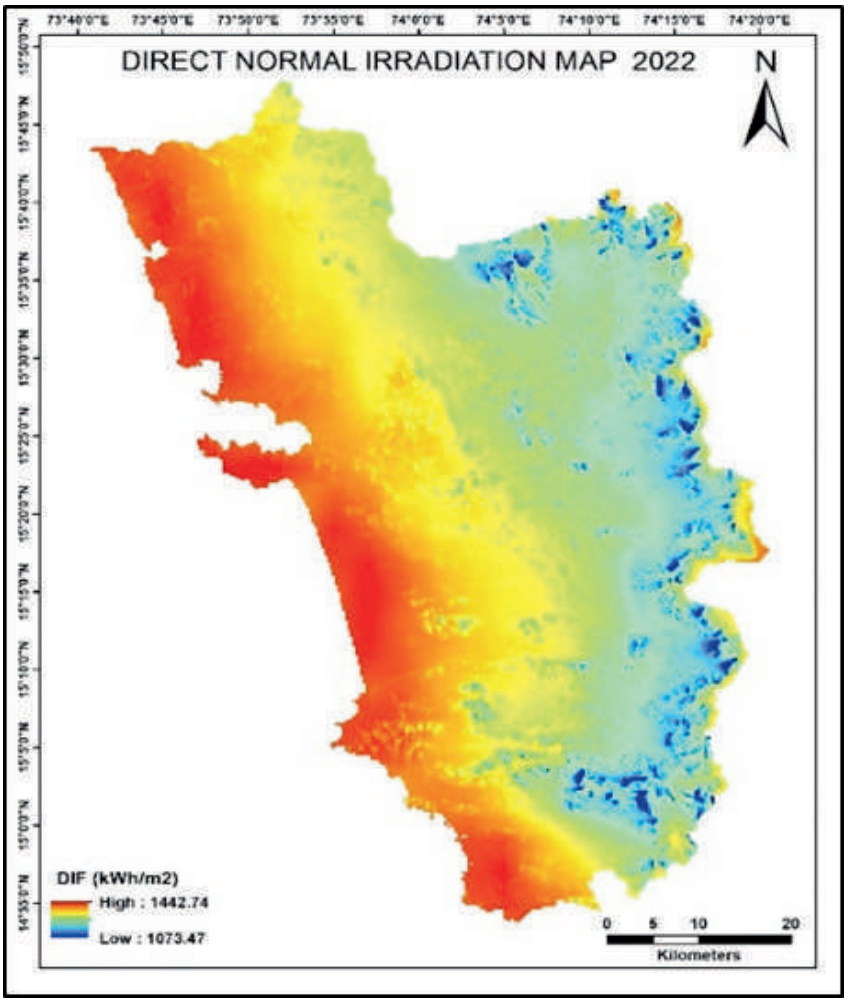


Figure 3: Diffuse horizontal irradiation map of Goa for the year 2022.

Global Horizontal Irradiation

Global horizontal irradiation (GHI) refers to the total solar radiation received from above by a horizontal surface. It includes both the direct component of solar radiation coming directly from the sun, as well as the diffuse component, which is scattered and reflected by the atmosphere and clouds before reaching the Earth's surface. Mathematically, it is the sum of the direct normal irradiance and the diffuse horizontal irradiance. GHI is an important parameter in solar energy applications, as it represents the total solar energy available at a specific location. It is used in the design, planning, and performance evaluation of solar energy systems such as photovoltaic panels, solar thermal collectors, and concentrating solar power (CSP) systems. Fig. 3 illustrates the global horizontal irradiation map of Goa. The diffuse horizontal irradiation map ranges from 1607.83 (Lowest) to 1961.39 (Highest) in kilowatt per hour per square meter as shown in Fig. 3.

Total Solar Photovoltaic (PV) Potential

Solar photovoltaic power potential refers to the amount of electricity that can be generated from solar energy using photovoltaic panels. It depends on various factors including the available solar irradiation, the efficiency of the PV panels, the tilt and orientation of the panels, shading, temperature, and system losses. To estimate the PV power potential of a specific location, various tools and methods are used. Solar irradiation data, such as global horizontal irradiation, direct normal irradiation, and diffuse horizontal irradiation, are typically used as inputs. These data, combined with information about the PV system configuration and performance characteristics, can be used to model the expected electricity generation over time. The solar PV potential of Goa ranges from 1430.68 to 162.71 in the unit of kWh/kWp as shown in Fig. 4.

The potential of solar PV can be broadly discussed as the potential of rooftop solar, ground-mounted solar, floating solar, etc.

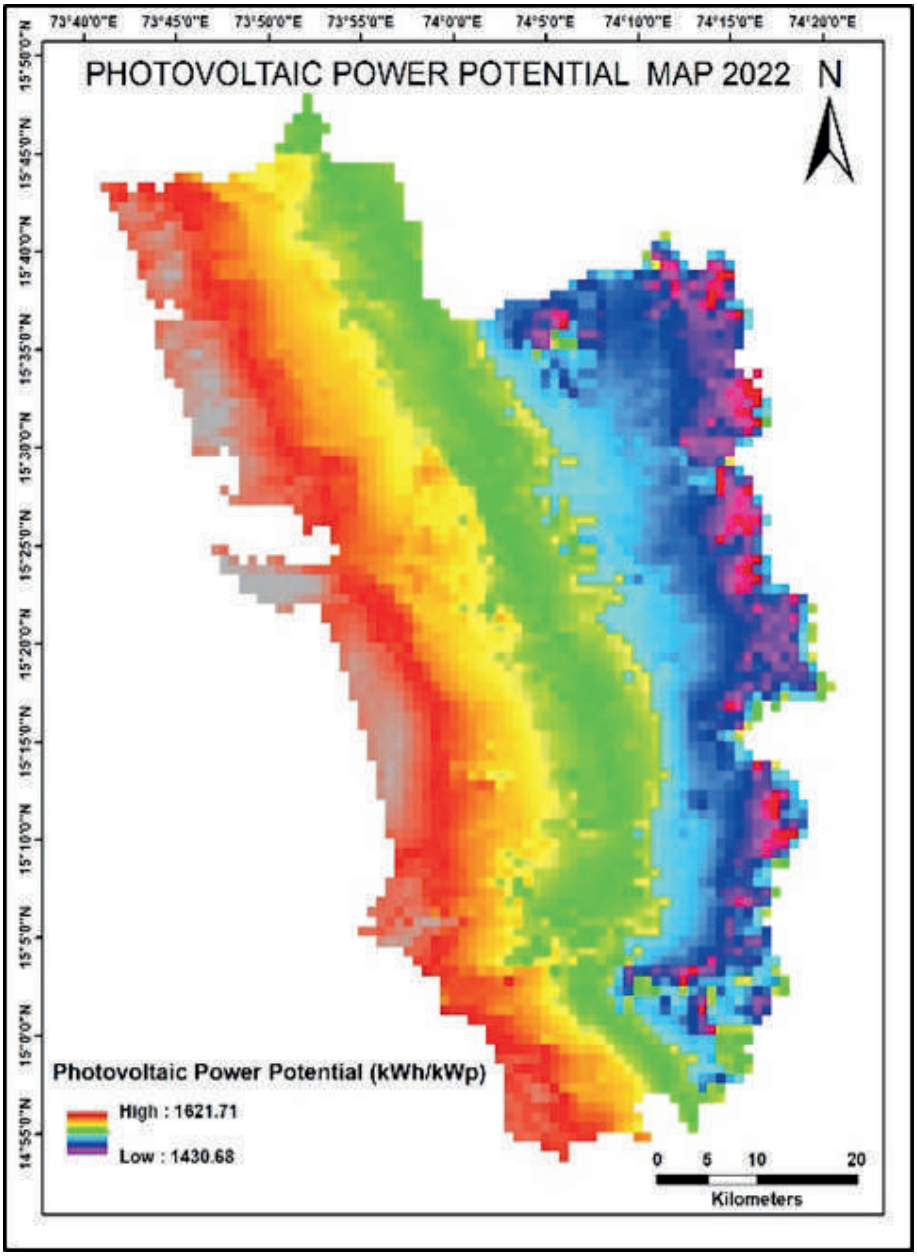


Figure 4: Solar PV potential map of Goa for the year 2022.

a) Rooftop Solar Potential: In addition to ground-mounted solar installations, Goa possesses significant rooftop solar potential. This potential was assessed through GIS-based building footprint data, roof orientation, slope analysis, and shading effects. Urban areas, where energy demand is concentrated, show the greatest promise for rooftop solar installations, particularly in commercial and industrial sectors. Goa's high urbanization rate makes rooftop solar an attractive option to enhance decentralized energy generation and improve energy security at a local level. Given the total potential of 1.9 GW, 450 MW can be installed by 2030. In our subsequent analysis we will identify the location for installing this solar power.

b) Ground-Mounted Solar Potential: Goa has an estimated ground-mounted solar potential of around 880 MW. This figure was derived by analyzing factors such as solar radiation levels, land availability, and technical feasibility. The assessment utilized GIS mapping to identify large tracts of land with optimal solar irradiance, minimal shading, and suitable slopes. Areas identified for potential solar development were cross-referenced with existing land-use data to ensure environmental and agricultural regulations compatibility.

c) Floating Solar Potential: The initial potential of floating solar of around 120 MW is calculated based on identified major water bodies in the state of Goa, such as lakes, dams, rivers, etc. The floating solar potentials in kWh against each major lake of the state of Goa are depicted in Tabular format in Table 1. Moreover, these identified lakes are shown in the picture along with their respective coordinates.

Table 1: Floating Solar Potential for Major Lakes of the State of Goa

Photovoltic Power Potential PPP (kWh/kWp)	
Cambolim lake	1580.44
Anjunem lake	1499.92
Moisai Dam	1551.22
Salaulim	1532.41
Cahapoli	1585.68
Amtonem	1556.14
Batim lake	1596.87
Sukanya lake	1567.29
Sarzora lake	1591.39
Banastari Wetlands	1568.38
Mayem lake	1562.91

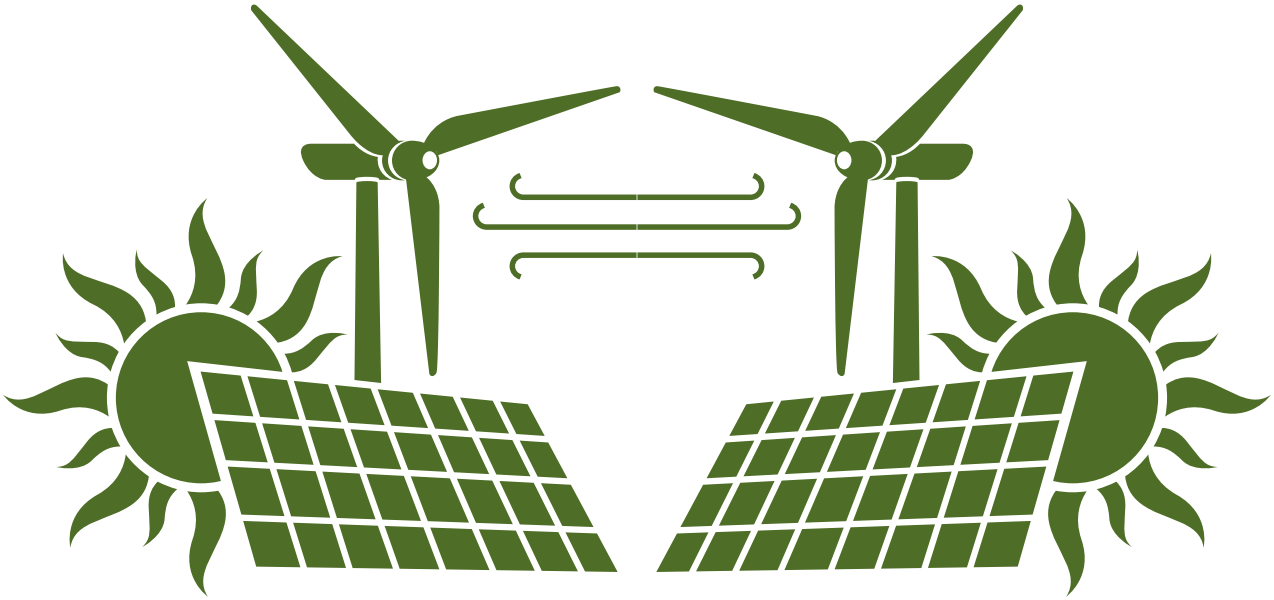
Goa's total solar energy potential could reach up to 3 GW by 2050 when considering both ground-mounted, floating solar, and rooftop options. Optimal regions for solar deployment include the coastal plains for ground-mounted systems and urban centers for rooftop installations. Solar energy can play a pivotal role in meeting Goa's Renewable Purchase Obligations (RPO), particularly in achieving the target by 2030.

3.2: Biomass

Goa's biomass energy potential of around 200 MW is identified, including the use of agricultural residues, forest residues, and organic waste. The biomass potential assessment was conducted through auxiliary data from the MNRE and other state resources, identifying potential biomass sources. Biomass could offer smaller-scale energy solutions, particularly for rural areas and agricultural sectors.

3.3: Wind

Wind energy potential of 100 MW in Goa is still under assessment and represents a complex challenge due to the state's geography and topography. Initial data suggests that wind energy deployment in Goa will require detailed meteorological studies to identify high-wind zones. Wind density data, terrain analysis, and local meteorological records will be integrated into GIS models to create a more comprehensive picture of the state's wind energy viability. The comprehensive use of GIS mapping tools has proven crucial in identifying the best locations for renewable energy installations. The GIS maps have provided spatial data on RE potential for solar, wind, and biomass, helping to develop location-specific strategies for integrating RE into Goa's power grid. These maps will be used to plan future installations and estimate grid augmentation requirements.



4.0 RE potential of Goa



Goa's power grid, dependent on coal imports with limited solar, biomass, and wind, faces congestion and lacks storage to balance renewable supply and demand.

4.1: Current Status of Goa's Power Network

Goa's power distribution network consists of multiple substations and transmission lines operating at different voltage levels. The network relies on coal-based imports, with limited in-state solar, biomass, and wind generation.

The existing grid infrastructure faces constraints, including high line congestion and the need for storage solutions to balance RE supply and demand.

The overall components of the current electrical network of Goa are listed in Table 2.

Table 2: Floating Solar Potential for Major Lakes of the State of Goa

Sl.No.	Component / Particulars Name			Number of Components
1.	Substations		220/110/33/11kV	3
			220/33 kV	1
			220/33/11 kV	1
			110/33 kV	1
			110/33/11 kV	1
			33/11 kV	53
2.	Lines between substations and substations to feeders/loads		220 kV	10
			110 kV	7
			33 kV	199
			11 kV	361
3.	Transformers	220/110 kV	100 MVA	8
		220/33 kV	50 MVA	7
			63 MVA	2
		110/33 kV	50 MVA	5
			40 MVA	11
			30 MVA	1
		33/11 kV	30 MVA	1
			20 MVA	8
			10 MVA	46
			8 MVA	7
			6.3 MVA	66
			3.15 MVA	2
4.	Generators	Coal		3
		Nuclear		3
		Wind		3
		Solar		3
		Biomass		3
		Gas		3
5.	Loads and Feeders loads			397

Source: Electricity Department, Govt. of Goa 2023-24

The transmission and distribution line network of the State of Goa as of 2023-24 is depicted in Fig. 5.

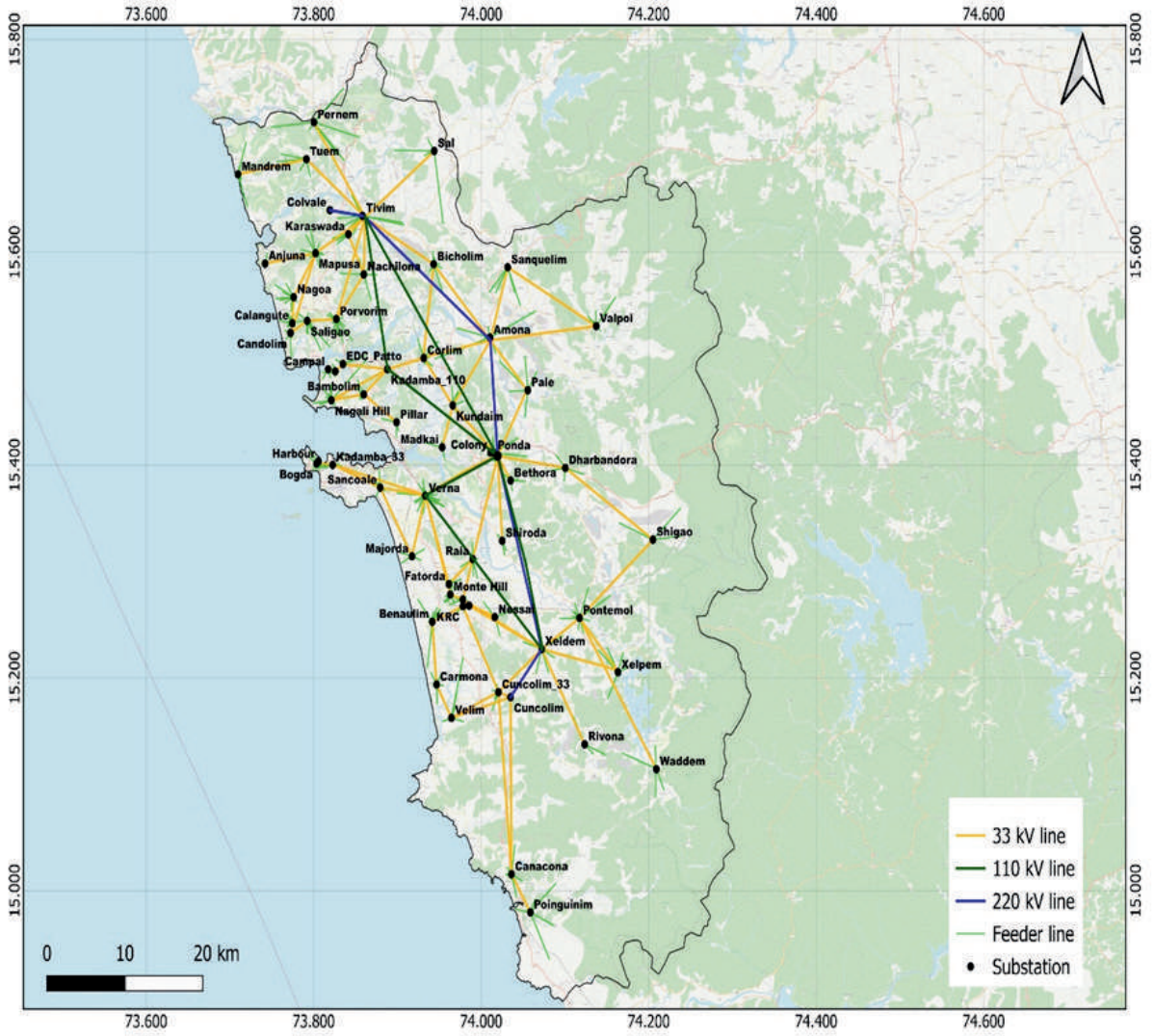


Figure 5: Electrical network map of Goa as of 2023-24.



5.0 Approach and Methodology



The approach focuses on comprehensive modelling and simulation of Goa's power network to optimize renewable energy integration and storage strategies.

The method and approach of this study are discussed in detail in this section.

5.1: Approach

The approach adopted in this study integrates spatial analysis, power system modelling, and optimization techniques to support the strategic planning of renewable energy (RE) integration in Goa's power network. The study is anchored in the Clean Energy Roadmap 2050 (CER), with a focus on assessing the existing power infrastructure and evaluating potential RE augmentation strategies to support a 100% renewable transition.

Step-1: Power Network building

The first stage involved constructing a comprehensive representation of Goa's existing power distribution network. This included substations, transmission lines, transformers, feeders, and load points, using both single-line diagrams (SLDs) and geospatial datasets. Hourly load profiles were digitized into CSV format from manual logbooks provided by the Goa Electricity Department (GED). The spatial structure of the network was mapped using Geographic Information System (GIS) tools to establish connectivity and topology, which are essential for system-level modeling. The analysis incorporated multiple voltage-level SLDs, including 220/110/66 kV, 33 kV, 11 kV, and distribution transformer/high-tension consumer (DTC/HTC, 415 V) networks.

Step-2: Power flow model building

To evaluate the operational dynamics of the power system and simulate optimal energy dispatch scenarios, the open-source PyPSA framework was employed. PyPSA enables high-resolution temporal modeling of generation, demand, and network constraints, while optimizing system performance with respect to cost, reliability, and efficiency. The optimization model was formulated to minimize the total system cost subject to constraints on generation capacity, storage availability, transmission limits, and demand-supply balance. For baseline network modeling, eleven input datasets were prepared using verified data on substations, transformers, transmission lines, and loads, as provided by GED.

Step-3: Power flow analysis-

Power flow analysis was conducted using the PyPSA framework across Goa's entire power network. This step aimed to evaluate the operational performance of the system under varying demand conditions. To capture the impact of seasonal load variations, both line

loading and transformer loading profiles were analyzed. The results provide critical insights into network reliability, congestion points, and overall system stability, forming the basis for subsequent optimization.

Step-4: Site suitability analysis-

In this stage, a comprehensive Site Suitability Assessment Framework was developed using a Multi-Criteria Decision (MCD) model integrated with Geographic Information System (GIS) tools. The framework incorporates technical parameters (e.g., line loading, distribution transformer loading), spatial characteristics (land use/land cover LULC, slope, global horizontal irradiance), and infrastructural factors (road accessibility). Weights were assigned to each parameter using the Analytic Hierarchy Process (AHP), ensuring a systematic and objective evaluation. The site suitability model was applied across Goa's entire power network, and the results identified eight highly suitable substations for subsequent analysis.

Step-5: Case Study

To examine potential future scenarios, two case studies have been carried out: (i) solar injection at the distribution transformer (DT) level, and (ii) integration of battery storage to enhance renewable energy uptake at the 11 kV level.

For the solar injection study, a mixed-conductor feeder was selected, modelled, and simulated to assess its impact at the DT level. In contrast, the storage integration study focused on the 11 kV network, where seasonal loading conditions were analyzed to evaluate the benefits of battery deployment.

The approach is iterative and modular, allowing scenario-based assessments of RE capacity addition, its feasibility at the substation/feeder level, and its implications for grid stability and performance.

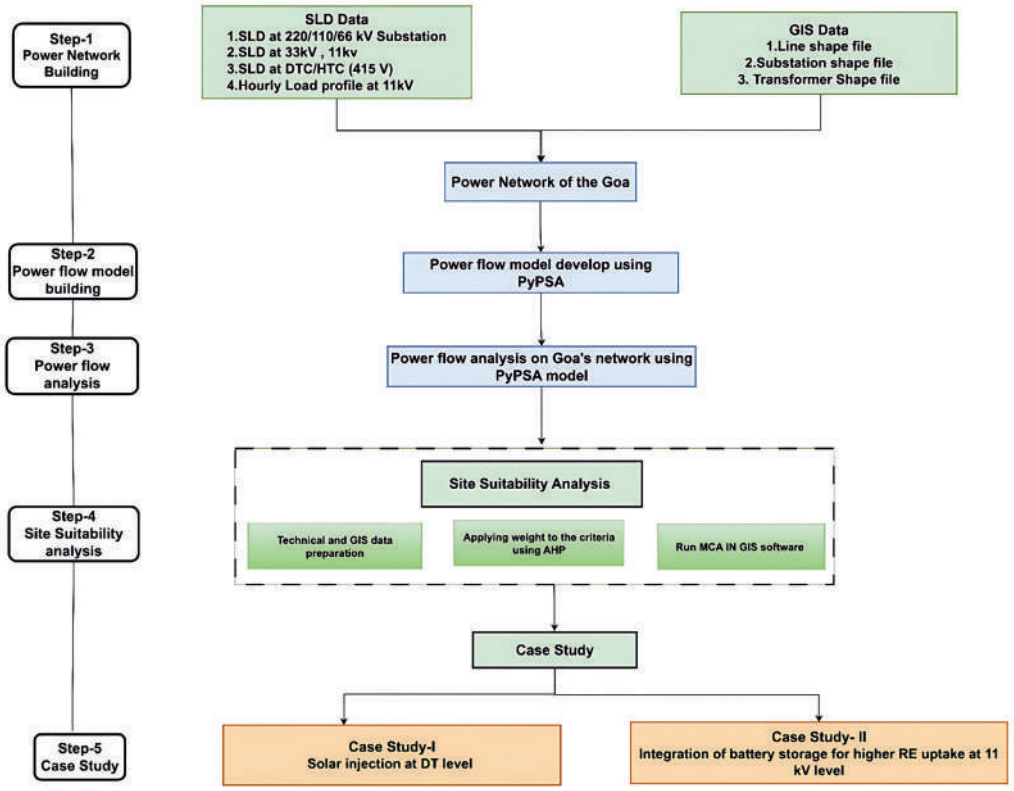


Figure 6: Flow of activities performed.

5.2: Methodology

5.2.1 Power Network building

The first step involved comprehensive data collection regarding Goa's existing power distribution infrastructure (provided by GEDA). For this, the key parameters are:

- **Network Map:** GIS-based network map has been provided by GEDA
- **Substations:** Location, rated voltage, and capacity of substations across the state.
- **Transmission/Distribution Lines:** Length, rated line capacity, resistance, and inductance of key transmission and distribution lines for the whole network.
- **Power Transformers:** Power ratings and voltage transformations.
- **Load:** Hourly demand profiles from various feeders and consumers. The hourly load data is provided by GEDA for the year 2023. This baseline data is further integrated into the PyPSA tool to simulate the current operational conditions of Goa's electrical grid.
- **Generation Data:** Hourly generation profiles, particularly for renewable generators, and capital cost, marginal cost, etc.

The PyPSA tool models Goa's power network for the collected data. The model explored different generation mixes, including renewable energy sources such as solar and wind, to evaluate the impact of their integration on grid stability, reliability, and efficiency. Moreover, the network map considered for the modelling is illustrated in Fig. 5, showing the substations and the lines connecting them. Furthermore, the lines between each substation are represented by different colours. The detailed discussion of the developed network map (Fig. 6) is explained above:

a) Substations: In Goa, five substations operate at a 220 kV voltage level. Among these, Tivim, Ponda, and Amona substations receive imported electricity from the neighbouring states of Maharashtra and Karnataka. This electricity is subsequently stepped down and distributed across the entire state of Goa. The 220 kV voltage level is stepped down to 110 kV level and then to 33 kV at the same substation. Further, these 33 kV voltage levels of electricity are distributed to other 33 kV substations and stepped down to 11 kV voltages. The interconnection between substations is depicted in Fig.5.

b) Transformers: Power transformers convert voltage from one level to another by stepping down 220 kV to 110 kV and 33 kV within the same substation. In the PyPSA model, various transformer types are defined in a compatible format, considering voltage conversion levels, resistance, reactance, and power ratings, among other parameters. An example of a power transformer file is depicted in Fig. 7.

Transformer_Name	From_Bus	To_Bus	MVA	Voltage_level
Tivim_TF1	Tivim_110	Tivim_33	40	110/33
Tivim_TF10	Tivim_110	Tivim_33	50	110/33
Tivim_TF2	Tivim_110	Tivim_33	50	110/33
Tivim_TF3	Tivim_110	Tivim_33	50	110/33
Tivim_TF4	Tivim_220	Tivim_110	100	220/110
Tivim_TF5	Tivim_220	Tivim_110	100	220/110
Tivim_TF6	Tivim_220	Tivim_110	100	220/110
Tivim_TF7	Tivim_220	Tivim_33	63	220/33
Tivim_TF8	Tivim_33	Tivim_11	10	33/11
Tivim_TF9	Tivim_33	Tivim_11	10	33/11

Figure 7: Example of transformer file in PyPSA compatible format.

c) Lines: The electrical connections between substations and those lines between substations to feeders and loads are defined in a format compatible with PyPSA. Key parameters such as line rated capacity, resistance, reactance, and line length are considered during this process. Fig. 8 provides an example of the defined transmission lines.

The electrical connections between substations and those lines between substations to feeders and loads are defined in a format compatible with PyPSA. Key parameters such as line rated capacity, resistance, reactance, and line length are considered during this process. Fig. 8 provides an example of the defined transmission lines.

name	bus0	bus1	s_nom	r	x	length	s_nom_extendable	carrier
1	Colvale_220	Tivim_220	264	0.0263	0.391155	34	TRUE	AC
2	Colvale_220	Tivim_220	264	0.0263	0.391155	34	TRUE	AC
3	Colvale_220	Amona_220	215.6	0.547	0.383529	43	TRUE	AC
4	Colvale_220	Amona_220	215.6	0.547	0.383529	43	TRUE	AC
5	Amona_220	Ponda_220	215.6	0.547	0.383529	18	TRUE	AC
6	Amona_220	Ponda_220	176	0.0673	0.38727	18	TRUE	AC
7	Amona_220	Ponda_220	176	0.0673	0.38727	18	TRUE	AC
8	Amona_220	Ponda_220	215.6	0.547	0.383529	43	TRUE	AC
9	Ponda_220	Xeldem_220	165	0.0263	0.391155	80	TRUE	AC
10	Xeldem_220	Cuncolim_220	165	0.0263	0.391155	80	TRUE	AC
11	Tivim_110	Ponda_110	110	0.1024	0.141908	33	TRUE	AC
12	Tivim_110	Kadamba_110	110	0.1024	0.141908	33	TRUE	AC
13	Kadamba_110	Ponda_110	110	0.2187	0.412042	34	TRUE	AC
14	Ponda_110	Verna_110	110	0.0724	0.144	9.22	TRUE	AC
15	Ponda_110	Xeldem_110	110	0.1024	0.141908	33	TRUE	AC
16	Xeldem_110	Verna_110	110	0.0724	0.144	9.22	TRUE	AC
17	Altinho_33	Campal_33	13.2	0.102	0.103	2.1	TRUE	AC
18	Altinho_33	Campal_33	13.2	0.102	0.103	2.1	TRUE	AC
19	Altinho_33	IT Hub Feeder	11.682	0.211	0.116	0.55	TRUE	AC
20	Altinho_33	Marriotts Feeder	8.91	0.13	0.104	2.86	TRUE	AC
21	Amona_33	Corlim_33	75	0.016485	0.02012	18.5	TRUE	AC
22	Amona_33	Kundaim_33	50	0.008543	0.012393	8.311	TRUE	AC
23	Amona_33	Bicholim_33	13.95	0.3623	0.244	14.5	TRUE	AC
24	Amona_33	Sanquelim_33	7.92	0.0729	0.0459	17.5	TRUE	AC
25	Amona_33	Sanquelim_33	7.92	0.0729	0.0459	18.5	TRUE	AC
26	Amona_33	Valpoi_33	11.715	0.1	0.125657	35	TRUE	AC

Figure 8: Example of lines file in PyPSA compatible format.

d) Loads: The load file is prepared based on the connected loads at each substation and the feeders extending from it, as illustrated in Fig. 9.

Additionally, a separate file is created, as shown in Fig. 10, to indicate the hourly load profiles for these defined loads.

name	bus	control
Marriotts	Marriotts Feeder	PQ
IT Hub	IT Hub Feeder	PQ
Cabo	Cabo Feeder	PQ
Fire Station	Fire Station Feeder	PQ
Lydia Garden	Lydia Garden Feeder	PQ
Manoshanti	Manoshanti Feeder	PQ
Circuit House	Circuit House Feeder	PQ
National	National Feeder	PQ
Tonca Miramar	Tonca Miramar Feeder	PQ
Alcon	Alcon Feeder	PQ
Inox	Inox Feeder	PQ
Campal	Campal Feeder	PQ

Figure 9: Example of load file for a particular substation (Althinho) in PyPSA compatible format.

Time	Marriotts	IT Hub	Cabo	Fire Station	Lydia Garden	Manoshanti	Circuit House	National	Tonca Miramar	Alcon	Inox	Campal
05-11-2023 00:00	0.617	0.051	1.56	0.069	0.48	0.463	0.652	0.669	0.652	0.463	0.394	0.703
05-11-2023 01:00	0.617	0.051	1.595	0.069	0.463	0.36	0.634	0.634	0.634	0.412	0.412	0.754
05-11-2023 02:00	0.617	0.051	1.44	0.086	0.463	0.377	0.652	0.634	0.652	0.412	0.394	0.754
05-11-2023 03:00	0.617	0.051	1.526	0.086	0.412	0.412	0.652	0.634	0.652	0.412	0.412	0.754
05-11-2023 04:00	0.617	0.051	1.44	0.086	0.412	0.412	0.634	0.634	0.634	0.412	0.412	0.754
05-11-2023 05:00	0.617	0.051	1.44	0.086	0.412	0.497	0.634	0.652	0.634	0.463	0.377	0.72
05-11-2023 06:00	0.617	0.103	1.423	0.086	0.532	0.394	0.634	0.634	0.634	0.48	0.274	0.737
05-11-2023 07:00	0.617	0.051	1.492	0.086	0.532	0.377	0.634	0.617	0.634	0.412	0.274	0.737
05-11-2023 08:00	0.617	0.103	1.612	0.103	0.532	0.446	0.634	0.652	5.95	0.497	0.257	0.823
05-11-2023 09:00	0.617	0.051	1.543	0.103	0.754	0.514	0.806	0.857	0.806	0.549	0.326	1.08
05-11-2023 10:00	0.669	0.051	1.543	0.103	1.166	0.686	0.995	1.509	0.995	0.737	0.772	1.595
05-11-2023 11:00	0.669	0.051	1.492	0.12	1.337	0.772	1.08	1.698	1.08	0.72	0.892	1.715
05-11-2023 12:00	0.669	0.051	1.492	0.12	1.166	0.72	0.977	1.715	0.977	0.703	0.874	1.68
05-11-2023 13:00	0.72	0.051	1.475	0.12	1.183	0.686	0.977	1.698	0.977	0.652	0.772	1.595
05-11-2023 14:00	0.669	0.051	1.423	0.137	0.995	0.703	0.874	1.526	0.874	0.566	0.823	1.406
05-11-2023 15:00	0.669	0.051	1.457	0.137	1.046	0.634	0.96	1.612	0.96	0.583	0.754	1.492
05-11-2023 16:00	0.669	0.103	1.372	0.154	1.097	0.634	0.909	1.646	0.909	0.634	0.823	1.475
05-11-2023 17:00	0.669	0.103	1.406	0.154	1.115	0.703	0.943	1.612	0.943	0.703	0.909	1.543
05-11-2023 18:00	0.669	0.051	1.372	0.137	0.926	0.6	0.754	1.526	0.754	0.6	0.857	1.389
05-11-2023 19:00	0.72	0.051	1.68	0.154	0.874	0.583	0.754	1.457	0.754	0.652	0.772	1.303
05-11-2023 20:00	0.669	0.051	1.663	0.137	0.874	0.566	0.737	1.457	0.737	0.669	0.806	1.303
05-11-2023 21:00	0.617	0.051	1.56	0.137	0.72	0.532	0.806	1.44	0.806	0.583	0.72	0.463
05-11-2023 22:00	0.617	0.051	1.578	0.137	0.72	0.549	1.012	1.526	1.012	0.532	0.72	0.463
05-11-2023 23:00	0.617	0.051	1.389	0.12	0.532	0.532	1.046	1.44	1.046	0.532	0.72	0.446

Figure 10: Example of hourly load profile (one day) for a particular substation (Althinho).

e) Generator: The generator file is prepared based on the available generators' carrier types at major 220kV substation where the power is received from the PGCI (power grid corporation of India) and along with their installed capacity, as illustrated in Fig. 11. Additionally, a separate file is created, as shown in Fig. 12, to indicate the hourly generation profiles for these generators.

name	bus	p_nom	carrier	marginal_cost	efficiency	p_nom_extendable
NTPC_G1	Tivim_220	186.5333	Coal	2900	0.26	FALSE
NTPC_G2	Ponda_220	20	Coal	3000	0.26	FALSE
NTPC_G3	Amona_220	120	Coal	3500	0.26	FALSE
NPCIL_G1	Tivim_220	11.33333	Nuclear	2800	0.3	FALSE
NPCIL_G2	Ponda_220	5	Nuclear	2900	0.3	FALSE
NPCIL_G3	Amona_220	2	Nuclear	3500	0.3	FALSE
Wind_G1	Tivim_220	40	Wind	500	0.21	FALSE
Wind_G2	Ponda_220	40	Wind	500	0.21	FALSE
Wind_G3	Amona_220	40	Wind	500	0.21	FALSE
Solar_G1	Tivim_220	20	Solar	200	0.17	FALSE
Solar_G2	Ponda_220	20	Solar	200	0.17	FALSE
Solar_G3	Amona_220	20	Solar	200	0.17	FALSE
Biomass_G1	Tivim_220	0.77	Biomass	2000	0.25	FALSE
Biomass_G2	Ponda_220	0.77	Biomass	2000	0.25	FALSE
Biomass_G3	Amona_220	0.77	Biomass	2000	0.25	FALSE
Trade_1	Tivim_220	0	Mixed	3500	1	TRUE
Trade_2	Ponda_220	0	Mixed	3500	1	TRUE
Trade_3	Amona_220	0	Mixed	3500	1	TRUE
Hydro_G1	Tivim_220	0.666667	Hydro	2500	0.5	FALSE
Hydro_G2	Ponda_220	0.666667	Hydro	2500	0.5	FALSE
Hydro_G3	Amona_220	0.666667	Hydro	2500	0.5	FALSE

Figure 11: Example of generator file in PyPSA compatible format.

Additionally, a separate dataset is also created, as shown in Fig. 12, to indicate the hourly generation profiles for these generators including renewable energy sources. Hourly generation is considered to be equivalent to the hourly power drawn from the grid by the State (mainly from Western and Southern Grid) as per PPA and hourly demand.

time	Solar _G1	Solar_ G2	Solar_ G3	Wind _G1	Wind _G2	Wind _G3	Coal _G1	Coal _G2	Coal _G3	Gas_ G1	Gas_ G2	Gas_ G3	Nuclear _G1	Nuclear _G2	Nuclear_ G3
5/11/2023 0:00	0	0	0	0.144	0.144	0.144	1	1	1	1	1	1	1	1	1
5/11/2023 1:00	0	0	0	0.146	0.146	0.146	1	1	1	1	1	1	1	1	1
5/11/2023 2:00	0	0	0	0.142	0.142	0.142	1	1	1	1	1	1	1	1	1
5/11/2023 3:00	0	0	0	0.152	0.152	0.152	1	1	1	1	1	1	1	1	1
5/11/2023 4:00	0	0	0	0.16	0.16	0.16	1	1	1	1	1	1	1	1	1
5/11/2023 5:00	0	0	0	0.16	0.16	0.16	1	1	1	1	1	1	1	1	1
5/11/2023 6:00	0	0	0	0.157	0.157	0.157	1	1	1	1	1	1	1	1	1
5/11/2023 7:00	0.007	0.01	0.007	0.119	0.119	0.119	1	1	1	1	1	1	1	1	1
5/11/2023 8:00	0.203	0.2	0.203	0.094	0.094	0.094	1	1	1	1	1	1	1	1	1
5/11/2023 9:00	0.432	0.43	0.432	0.066	0.066	0.066	1	1	1	1	1	1	1	1	1
5/11/2023 10:00	0.594	0.59	0.594	0.034	0.034	0.034	1	1	1	1	1	1	1	1	1
5/11/2023 11:00	0.696	0.7	0.696	0.013	0.013	0.013	1	1	1	1	1	1	1	1	1
5/11/2023 12:00	0.745	0.75	0.745	0.003	0.003	0.003	1	1	1	1	1	1	1	1	1
5/11/2023 13:00	0.745	0.75	0.745	0	0	0	1	1	1	1	1	1	1	1	1
5/11/2023 14:00	0.68	0.68	0.68	0	0	0	1	1	1	1	1	1	1	1	1
5/11/2023 15:00	0.59	0.59	0.59	0	0	0	1	1	1	1	1	1	1	1	1
5/11/2023 16:00	0.448	0.45	0.448	0	0	0	1	1	1	1	1	1	1	1	1
5/11/2023 17:00	0.23	0.23	0.23	0	0	0	1	1	1	1	1	1	1	1	1
5/11/2023 18:00	0.018	0.02	0.018	0.005	0.005	0.005	1	1	1	1	1	1	1	1	1
5/11/2023 19:00	0	0	0	0.024	0.024	0.024	1	1	1	1	1	1	1	1	1
5/11/2023 20:00	0	0	0	0.059	0.059	0.059	1	1	1	1	1	1	1	1	1
5/11/2023 21:00	0	0	0	0.089	0.089	0.089	1	1	1	1	1	1	1	1	1
5/11/2023 22:00	0	0	0	0.099	0.099	0.099	1	1	1	1	1	1	1	1	1
5/11/2023 23:00	0	0	0	0.093	0.093	0.093	1	1	1	1	1	1	1	1	1

Figure 12: Example of hourly generation profile (one day) in PyPSA compatible format.

Goa's RE generation profile has been obtained from the RE Ninja database which is shown below in Figure 13. It shows the distribution of RE generation capacity over the hours in a day (in per unit basis i.e 1 KW).

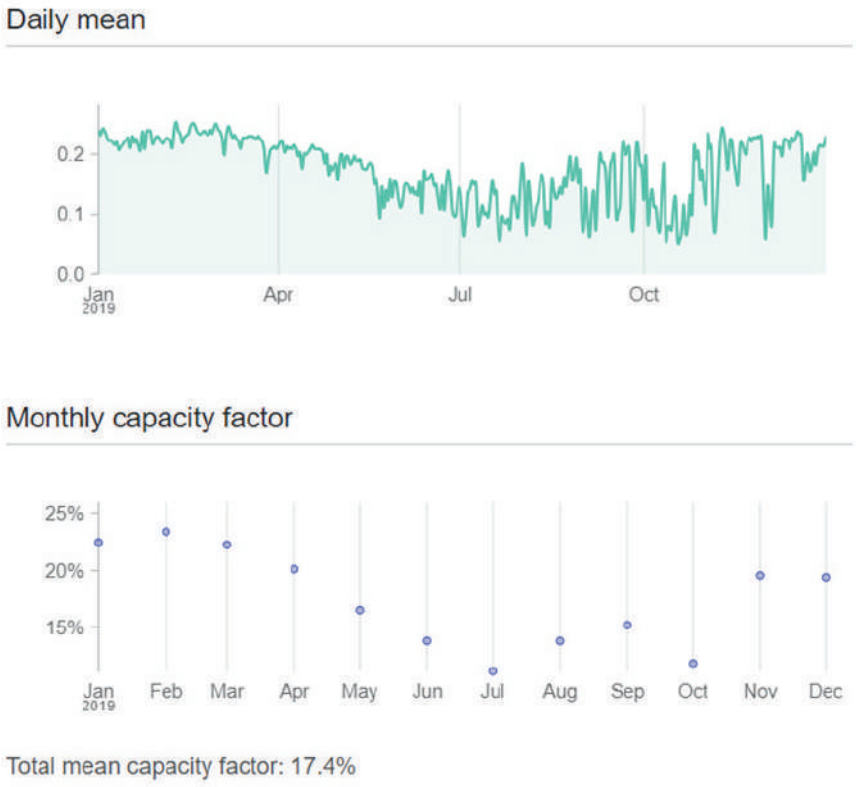


Figure 13: Hourly Solar generation profile of the State of Goa for a year.

5.2.2 Building power flow model using PyPSA (Python based Power System Analysis)

An electrical power system usually consists of Buses (i.e., the conductors), Generators, Transformers, Loads, Lines, and Links. Further, the flow of electricity depends mainly on the consumers' demand and the capacity of the generation from different energy sources. Hence, for performing an optimal operation of the electrical grid, the following data are required:

- Buses (name, v_nom, x, y(coordinates), v_mag_max, v_mag_min)
- Lines (name, from bus, to bus, inductance, resistance, length of line, s_nom, s_max, s_min)
- Generator (name, connected to the bus, capital cost, investment cost, cost of generation, efficiency, min_up time, min_down time, startup cost, shut down cost)
- Load (name, connected to the bus, p_set)
- Transformer (name, from bus, to bus, x, r, s_nom, capital cost, transformer ratio, v_ang_min, v_ang_max)
- Load_p_set: Load demands by hour/min
- generator_pmax_pu: generations from sources by hour/min.

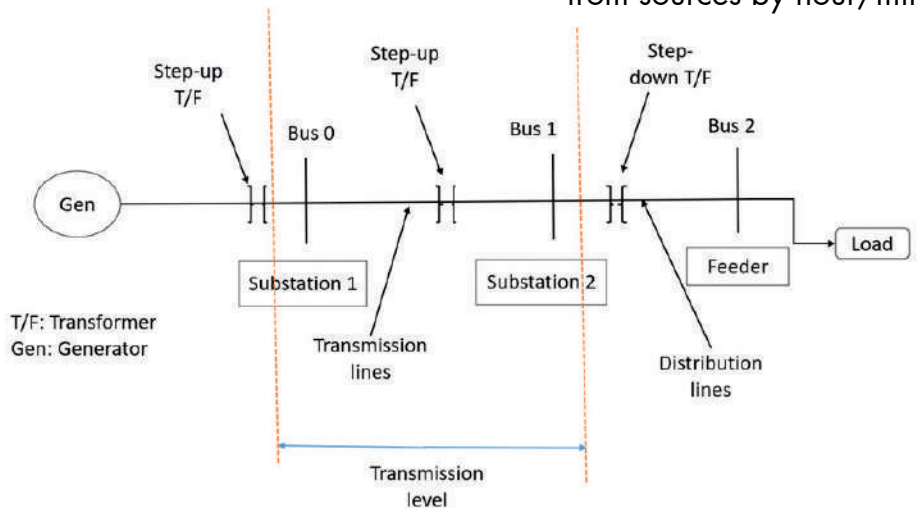


Figure 14: SLD of a representative network used in the PyPSA model for power flow analysis.

The following section describes the elements of the PyPSA static model used for this study.

A. Static Network Structure

i.**buses**

- Defines the electrical nodes (connection points).
- Contains bus ID, voltage level, carrier (AC/DC), geographic coordinates, etc.

ii.**lines**

- Defines transmission/distribution lines.
- Attributes: from_bus, to_bus, nominal voltage, resistance, reactance, thermal limit, length, type.

iii.transformers

- Defines individual transformers connecting buses at different voltage levels.
- Attributes: from_bus, to_bus, type (linked to transformer_types.csv).

iv.**transformer_types**

- Library of standard transformer electrical parameters.

- Attributes: nominal voltages, short-circuit reactance, resistance, copper losses, etc.

B. System Elements

i. **loads**

- Defines demand points connected to buses.
- Attributes: bus, carrier, nominal power, nameplate values.

ii. **generators**

- Defines supply sources (thermal, hydro, solar, wind, etc.).
- Attributes: bus, carrier, nominal power capacity, efficiency, marginal cost, p_max_pu (availability factor).

C. **Time Series Data (linked to snapshots)**

i. **snapshots**

- Defines the time steps (hours, days, or custom intervals) for simulation.
- Used as the index for time-varying profiles.

ii. **loads-p_set**

- Time series of active power demand at each load.
- Indexed by snapshots × load IDs.

iii. **loads-q_set**

- Time series of reactive power demand at each load.
- Same structure as above.

iv. **generators-p_set**

- Time series of generator dispatch (active power) or availability profiles (e.g., solar/wind).
- Indexed by snapshots × generator IDs.

PyPSA is used to develop and simulate the power system model for the state of Goa. Among the existing power system tool, the python Power System Analysis (PyPSA) is a free open-source software, which allows the results to be reproduced by any third party and helps the user to grow. Based on these results large investment decisions can be made in connection with energy system modelling.

Structure of the Models used in the study

i) **Linear Optimized Power Flow (LOPF)**

The Linear Optimal Power Flow model is a fast, linearized approximation of the power flow optimization problem. It balances supply and demand at least cost while respecting generator and transmission constraints, making it a practical tool for system planning and policy analysis, though less precise than full AC OPF, as shown below in equation (1).

$$\textbf{Min (TC)} = \left[\sum_{l} C_l . f_l + \sum_{n,r} C_{nr} . G_{nr} + \sum_{n,r,t} (w_t . o_{nr} . g_{nrt} + suc_{nrt} + sdc_{nrt}) + \sum_{n,s} C_{ns} . H_{ns} + \sum_{n,s} C_{ns} . E_{ns} + \sum_{n,r,t} w_t . o_{nst} . H_{nrt}\right] \quad (1)$$

C_l: *fixed cost per capacity;*
f_l: *branch capacities;*
G_{nr}: *generator capacity at each bus;*
C_{nr}: *fixed cost of generators;*
g_{nrt}: *dispatch of the unit at time t;*
o_{nr}: *associated variable costs;*
H_{ns}: *storage capacity,*
E_{ns}: *energy capacity of storage;*
C_{ns}: *fixed cost of storage dispatch*
w_t: *Weighting of snapshots*

ii) **AC Power Flow Analysis**

AC Power Flow Analysis is a numerical method to compute how electricity flows in an alternating current network, ensuring reliable operation of the grid. At its core, AC power flow solves a set of non-linear algebraic equations based on, as mentioned in equations (2) and (3).

$$P(i) = \sum_{J=1}^{N} V_i V_j [G_{ij} \cos(\theta_i - \theta_j) + B_{ij} sin(\theta_i - \theta_j)] \quad (2)$$

$$Q(i) = \sum_{J=1}^{N} V_i V_j [G_{ij} \sin(\theta_i - \theta_j) + B_{ij} cos(\theta_i - \theta_j)] \quad (3)$$

where:

$P(i)$: *Active power injected at bus i*

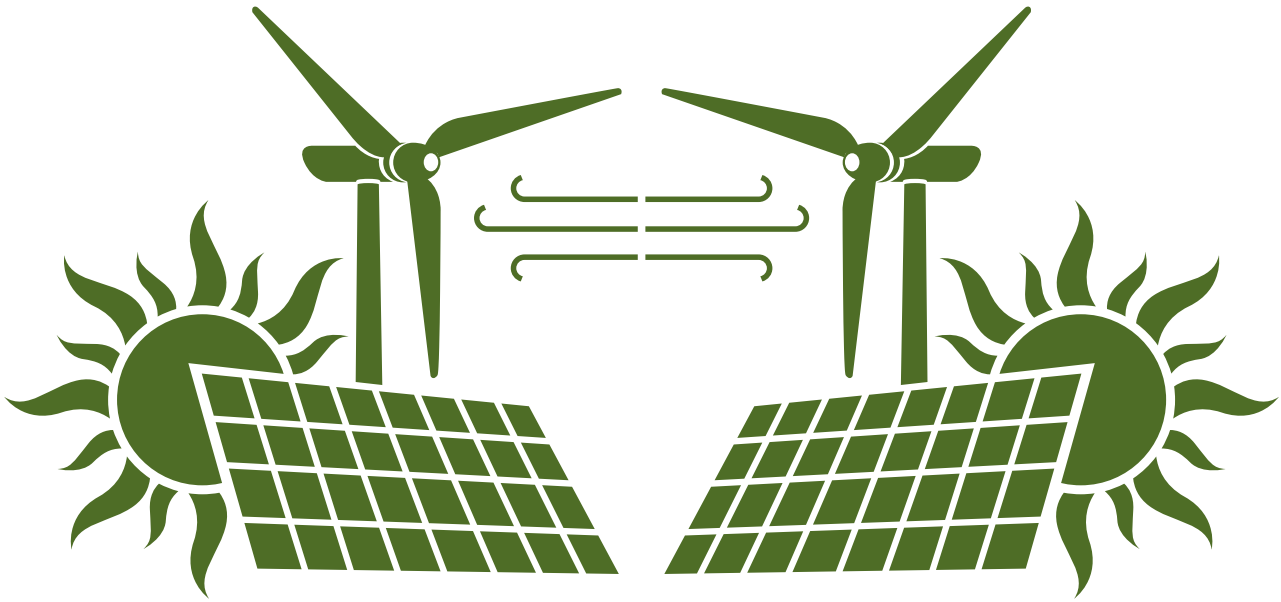
$Q(i)$: *Reactive power injected at bus i*

V_i, V_j: *Voltage magnitudes at buses i and j*

G_{ij}: *Conductance of the line between buses i and j*

B_{ij}: *Susceptance of the line between buses i and j*

θ_i, θ_j : *Voltage phase angles at buses i and j*



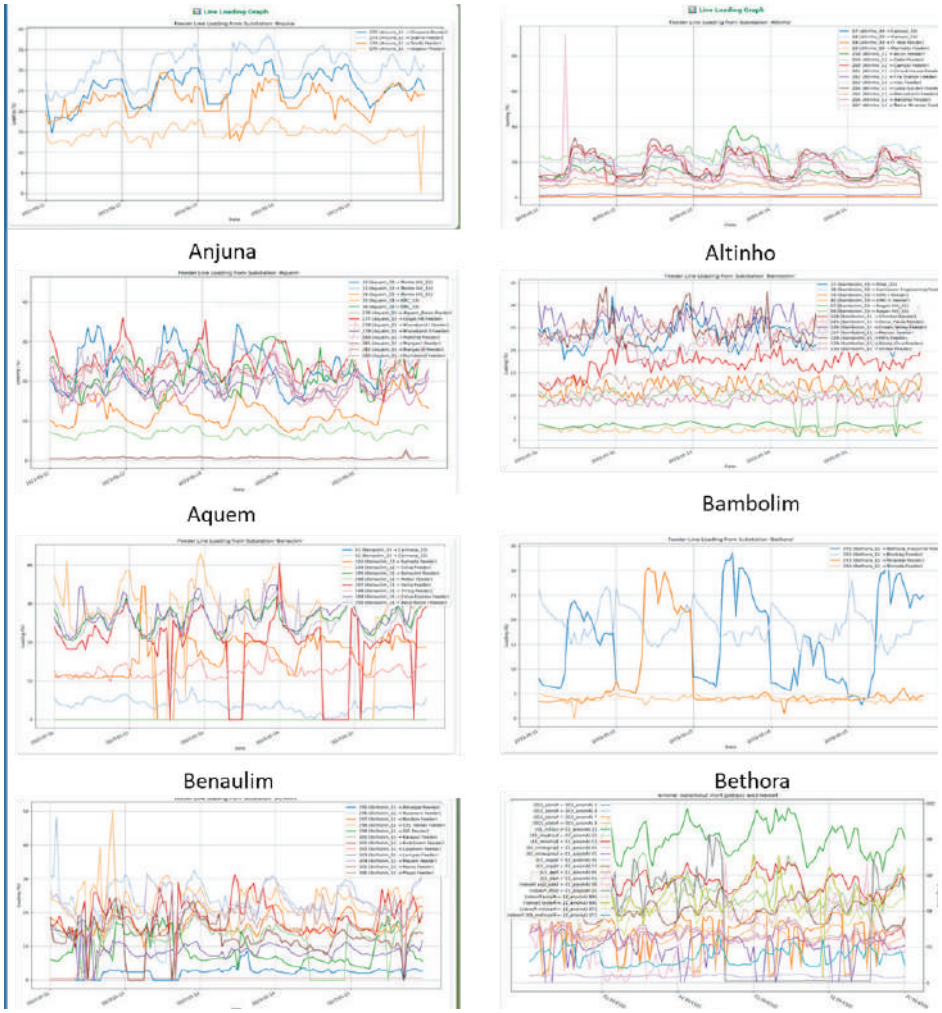
6.0 Power flow analysis



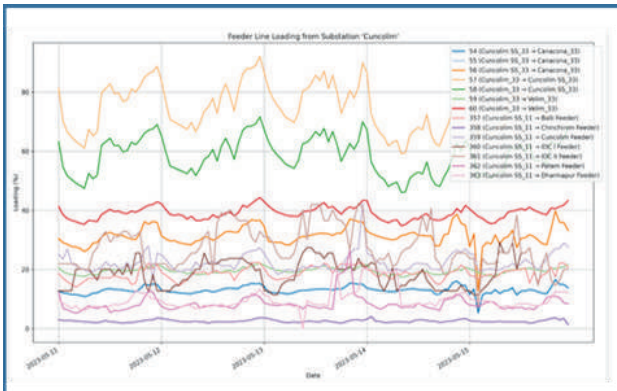
Goa-PyPSA power flow study analyzes seasonal and hourly load variations across substations up to 11kV

Power flow study has been performed using Goa-PyPSA Model for the whole state of Goa using the LOPF model structure as explained above. For a better understanding of the network conditions seasonal and hourly load variation have been considered. Impacts on the network have been analyzed in terms of line / feeder & transformer loading as shown below by each sub-station in the State. Figure 15 and Figure 16 shows the sub-station wise feeder and transformer loading respectively for the month of May 2023. The detailed information has been shown below in annexure 2: Results for whole state of Goa upto 11kV.

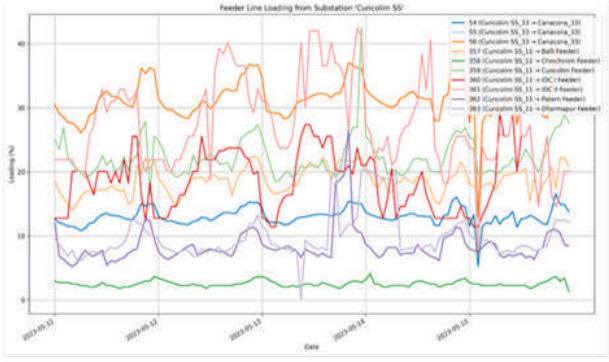
Feeder loading condition by Substations



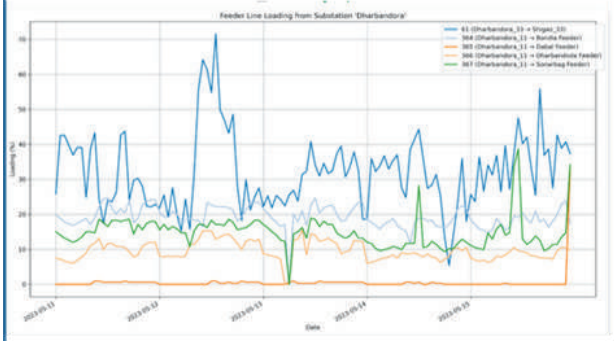

Bogda
Calangute
Champal
Canacona
Candolim
Carmona
Colony
Corlim



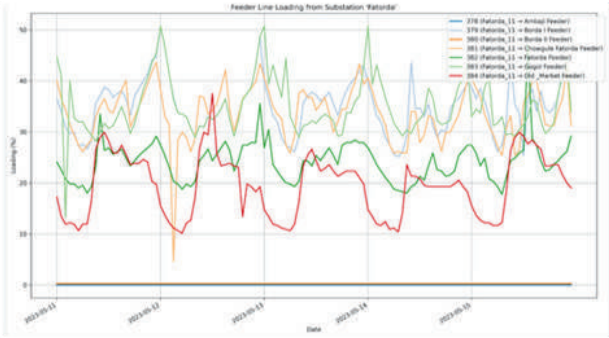
Cuncolim



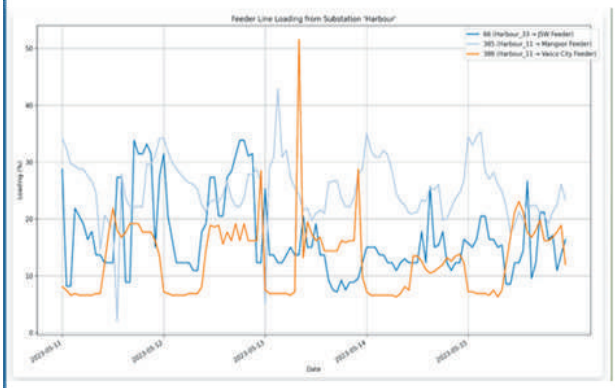
Cuncolim SS



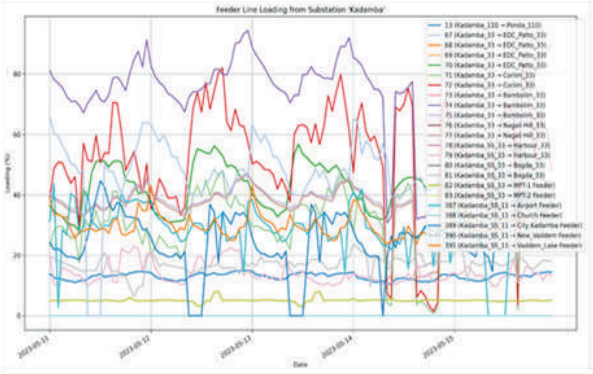
Dharbandora



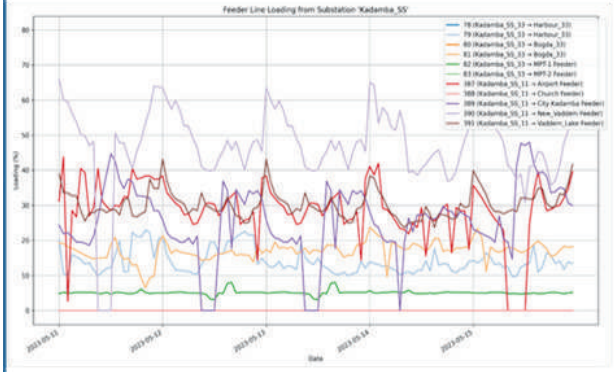
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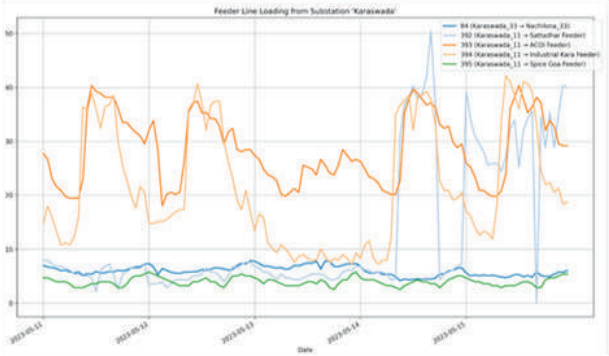
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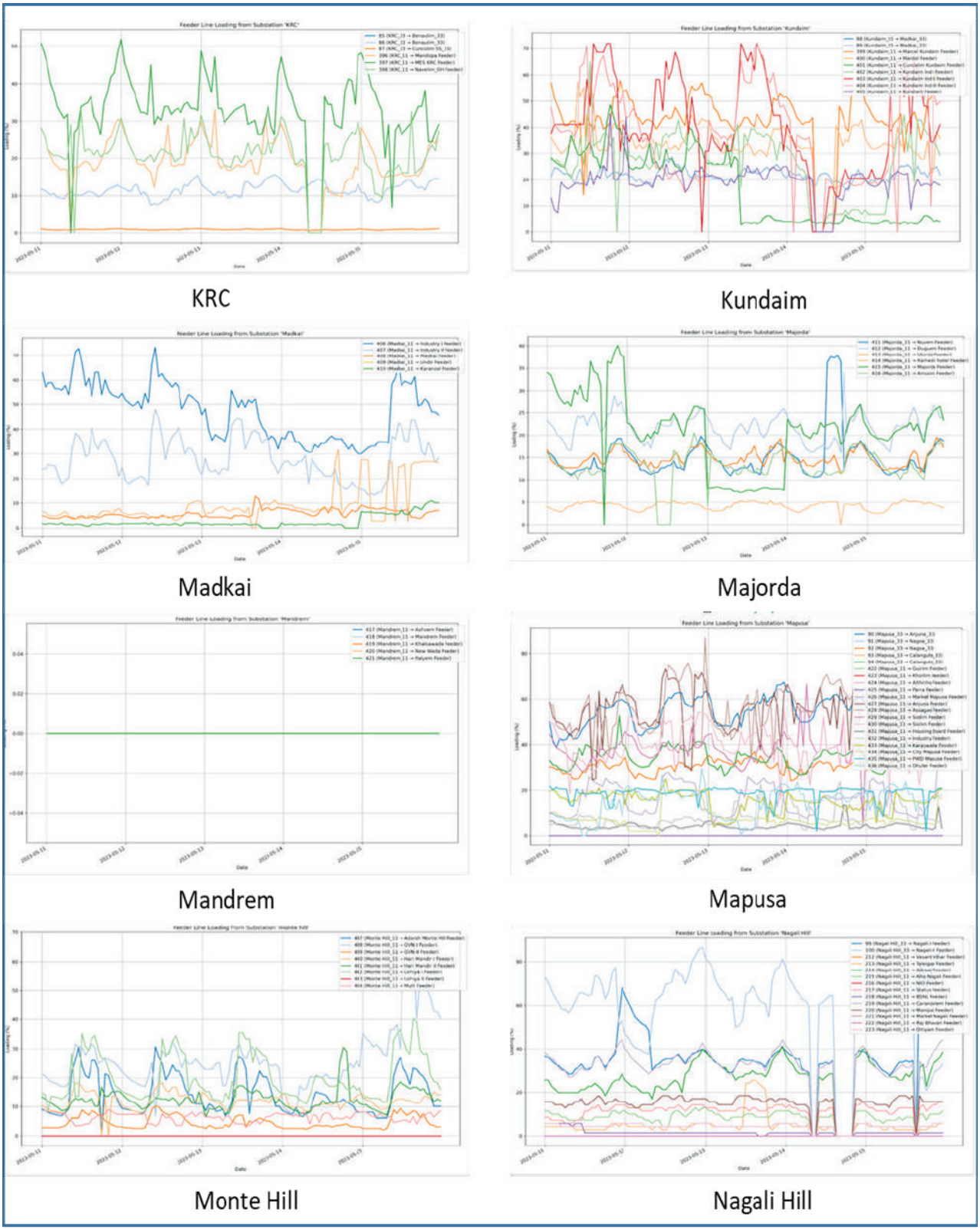
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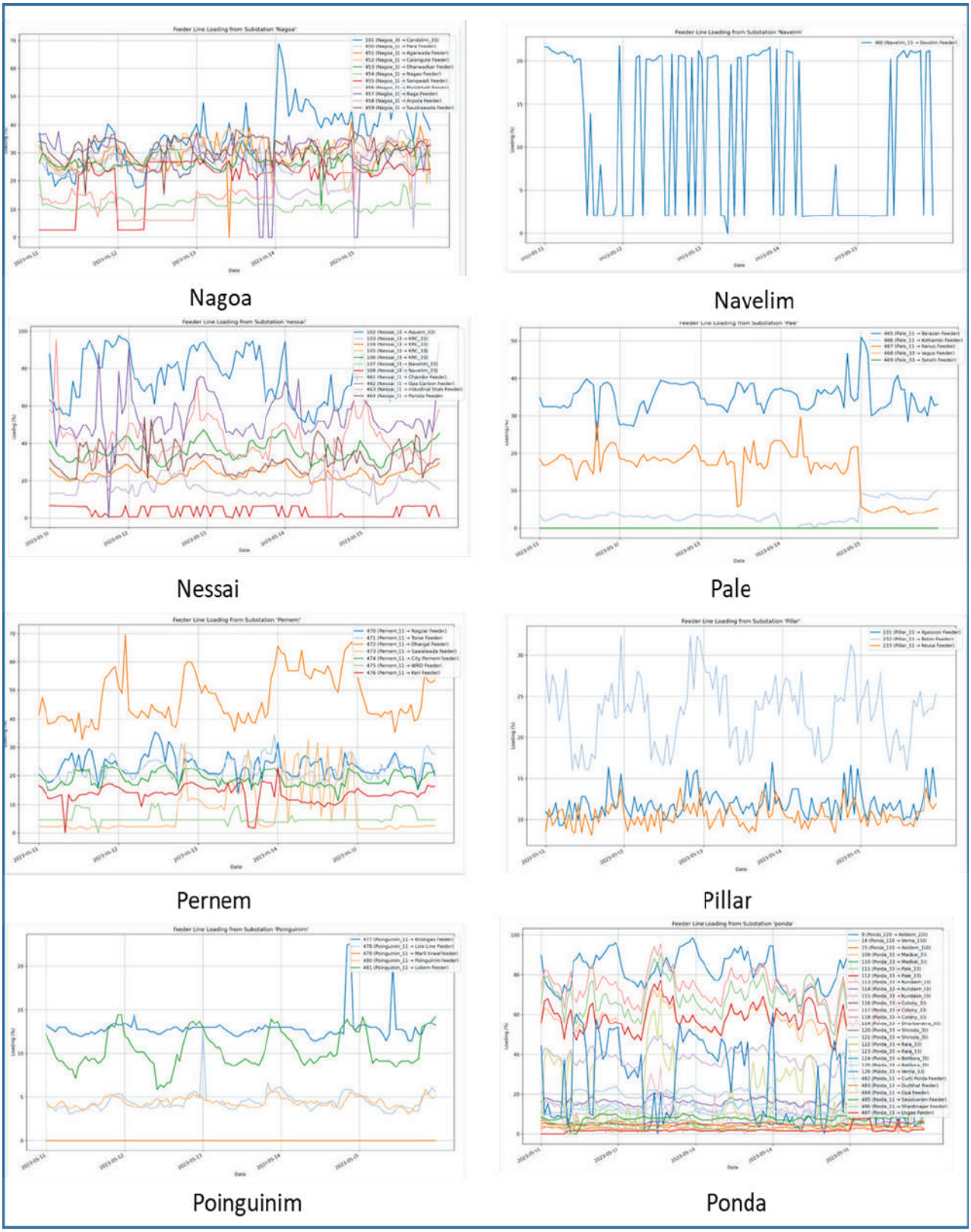


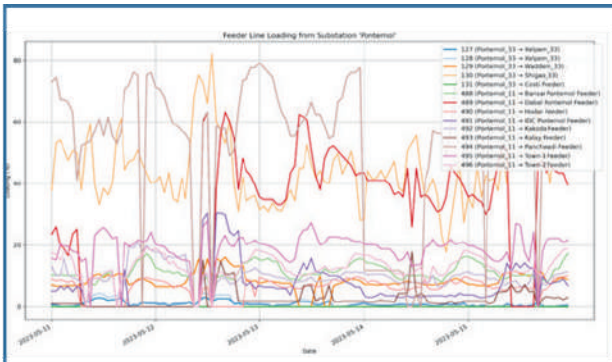
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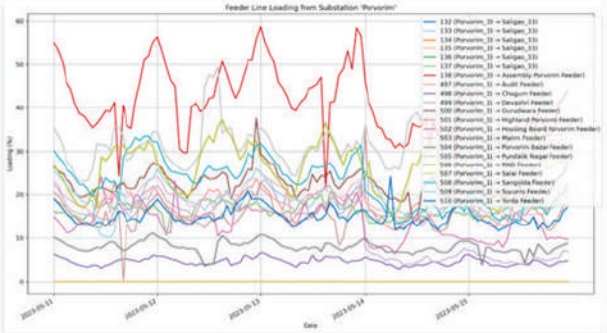
Karaswada


KRC
Kundaim
Madkai
Majorda
Mandrem
Mapusa
Monte Hill
Nagali Hill

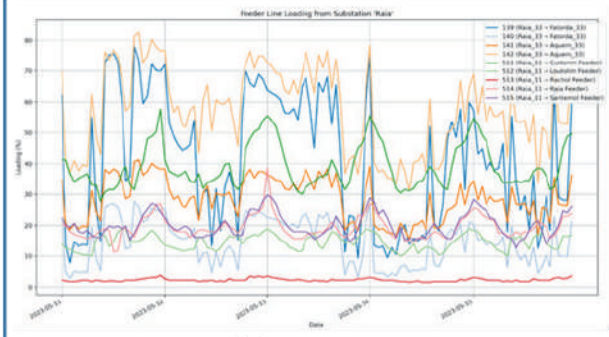

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Pernem
Pillar
Poinguinim
Ponda



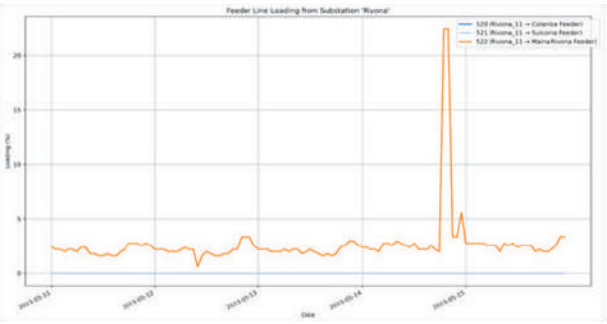
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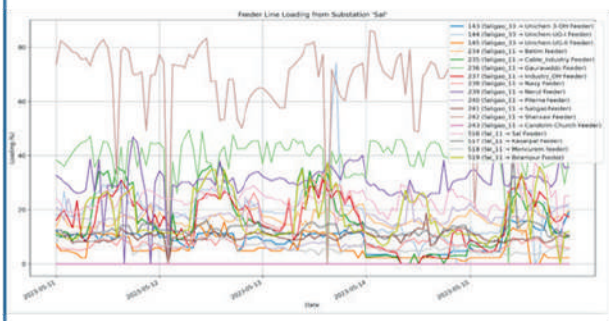
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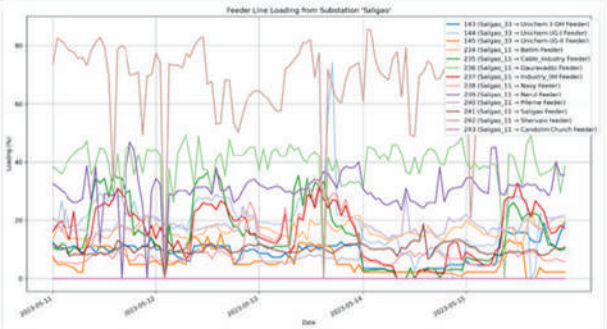
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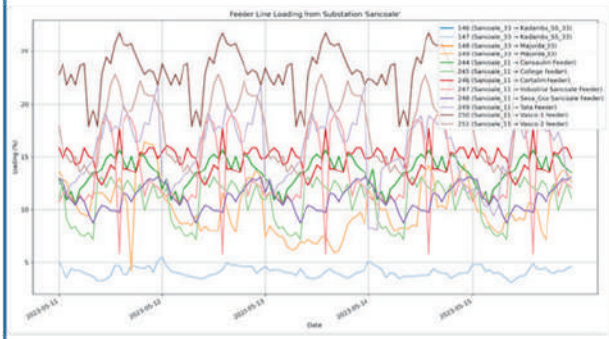
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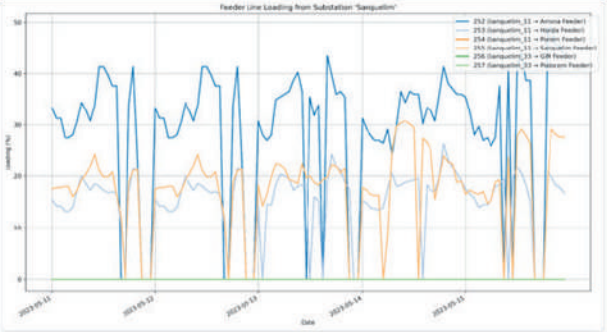
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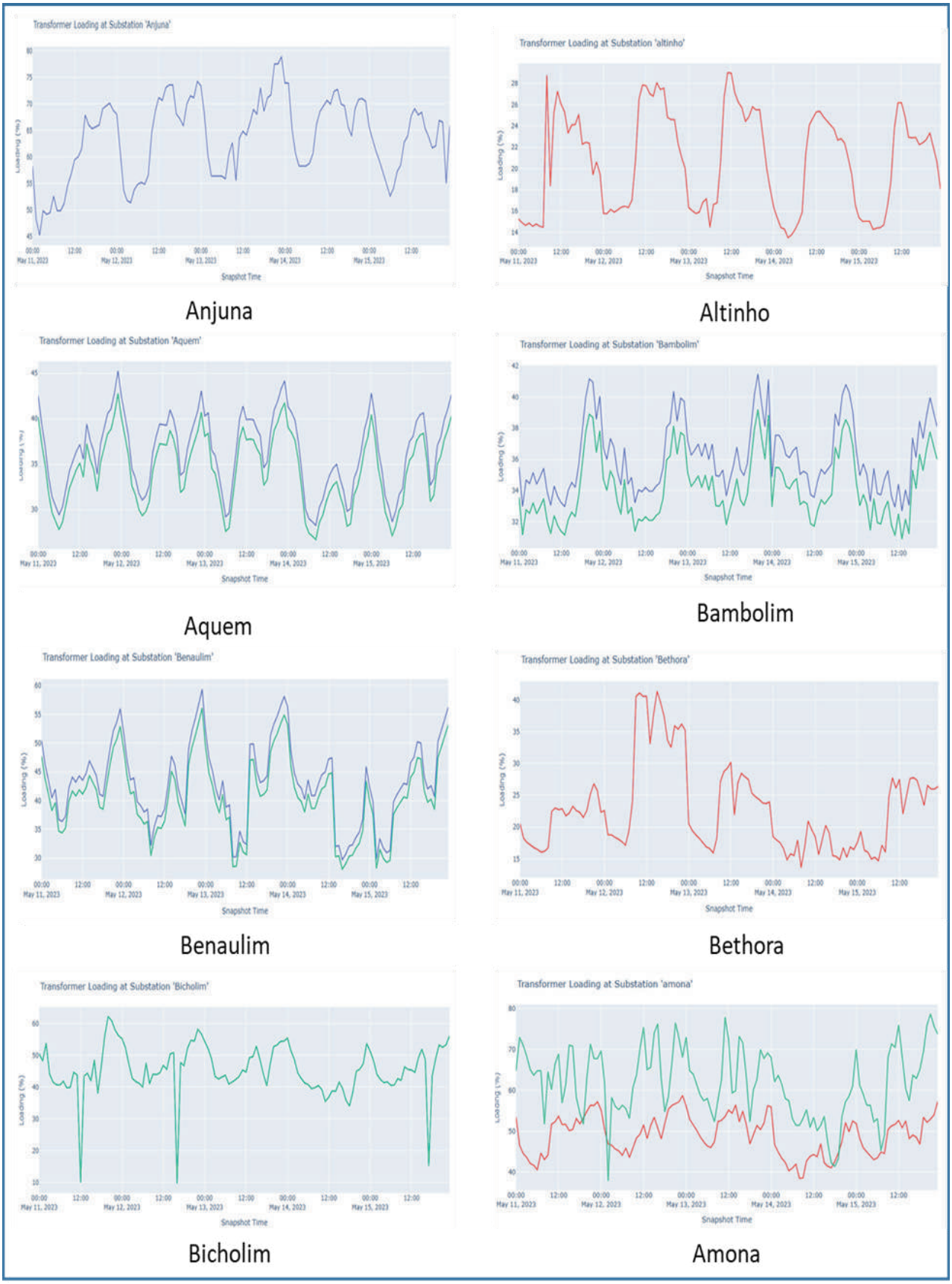


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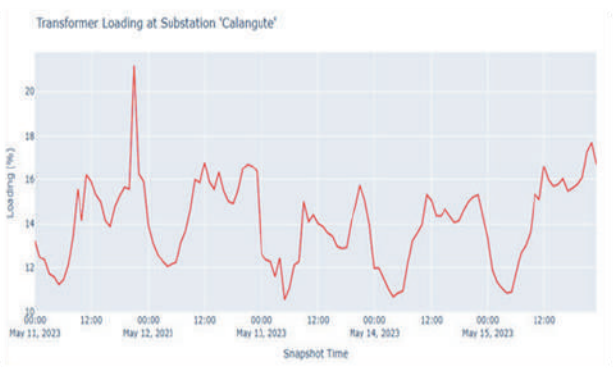
Figure 15: Feeder loading status by substations for the month of May 2023

Transformer Loading Condition by Substation

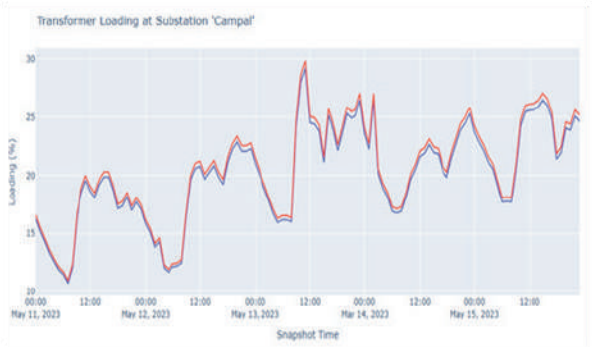




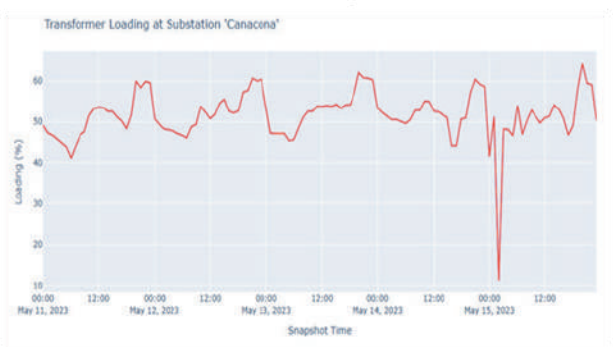
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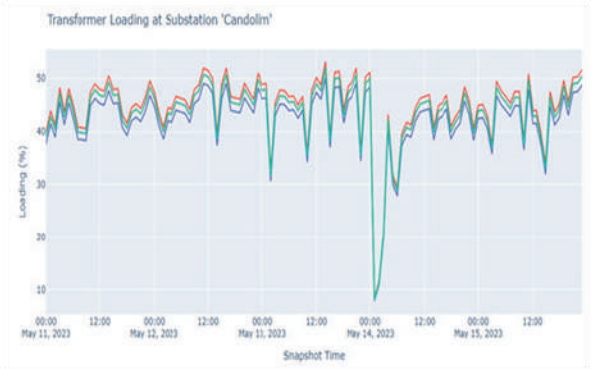
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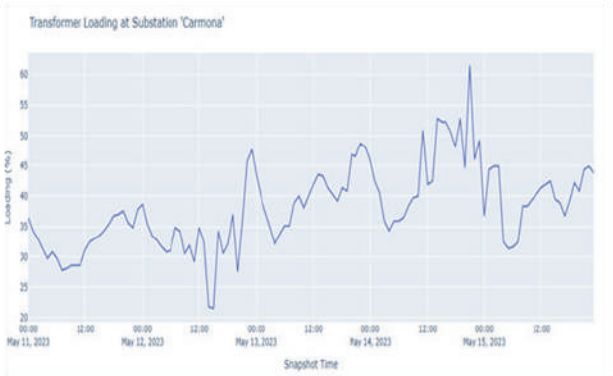
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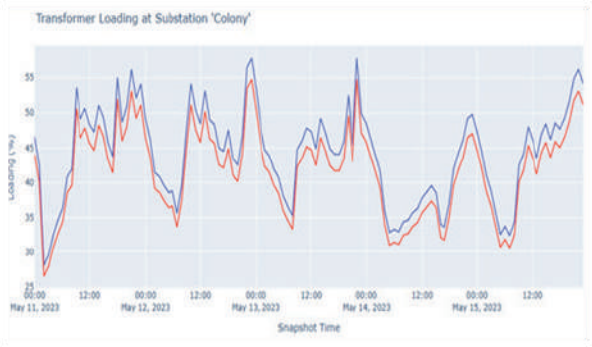
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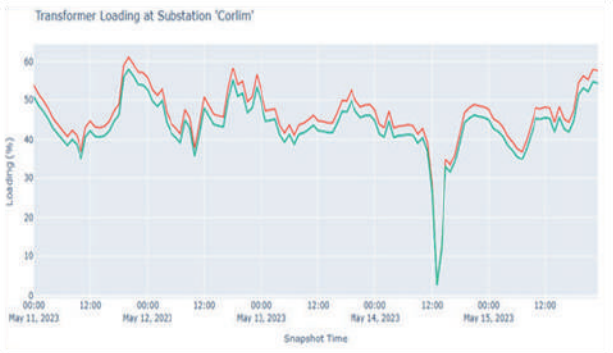
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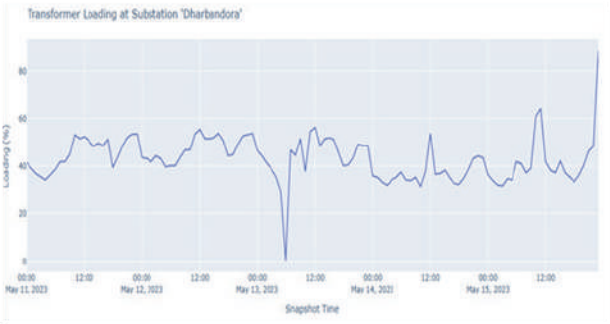
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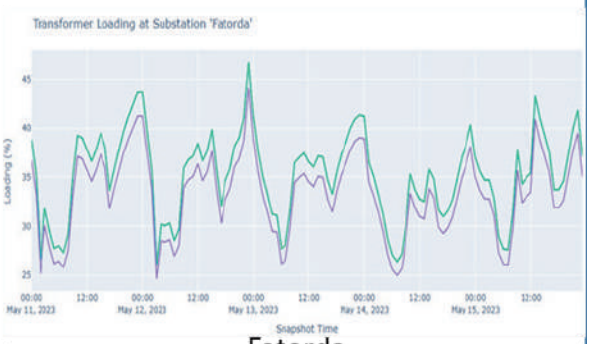
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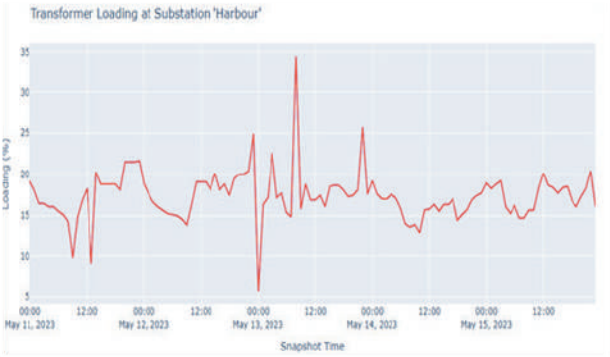
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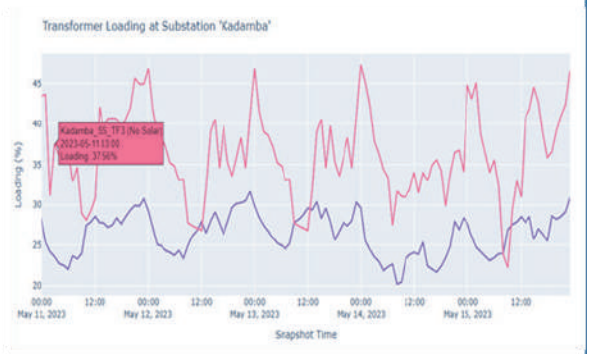
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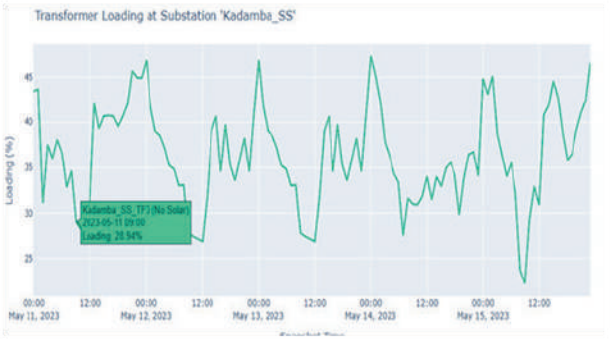
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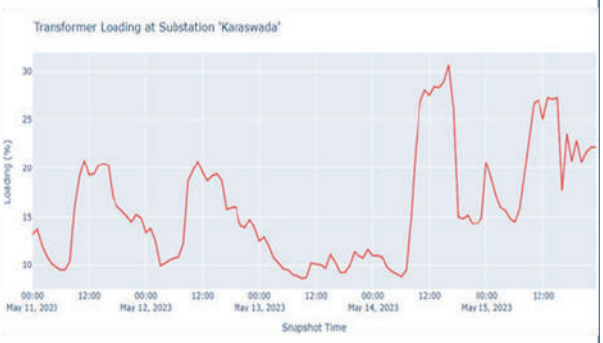
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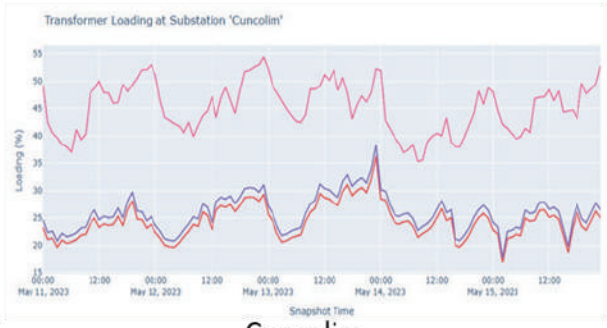
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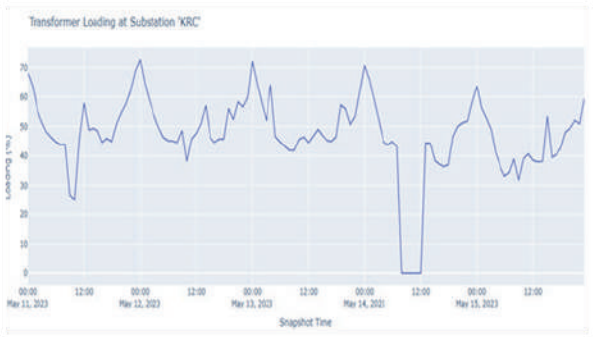
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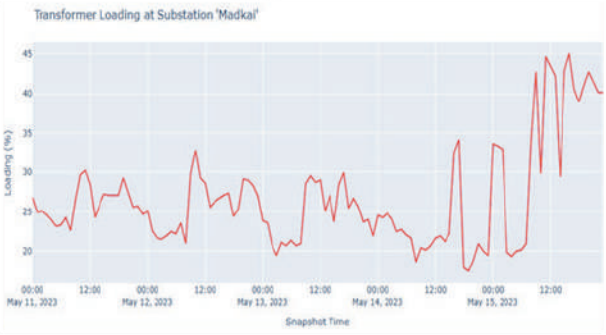
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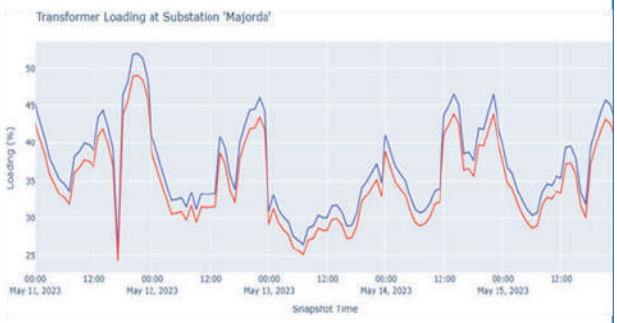
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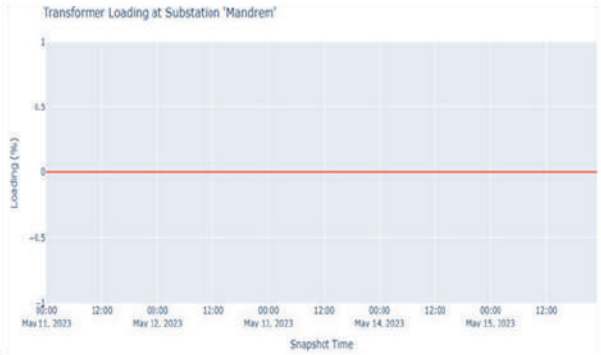
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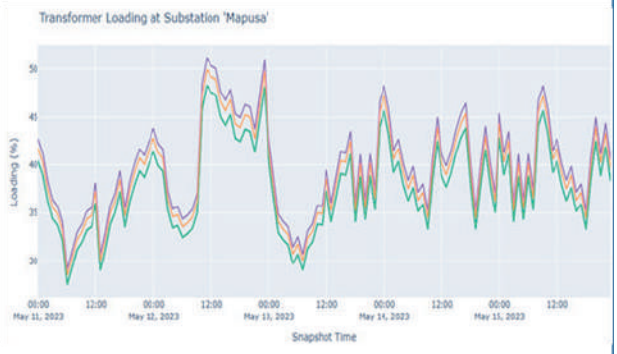
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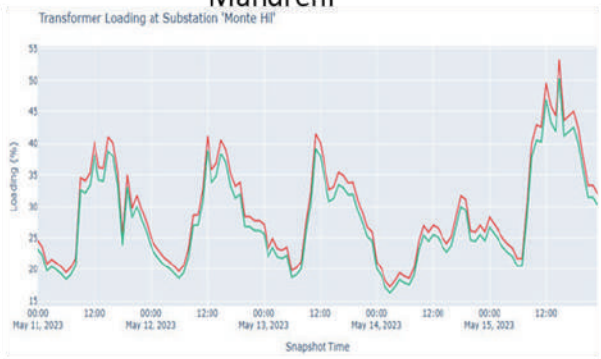
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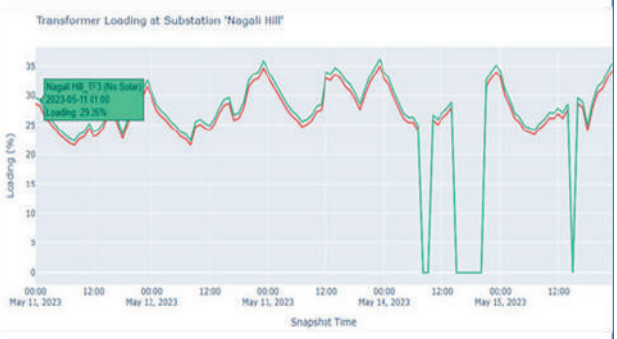
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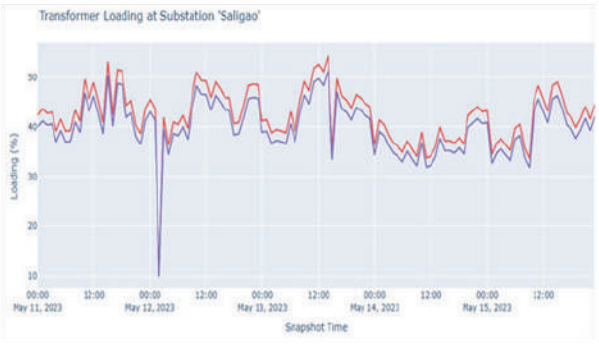
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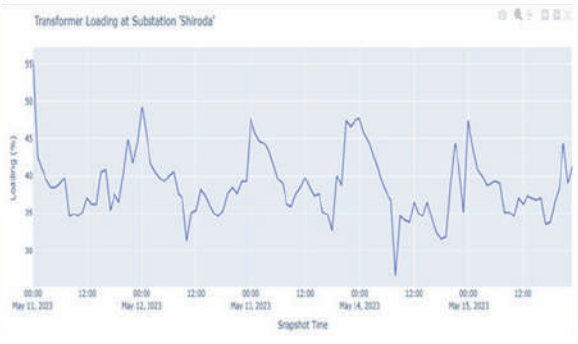
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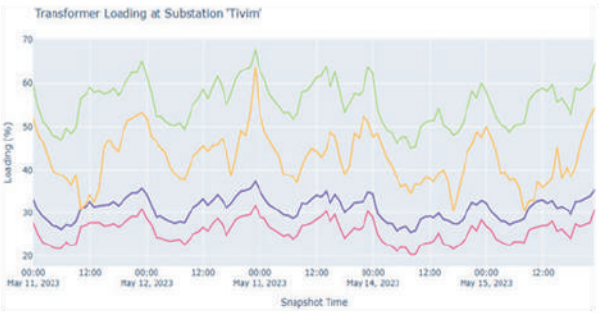
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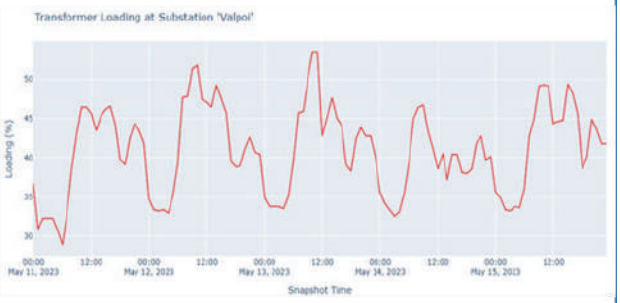
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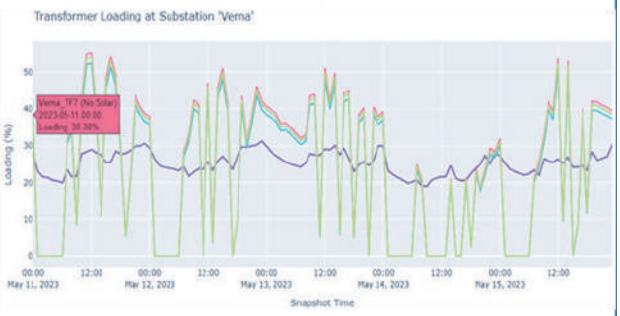
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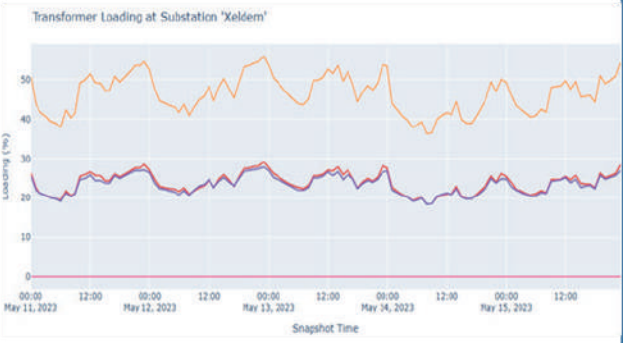
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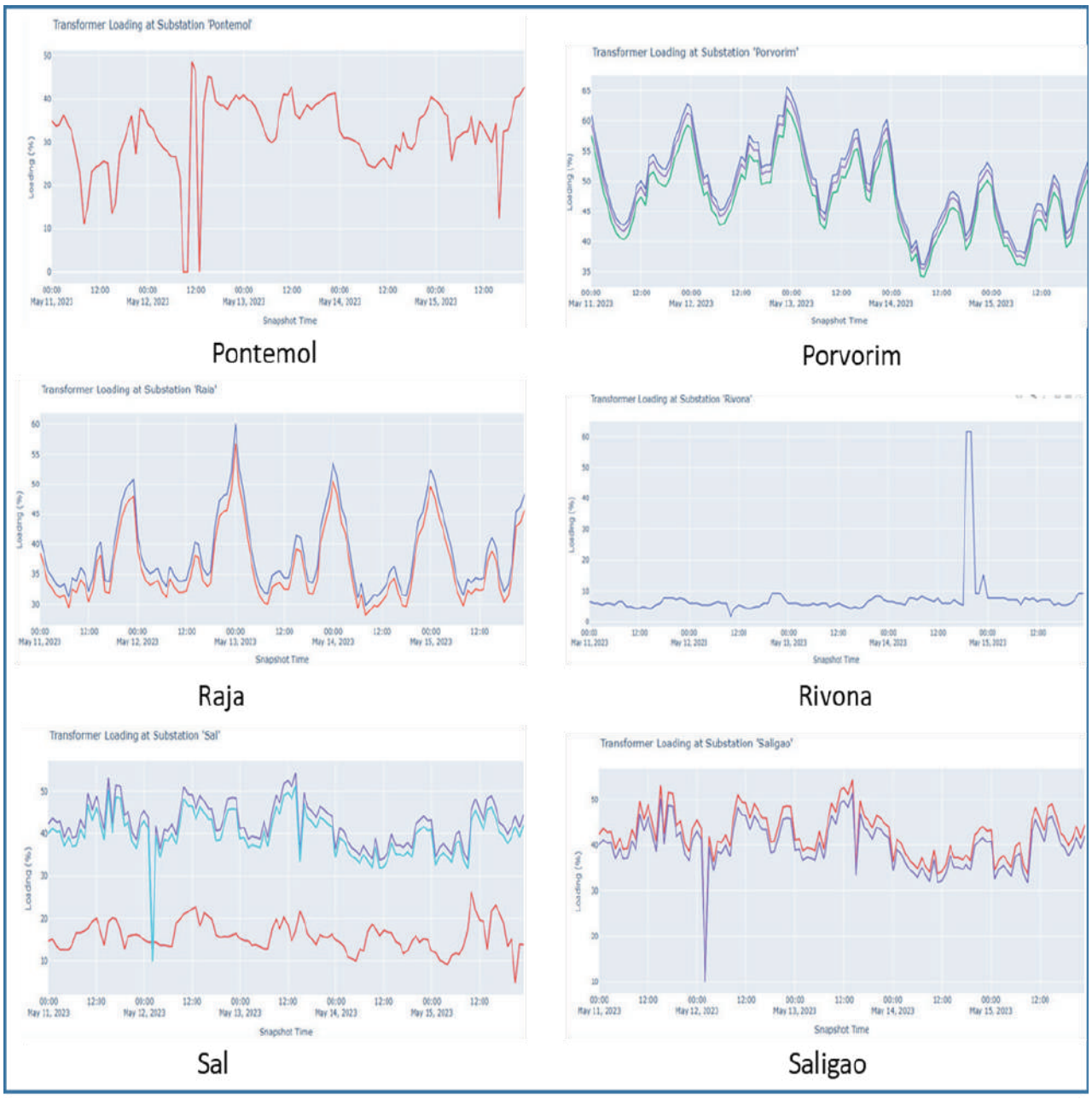


Figure 16: Transformer loading status by substations for the month of May 2023

However, summarized results for the selected substations such as Anjuna, Benaulim, Canacona, Carmona, KRC, Nagoa, Porvorim, and Saligao as analyzed considering a representative loading for January, May, August, and October 2023 which were required for the subsequent site suitability analysis have been depicted below in table 3.

Table 3: Seasonal Loading Profile Table (2023)

Substation	Month	Feeder Loading (%)	Transformer Loading (%)	Remarks
Anjuna	January	20–50	~40	Low-moderate load
	May	45	70–80	Approaching high transformer load
	August	35-65	70–80	Moderate feeders, high transformer
	October	30–60	65–75	Seasonal rise in transformer load
Benaulim	January	40–50 (Colva & Betal Batim ≅65)	Max 45	Balanced load
	May	50–70 (Ramada, Trinity ~20)	45–60	Uneven feeder load
	August	45-55–60 (Mobor ~10, Trinity&Ramada≅20)	30–55	Ample spare capacity
	October	40–60 (Mobor, Ramada, Varca, Trinity <20)	40–50	Balanced load with some underutilization
Canacona	January	20-55Gulem~10)	Max 55	Agonda feeder overloaded
	May	~ 40 (Agonda & Pogolem≅60)	Max 60	Consistent overload on Agonda
	August	< 55(Gulem<10%)	40–55	Similar pattern
	October	<60 (Gulem & Bharat Hotel <10)	45–55	Agonda continues to be a hotspot
Carmona	January	20-30	30–40	Underloaded
	May	~30	40–60	Still under capacity
	August	<25	35–40	Good candidate for solar integration
	October	<20	25–40	Highly underutilized
KRC	January	40–50	40–50	Stable
	May	60–80	50–70	Higher load in summer
	August	35–75(MES & Navelim OH ~20)	45–55	Moderate and stable
	October	30–60	40–55	Consistent load
Nagoa	January	<50 (Agarwada≅75)	<50	Local feeder congestion
	May	<70Mainbhatt & Nagao<30)	65–75	High feeder stress
	August	45–80 (Some >100)	45–55	Overloaded feeders
	October	60–80(Sanqwadi & Nagao ≅10-20	50–60	Needs capacity upgrade planning
Porvorim	January	20–70	<50	Stable
	May	20–70(Chogum≅10)	50–65	High single-feeder load
	August	25–50	40–50	Balanced
	October	40–70 (Chowgum & Salai <20)	<55	Growing but within limits
Saligao	January	<60	<40	Under capacity
	May	<80 (Gauravaddo & Shervani<20)	~<50	Moderate usage
	August	<80 (Nerul & Gauravaddo >80)	~<40	Good headroom
	October	<80	30–45	Consistently underutilized

Source: Authors' estimated using the Goa-PyPSA model

Summary Findings

- The existing distribution network, particularly 33 kV and 11 kV lines, is operating at over 60% capacity, highlighting the need for grid reinforcement and expansion to accommodate increased RE penetration.
- The power transformers are loaded on an average of 32% and a maximum of up to 77%.
- Evening peak loads are higher than the day time which indicates higher solar injection requires battery storage to reduce curtailment.





7.0 Identification of suitable sites for Solar installation



Site Suitability Assessment Framework for Solar PV Integration is using Multi-Criteria Decision (MCD) and GIS-based Analysis

Higer level of RE integration into the distribution network necessitates strategic and data-driven analysis for seamless integration. It is important to understand the electrical local network condition along with other non-technical but crucial information like LULC, elevation, population, density of physical infrastructure like building, road etc. Identification of suitable sites of RE (viz. Solar) therefore, needs careful consideration of multiple criteria which could be prioritize using weighted factors assigned by the stakeholders and the beneficiaries. In this context, a robust Site Suitability Assessment Framework has been developed using a Multi-Criteria Decision (MCD)[20] methodology depicted in Fig. 17, integrated with Geographic Information

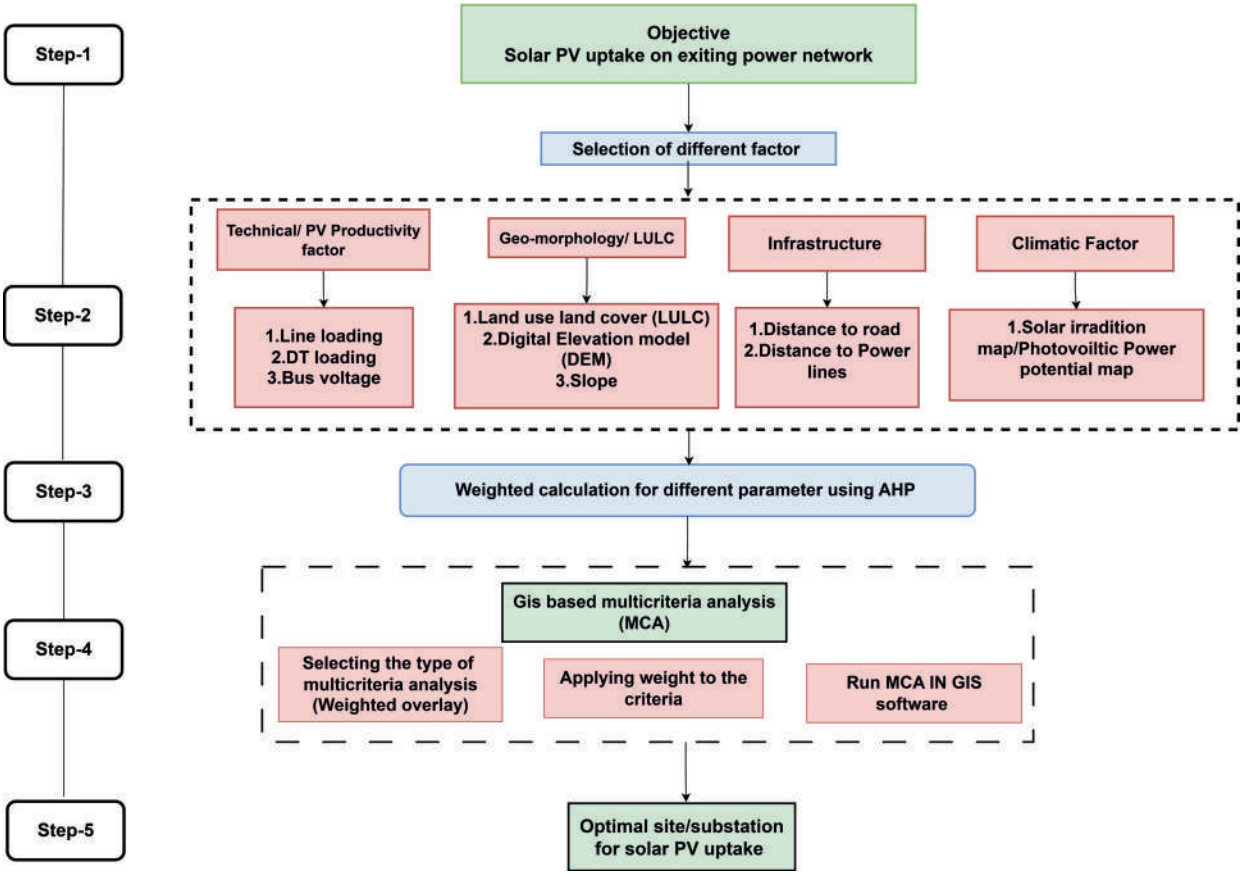


Figure 17: Site suitability assessment of solar uptake – a multi-criteria decision (MCD) Framework.

System (GIS) tools and load flow analysis. This framework aims to identify optimal locations for photovoltaic (PV) installations, balancing technical feasibility with spatial, infrastructural, and climatic considerations. The framework helps to identify suitable sites for establishing solar PV systems in the select area and network.

The site suitability framework ensures that the selected solar sites are not only technically feasible but also aligned with local land use, accessibility, and solar resource availability, whose GIS layers are depicted in Fig. 18 (a-g). The site suitability assessment involves the selection of a comprehensive set of criteria categorized into four broad domains:

The following section describes in detail various site suitability factors considered in this framework.

a) Technical Factors

This category includes parameters that reflect the electrical network's current operational conditions and constraints. Specifically:

- Line Loading (LL)
- Transformer Loading

These parameters are derived from load flow analysis conducted on the existing network using the PyPSA (Python for Power System Analysis) tool. The model output shows the electrical parameters of the network infrastructure, evaluating how power flows across lines and buses. The resulting line and transformer loading values help identify substations or feeders that are either overloaded or underutilized, which is critical for assessing the integration potential of additional loads such as PV generators. Moreover, the GIS layers are created using ArcGIS for line and transformer loading percentages and are depicted in Figs. 18 (f) and (g) respectively.

b) Geo-Morphological factor:

Land-related factors are equally essential in determining site suitability for any renewable energy generation plant setup. These include:

- Land Use and Land Cover (LULC) - The main factor influencing the process by which an area's landscape changes is LULC. The LULC map depicted in Fig. 18 (a) is derived from Landsat-8 using supervised classification in ArcGIS software, wherein four classes, such as agricultural land, built-up, forest, and waterbodies, are identified. The classes identify suitable zones, such as barren land or industrial areas, and water bodies and existing built-up areas are fixed constraints.
- Slope (Tilt of the land)- It is a critical factor in solar PV site selection because it directly affects technical performance, construction feasibility, and long-term economics. A site with a moderate slope aligned toward the sun (south-facing in the Northern Hemisphere, north-facing in the Southern Hemisphere) can enhance solar radiation capture. Steeper or irregular slopes may cause self-shading or shadows from nearby terrain, reducing generation. Flat or gently sloping land (<5%) is ideal because it minimizes earthwork, grading, and mounting structure costs. Steep slopes require more civil works (cut-and-fill, terracing, stronger foundations). Very steep slopes can create erosion and water runoff issues, affecting soil stability and

panel supports. The slope map shown in Fig. 18 (c) has been created from the ASTER DEM satellite image of the study area. The most adequate slopes (lower slopes) were combined with the most suitable aspect (mainly the west part). Due to their low economic viability, high slope sites are not suitable for solar PV.

- Elevation- Higher elevations often receive stronger solar radiation (thinner atmosphere, less scattering), which improves PV efficiency. PV panels lose efficiency at higher ambient temperatures. Elevated sites are usually cooler, helping panels operate more efficiently. DEM in Fig. 18 (d) contains the elevation profile of the area ranging from 0 to 1026 m. The eastern and southeastern sides signify high altitude, considering less suitable areas, whereas the western coastal parts belong to a low elevation, considered more suitable areas for solar PV.

c) Infrastructure Proximity

- Infrastructure-related factors reflect the practical accessibility and connectivity of a site, including Distance to existing roads. This parameter is also vital for construction and operational access of solar PV as well as EV charging stations. The road network is extracted from the Open Street Map (OSM), and proximity to road accessibility was calculated using the Euclidean Distance tool in ArcGIS, and the final road network layer is depicted in Fig. 18 (e).

d) Climatic Factors:

Climatic and environmental conditions significantly influence PV energy generation. GHI is a direct outcome of climatic factors like cloud cover, humidity, aerosols, elevation, and latitude. That's why solar PV potential maps are usually built from long-term GHI datasets, tightly tied to local climate and weather variability. High humidity absorbs and scatters sunlight, reducing solar irradiance. Coastal and equatorial regions often see lower GHI compared to arid zones. Satellite-based irradiance models are used to estimate the ground-level solar radiation product, such as Global Horizontal Irradiance (GHI) layer depicted in Fig. 18 (b). Further, the GHI layer is used to calculate the potential of solar PV.

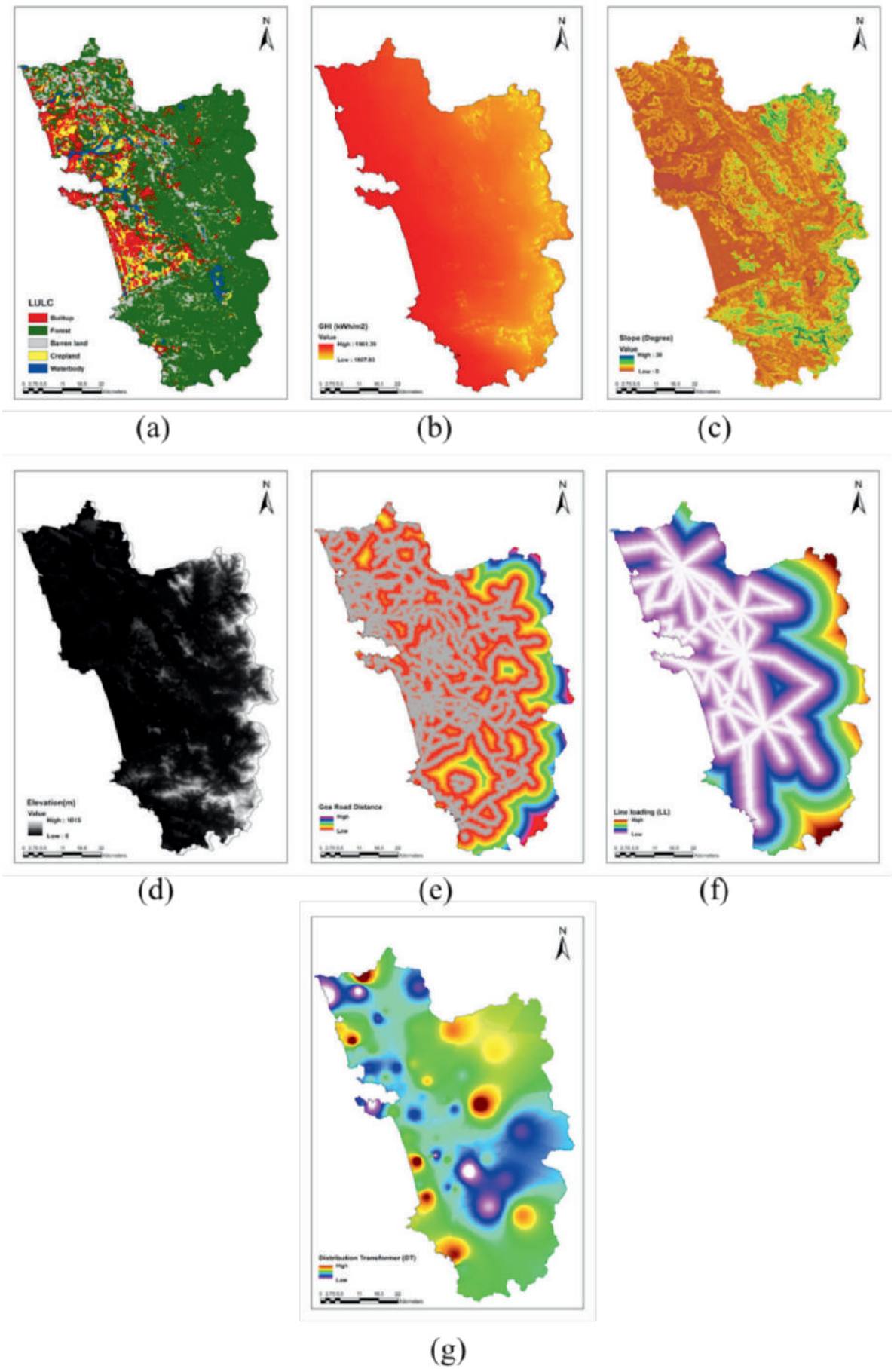


Figure 18: Parameter maps a) LULC b) GHI c) Slope d) Elevation e) Road Distance f) Line loading g) Power Transformer.

The input datasets utilized in the GIS model underwent various raster processing techniques and spatial analyses to carry out a multi-criteria decision model using ArcGIS software. All the layers are resampled to the same resolution at 30 m and the same UTM projection system. These maps are reclassified into a 1 to 5 scale, indicating very low to very high using natural breaks compatible with the weighted overlay tool. These procedures generate the final seven input layers for the MCDM process: Line Loading, Power Transformer Loading, LULC, DEM, Slope, GHI, and proximity to road infrastructure.

Analytical Hierarchy Process (AHP) - AHP [21] is a structured decision-making technique that quantifies the relative importance of each factor based on expert judgment or empirical analysis. A pairwise comparison matrix is conducted between all criteria, leading to the calculation of normalized weights that reflect each factor's contribution to the overall site suitability. It incorporates assigning different weights to the seven selected individual factors, which are then rated on a scale from 1 to 9 based on their relative significance as indicated in Table 4, as Saaty's scale of preference.

Table 4: Saaty's Scale of Preference

Intensity importance	Definition
1	Equal Importance
3	Moderate importance for one over another
5	Essential or Strong Importance
7	Very strong importance
9	Extreme Importance
2, 4, 6, 8	Intermediate values

AHP also offers a quantitative method to assess the consistency of the assigned preferences. The reliability of the judgments or the comparison matrix can be evaluated using the Consistency Ratio (CR), which determines whether the preferences are acceptably consistent. A set of preferences is considered consistent only if the CR is less than or equal to 0.10. The consistency ratio is calculated using the formula, as given in equation (4):

$$CR = \frac{CI}{RI} \qquad (4)$$

Table 5: Random Index (RI) Value According to the Parameters

Size of Matrix (n)	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

CI and RI [22] values are defined by the number of parameters (n) as listed in Table 5. Since we have considered only 7 parameters (layers) for this study, hence, the RI value is taken as 1.32. The consistency index (CI) is expressed as shown in equation (5):

$$CI = \frac{(\lambda_{max} - 1)}{n - 1} \quad (5)$$

where λ_{max} is the largest eigenvalue of the comparison matrix, and n is the number of criteria. Using Eq. (2), the Consistency Index (CI) is calculated and then used to estimate the Consistency Ratio (CR). Based on Eq. (1), the CR is found to be 0.09, using CI and RI values of 0.12 and 1.32, respectively. The eigenvector, which indicates the priority weight of each criterion, was computed, and the sum of all weights is equal to one, as represented in Table 6. The reclassified raster layers are assigned to their respective weights (W) based on the consistent comparison matrix listed in Table 7. Furthermore, the site suitability map is generated using a weighted overlay tool in the ArcGIS software, and the Site Suitability Index (SSI) values obtained from Equation (6).

Table 6: Weighted of Parameters

Parameters	Weighted
WGHI	0.24
WTL	0.29
WLL	0.27
WLULC	0.07
WElevation	0.06
WSlope	0.04
WRoadNet	0.03

Table 7: Pairwise Comparison Matrix of the Adopted Decision Criteria

	GHI	Transformer Loading (TL)	Line Loading (LL)	LULC	Elevation	Slope	Road Network
GHI	1	1	1	7	5	5	3
Transformer Loading (TL)	1	1	1	7	7	5	7
Line loading (LL)	1	1	1	7	5	7	5
LULC	0.14	0.14	0.14	1	2	3	3
Elevation	0.2	0.14	0.2	0.5	1	2	5
Slope	0.2	0.2	0.14	0.33	0.5	1	2
Road Network	0.33	0.14	0.2	0.33	0.2	0.5	1

$$SSI = (W_{GHI} \times GHI) + (W_{TL} \times TL) + (W_{LL} \times TL) + (W_{LULC} \times LULC) + (W_{Elevation} \times Elevation) + (W_{Slope} \times Slope) + (W_{RoadNet} \times RoadNet) \quad (6)$$

Based on this analysis, the final output suitability map is categorized into three classes: high, medium, and low. As a result, the site suitability map, illustrated in Fig. 19 (a-c), the western part of the coastal area exhibits a greater concentration of highly suitable sites, 302.75 km2 for utility-scale solar PV power plants, primarily because of its high solar irradiance, gentle terrain, and proximity to major roads, transmission lines, and urban centers. It is also observed that a limited number of suitable sites also exist in the south and south-western parts of the study area. Narrow strips of suitable land are also identified along the northern part. In contrast, the eastern region, which encompasses the dense forest, is largely unsuitable for such installations due to high altitude and the sparse presence of major roads, transmission lines, and urban settlements. Fig. 19 (a-c) illustrates the season-wise suitability map for January, May, and August, considering the respective month-wise transformer loading, line loading, and GHI layer. From these figures, it is shown that May has the maximum suitable area, so May's suitability map is considered for further analysis.

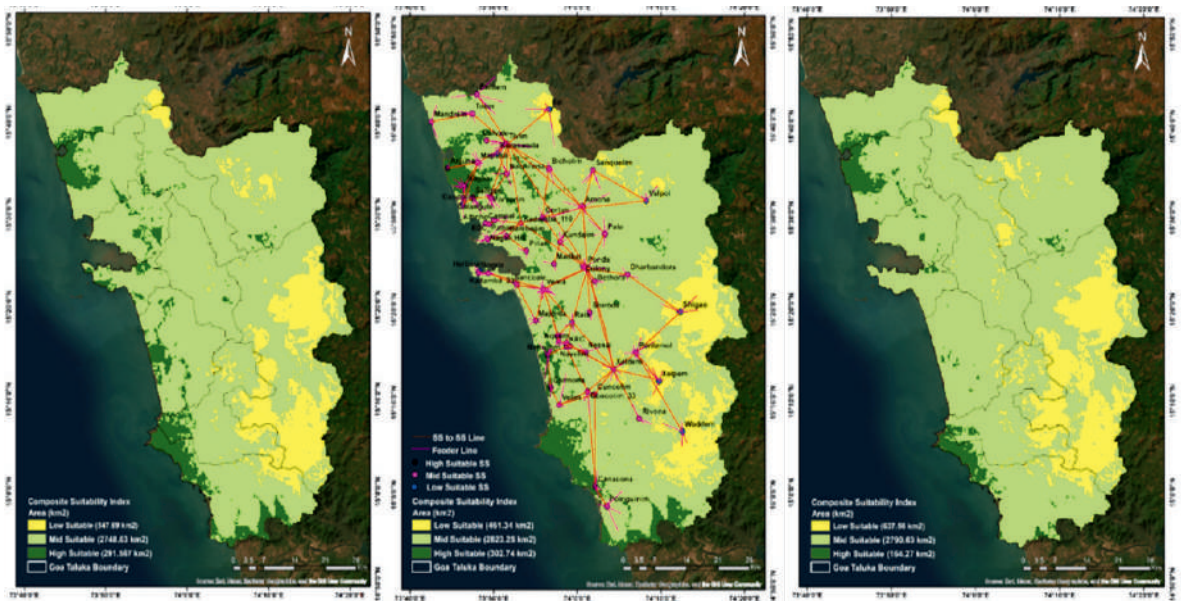


Figure 19: Comparison of month-wise site suitability map: a) January, b) May, c) August.

The site suitability map, illustrated in Fig. 20, highlights the solar PV uptake potential across multiple substations in Goa by analyzing a 3 km radius around each highest suitable substation. A total of eight substations, namely Anjuna, Benaulim, Canacona, Carmona, KRC, Nagoa, Porvorim, and Saligao, are identified as the most suitable locations for injecting solar. A 3 km radius buffer around each substation was adopted to evaluate the local solar potential, with the intent of minimizing transmission losses and ensuring ease of integration with the existing distribution network. This assessment utilized multi-layered geospatial data, including rooftop building footprints, water bodies, and agricultural land use, to quantify the deployable area for three distinct solar

PV installation models: rooftop PV, floating solar, and agro-PV systems. The central map of Fig. 20 illustrates the composite solar suitability index, derived through GIS-based Multi-Criteria Decision Modeling (MCDM), which classifies the regions into low, medium, and high suitability zones based on physical, technical, and environmental constraints. The left picture of Fig. 20 indicates the rooftop solar potential around a 3 km radius of Anjuna substation, whereas the right picture indicates the solar potential on agricultural and water bodies. To quantify the solar generation potential within the selected buffer zones, the following assumptions were made:

- 50% of the total rooftop area was considered usable for PV installations.
- 10% of agricultural land was considered for agro-PV, balancing food-energy trade-offs.
- 10% of the water body surface area was assumed feasible for floating solar deployment.

The resulting solar potential estimates, summarized in Table 8, reflect the combined capacity from all three installation types. Substations such as KRC, Nagoa, and Porvorim exhibit the highest overall potential due to their sizable available rooftop spaces and high irradiance zones. For example, the KRC substation demonstrates the highest estimated potential at 430.04 MW, primarily driven by extensive rooftop suitability (385.03 MW). On the other hand, Porvorim shows a more balanced distribution across rooftop (217.07 MW), agro-PV (105.31 MW), and floating solar (35.69 MW) options.

Table 8: Estimated Solar PV Potential in MW

Sl.No.	High Suitable Sub-stations	Rooftop	Agri-PV	Waterbodies	Total
1	Anjuna	124	46	47	217
2	Benaulim	140	49	13	203
3	Canacona	62	56	23	142
4	Carmona	73	42	118	233
5	KRC	385	36	8	430
6	Nagoa	230	79	56	365
7	Porvorim	217	105	35	358
8	Saligao	77	29	58	164

Note: The potential estimates reflect only technically and spatially feasible capacities under conservative land-use assumptions.

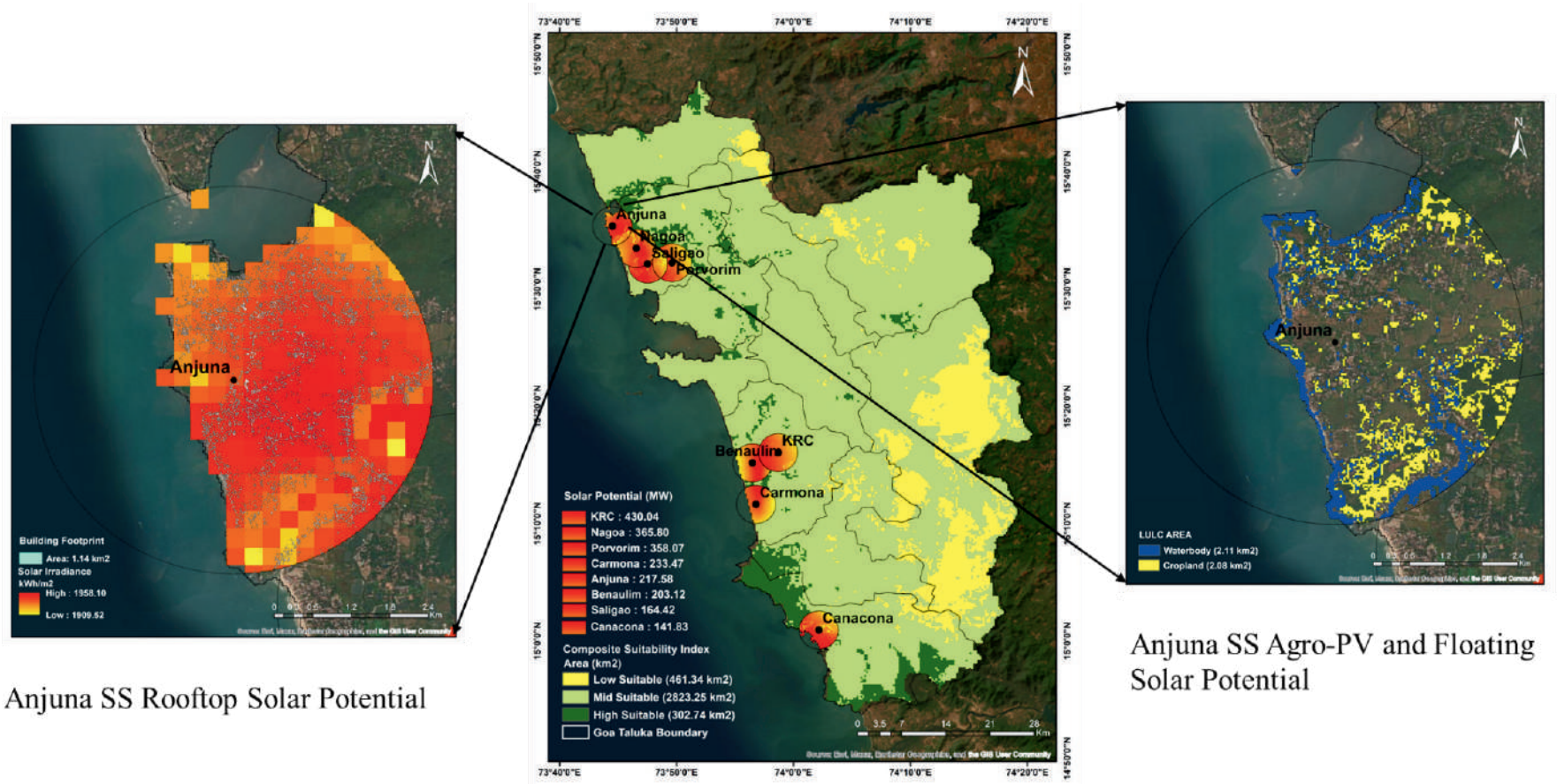


Figure 20: Highest suitable substations for solar PV uptake, along with rooftop, agro-PV, and floating solar potentials around a 3km radius of Anjuna substation.

Further, the estimated total solar PV potential for each substation, as summarized in Table 8, is incorporated into the existing electrical network to assess its impact on the system. A detailed load flow analysis evaluates how this additional solar injection influences line loadings, voltage profiles, and transformer capacities across the distribution network. The findings from these simulations are presented and discussed in the following sub-sections, providing insights into the operational feasibility and resilience enhancement offered by distributed solar PV deployment in Goa's power infrastructure.

8.0 Case studies



Case Studies on Model-Based Capacity Augmentation for Solar Integration and Grid Optimization

In this section, we have described two separate case studies to demonstrate the importance of model-based capacity augmentation planning for solar injection in the network to improve the efficiency of the system as well as reduce the network snapping and faults.

First Case Study is to demonstrate how to identify the maximum solar injection potential at a DT level (including ground-mounted and rooftop) based on the impact analysis of solar injection at the DT level in a select feeder (Porvorim Bazar) of a suitable substation like Porvorim.

The second case-study demonstrates how to assess the requirement of grid level battery storage integrated solar capacity augmentation in the network and the impacts on enhancing the solar generation suitable for RPO determination and planning.

8.1 Solar injection at DT level

To demonstrate the impact of solar injection at DT level (below 11kV), a representative feeder has been chosen for this study. As Porvorim substation is among those 8 substations which were found to be suitable for solar potential, Porvorim Bazar feeder of the same SS was chosen and analyzed for this case study. Moreover, as the Porvorim Bazar feeder has a mixed conductor type characteristic, the power flow analysis pertaining to line loading were also evaluated for both solar and non-solar hours. A Representative model has been developed considering the Porvorim Bazar feeder, which is explained below.

Although most of the data were received as excel and pdf format, only the hourly load data at 11kV feeder level was images of handwritten document. The hourly load profile for 5 representative days (11th, 12th, 13th, 14th and 15th) for the month of May 2023 have been considered for the case study. The image file of the hourly load for Porvorim bazar on 11th May has been shown below in figure 21.

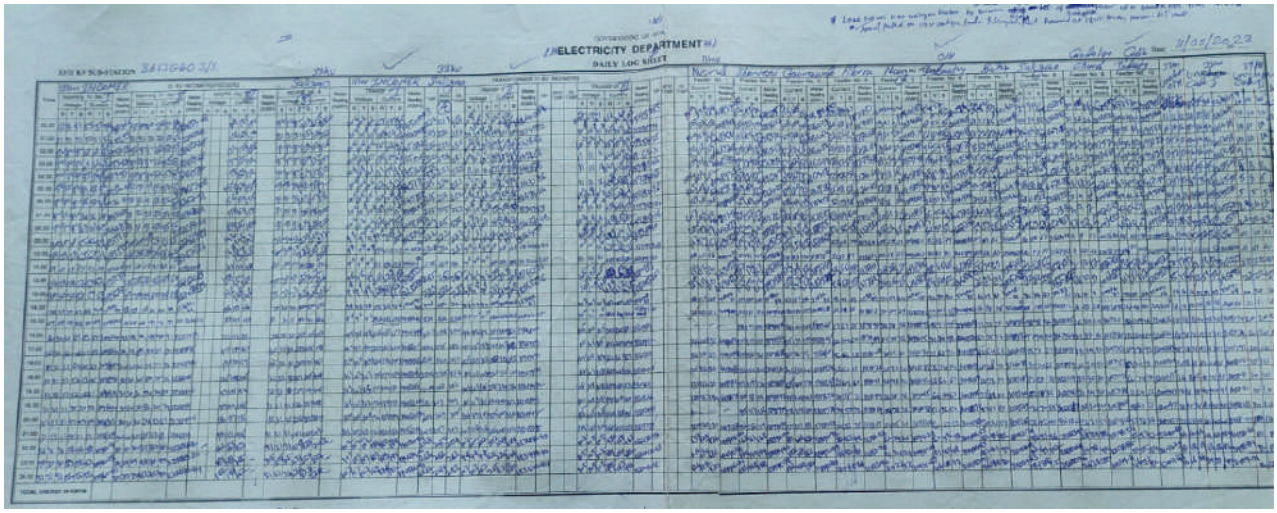


Figure 21: Image of hourly load data of Provorim Bazar feeder

8.1.1 Preparing Goa-PyPSA Model Compatible Input Files

As already mentioned in the earlier section, 10 input files (.csv) are required for network building. These are namely, buses.csv, lines.csv, loads.csv, generators.csv, loads-p_set.csv, loads-q_set.csv, generators-p_set.csv, transformers.csv, transformer_types.csv. and snapshots.csv. (for details, please see section 5.2.2).

At first, the buses.csv files were prepared considering the SLD diagrams (at Sub Station) at 33kV and 11kV level, so that we can enter the information of all the connecting points of the network along with its geographical location. As we need to define the Generator bus, as well as the load bus for power flow study, we collected the information from the SLD files received from GED. The data corresponding to the Porvorim Bazar feeder has been shown below in Figures 22 and 23.

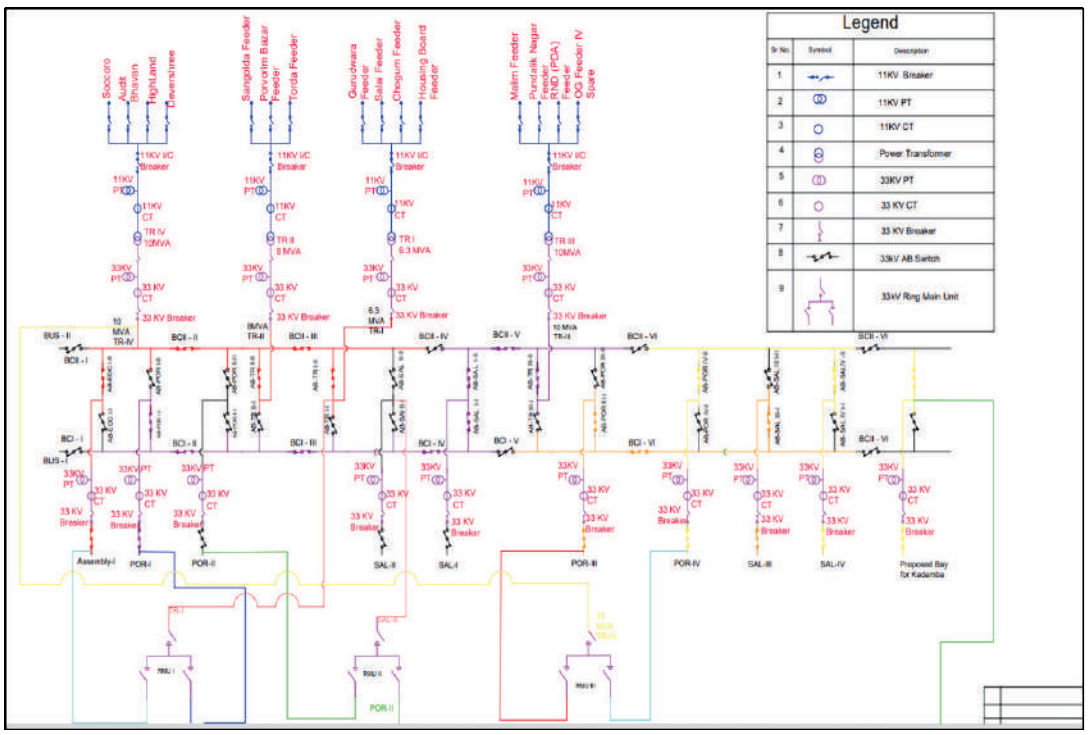


Figure 22: SLD of Porvorim Sub-station showing the Provorim Bazar feeder

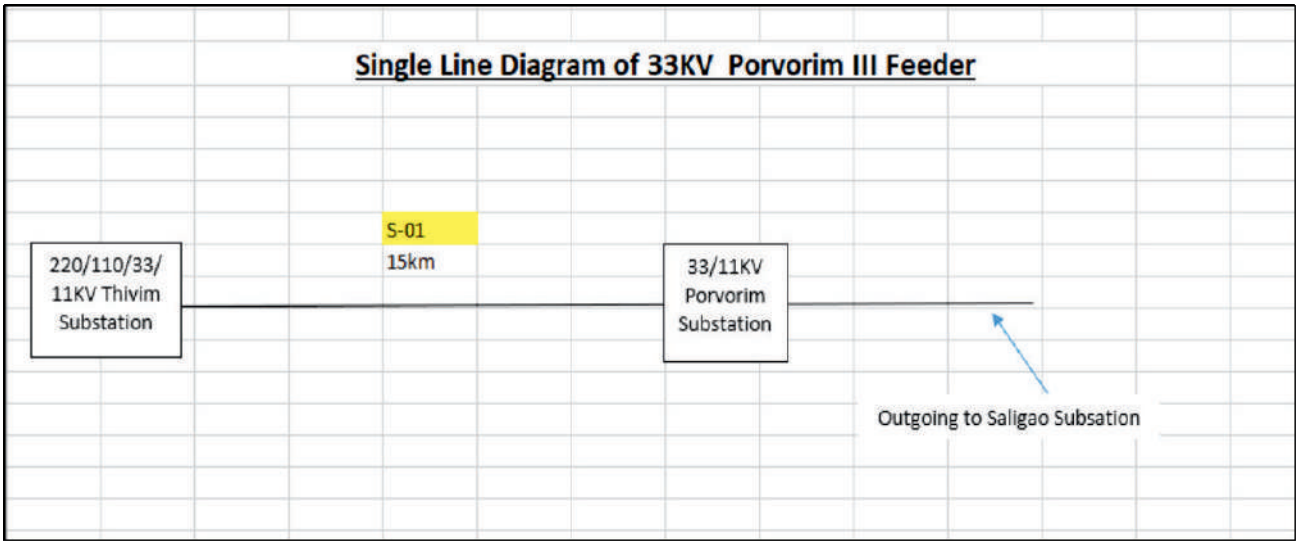


Figure 23: SLD of incoming of Porvorim Sub-station from Thivim

The subsequent network for the feeder is built using the detailed SLD of the sub-station and feeder line provided by the GED. The feeder is split into 5 subsections with different conductor types. Figure 24 below shows the SLD of the feeder.

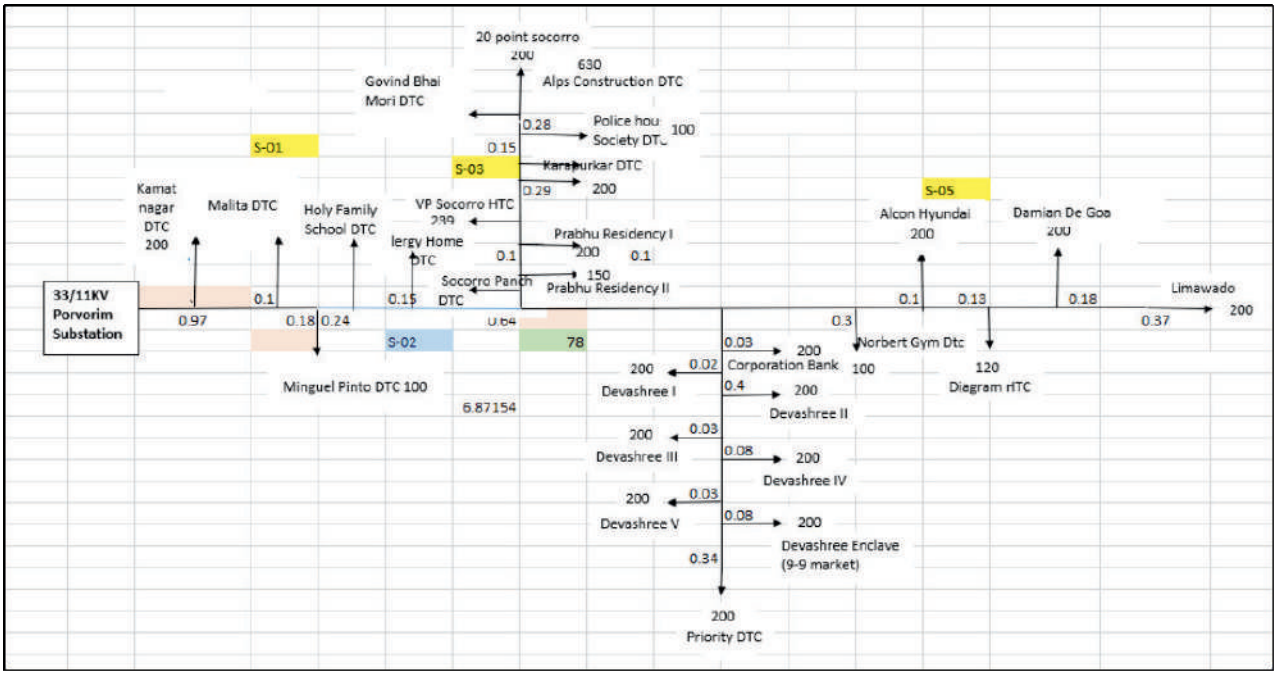


Figure 24: SLD of Porvorim Bazar 11 kV feeder

Based on these SLD diagrams, all the connecting components for Porvorim Bazar feeder (Tivim220/33kV SS, Porvorim 33/11 SS, and further 27 DT connected to Porvorim Bazar feeder) were entered in the buses.csv file. The details of this file are provided in the section "Goa-PyPSA Model Input Files: buses.csv" under the annexure.

Next, the lines.csv files were prepared from the given SLD data as shown above in figure 24 and the data received from GED related to the line conductors. These are shown below in Figures 25 and 26 for 33kV and 11kV lines, respectively.

Sr no	Name of Feeder	Voltage in kv 220/110/33/11	Section	Type of conductor	Size	Rated Current of Conductor	Total HTC/DTC on section	Resistance	Reactance	Length
1	33kV Porvorim III Feeder	33	S-01	XLPE Cable	3C X 400 sq.mm	630A in ground	0	1.69	1.9097	16.9

Figure 25: Porvorim Bazar line(33kV) parameters

Sr no	Name of Feeder	Voltage in kV 220/110/33/11	Section	Type of conductor	Size	Rated Current of Conductor	Total HTC/DTC on the section	Resistance	Reactance	Length	total connected load in kVA
1	Porvorim Bazaar	11	S-01	ACSR	Raccoon	250A in air	3	1.076	0.024	1.185	400
2	Porvorim Bazaar	11kV	S-02	Xlpe	300sqmm	355 A in ground	2	0.092	0.014	0.71	300
3	Porvorim Bazaar	11kV	S-03	ACSR	Raccoon	250A in air	9	2.097	0.046	2.31	2119
4	Porvorim Bazaar	11kV	S-04	ACSR	Raccoon	250A in air	8	0.744	0.016	0.82	1600
5	Porvorim Bazaar	11kV	S-05	ACSR	Raccoon	250A in air	5	0.935	0.021	1.03	1020

Figure 26: Porvorim Bazar line(11kV) parameters

The detail calculations for every parameter related to the lines/feeders along with the lines.csv file are provided in the section "Goa-PyPSA Model Input Files: lines.csv" under the annexure.

Next, the transformer.csv file was prepared from the SLD diagram, shown in figure, which identifies 8MVA, 33/11 kV transformer at which Porvorim Bazar feeder is connected to. Furthermore, DTs were identified from the 11kV SLD shown in Figure 27 and the data received as shown below:

Sr no	Name of Feeder	DTC/HTC name	DT capacity in kVA	Impedance voltage %	Full load primary current	Full load secondary current	Fault in MVA	Three Phase Fault current	Short circuit current at 11kV side in kA	Short circuit current at LT side
1	11kV Porvorim Bazar Feeder	Limawado	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
2	11kV Porvorim Bazar Feeder	Damian De Goa	120	4.75	6.3	159.96	2.5263158	3.32 KA	0.13 KA	3.32 KA
3	11kV Porvorim Bazar Feeder	Diagram HTC	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
4	11kV Porvorim Bazar Feeder	Alcon Hyundai	100	4.82	5.25	133.3	2.0746888	2.72 KA	0.11 KA	2.72 KA
5	11kV Porvorim Bazar Feeder	Priority DTC	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
6	11kV Porvorim Bazar Feeder	Devashree V	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
7	11kV Porvorim Bazar Feeder	Devashree IV	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
8	11kV Porvorim Bazar Feeder	Devashree III	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
9	11kV Porvorim Bazar Feeder	Devashree II	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
10	11kV Porvorim Bazar Feeder	Devashree Enclave (9-9 market	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
11	11kV Porvorim Bazar Feeder	Devashree I	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
12	11kV Porvorim Bazar Feeder	Corporation Bank	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
13	11kV Porvorim Bazar Feeder	Norbert Gym Dtc	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
14	11kV Porvorim Bazar Feeder	Police housing Society DTC	100	4.82	5.25	133.3	2.0746888	2.72 KA	0.11 KA	2.72 KA
15	11kV Porvorim Bazar Feeder	20 point Socorro	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
16	11kV Porvorim Bazar Feeder	Alps Construction DTC	630	4.4	33.08	839.92	14.318182	18.79 KA	0.75 KA	18.79 KA
17	11kV Porvorim Bazar Feeder	20 point Socorro	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
18	11kV Porvorim Bazar Feeder	Karapurkar DTC	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
19	11kV Porvorim Bazar Feeder	VP Socorro HTC	239	4.45	15.23	386.7	5.3707865	7.05 KA	0.34 KA	7.05 KA
20	11kV Porvorim Bazar Feeder	Prabhu Residency I	150	4.75	7.88	200.08	3.1578947	4.14 KA	0.17 KA	4.14 KA
21	11kV Porvorim Bazar Feeder	Prabhu Residency II	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
22	11kV Porvorim Bazar Feeder	VP Socorro DTC	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
23	11kV Porvorim Bazar Feeder	Clergy Home DTC	100	4.82	5.25	133.3	2.0746888	2.72 KA	0.11 KA	2.72 KA
24	11kV Porvorim Bazar Feeder	Holy Family School DTC	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
25	11kV Porvorim Bazar Feeder	Minguel Pinto DTC 100	100	4.82	5.25	133.3	2.0746888	2.72 KA	0.11 KA	2.72 KA
26	11kV Porvorim Bazar Feeder	Kamat Nagar	200	4.51	10.5	266.6	4.4345898	5.82 KA	0.23 KA	5.82 KA
27	11kV Porvorim Bazar Feeder	Malita DTC	100	4.82	5.25	133.3	2.0746888	2.72 KA	0.11 KA	2.72 KA

Figure 27: Parvorim Bazar feeder level DT information

The detail of the transformers.csv file is provided in the section "Goa-PyPSA Model Input Files: transformers.csv" under the annexure.

Next, the loads-p_set.csv and loads-q_set.csv files have been prepared considering the feeder load as shown in figure 21 and from the load distribution as per SLD diagram in figure 24. The detailed calculation and the hourly load profiles have been shown in the section "Goa-PyPSA Model Input Files: loads-p,q_set.csv" under the annexure. The details the generator.csv file, generator-p_max_pu.csv loads.csv file and snapshot.csv are mentioned in the section "Goa-PyPSA Model Input Files: generator.csv" under the annexure-1.

8.1.2 Load duration profile of the PB feeder & DTs

While investigating the Feeder profile and corresponding potential of solar injection it is important that the feeder and DT load durations are analyses adequately. The daily LDC of the feeder is created based on the load data received from the GED on that particular feeder. This provides insights into the upper limit of Solar capacity injection, back feeding and storage requirement for reducing curtailment of the RE generation and improving the overall cost of supply. Figure 28 shows the PV Bazar feeder load duration curve for the 5 representative days of the month of May 2023 as explained above.

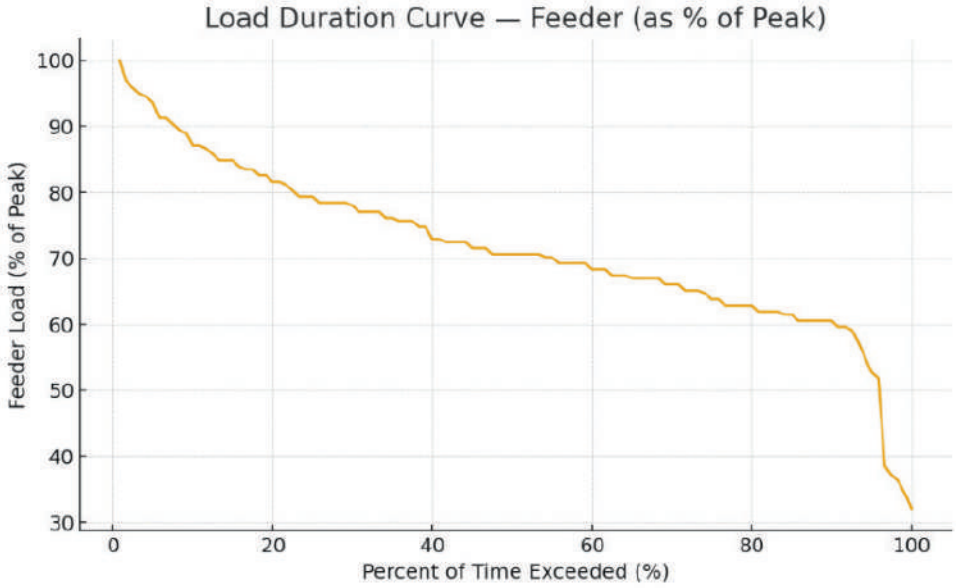


Figure 28: Parvorim Bazar feeder level load duration for 5 days

What this LDC interprets?

- **High load factor:** With the mid-section hovering around 65–72% for most of the year, the implied load factor is roughly ~0.68–0.70. That's a relatively flat feeder with good asset utilization.
- Moderate peakiness: Only ~5–10% of hours are within 10% of peak. That means targeted peak shaving (e.g., a few hours on hot days) could materially defer capacity upgrades
- Strong "base" load: Even in the lowest-load hours the feeder stays above ~30% of peak, so there's a substantial base load.
- Steep tail at the far right: The sharp drop in the last ~5% of hours indicate occasional deep valleys (likely overnight/shoulder-season).

Those few hours dominate reverse-power/voltage-rise risk if you add lots of midday PV without control or storage.

- Hosting-capacity rule of thumb: Without allowing reverse power, aggregate net generation should stay below the minimum load (~32% of peak). If a small amount of back feed is allowed (e.g., 10%), that limit nudges to ~35% of peak. Beyond that, you'd plan on curtailment, smart-inverter controls, or storage.

Figure 29 below shows the 5-day LDC of representative DT25 of the PV Bazar Feeder, which is tested with the solar injection for identification of maximum hosting capacity.

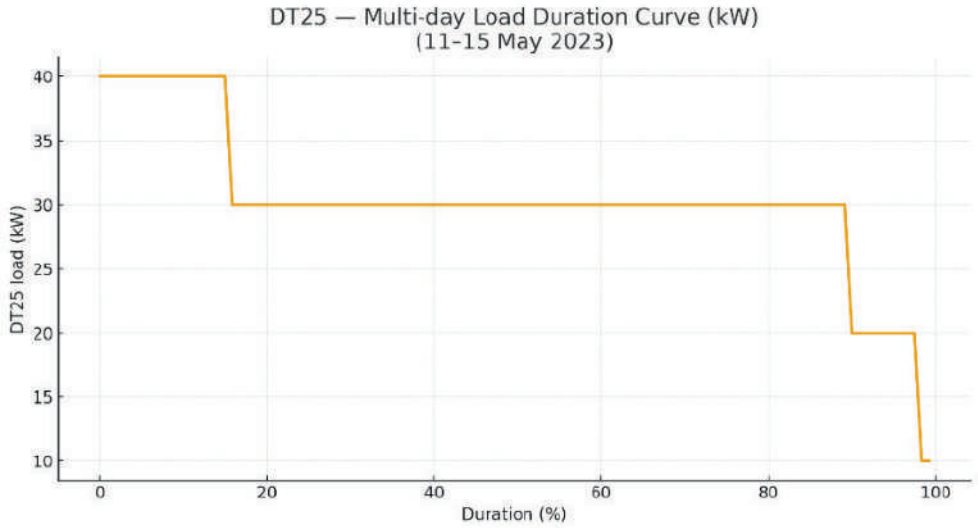


Figure 29: DT25 level load duration for 5 days

What this LDC interprets?

- DT25 sits at ≥30 kW for ~90% of the time, with short peaks to 40 kW.
- The bottom tail drops to 20–10 kW only for the lowest ~10% of hours.
- This shape indicates a fairly flat daily profile with three main plateaus (40 → 30 → 20 → 10 kW), which is useful for sizing firm capacity or storage covering the top 10–15% of durations.

8.1.3 Interpretation of the feeder and DT level load profile

The following section summarizes the findings of the current feeder and DT load profile and corresponding scopes of solar hosting capacity. The major findings are as follows:

- **Concentrated peaks at night:** The top of the duration curve sits flat at ~100% of peak for only the first ~15–20% of hours. That's a classic sign the **daily peak occurs after sunset**, so PV doesn't shave the system peak.
- **Long mid-level plateau:** For ~70–75% of hours the net load sits around **~75% of peak**. This is the "everyday" loading level of the transformer.
- **Midday valley from PV:** A small tail near the end of the curve drops to **~50%** and occasionally **~25% of peak**. Those hours correspond to strong-sun, low native-load periods where PV depresses net load the most (and where reverse power is most likely if export isn't allowed).

That implies an average loading (load factor) on the order of **~75–77% of peak**.

8.1.4 Interpretation under solar injection

The following section explains given the feeder and DT loading condition how to inject solar generation in network managing the evening peak, back feeding conditions and curtailments. The following conditions are considered while developing the solar injection scenarios in the study.

- **Capacity value is low:** Because the peak is in evening/night, incremental PV does **not** reduce the top of the LDC. It lowers energy and midday loading but **won't defer a DT25 upgrade** driven by evening peaks.
- **Midday headroom vs. export limits (hosting capacity)**

a) Minimum net load drops to ~**25–50% of peak** in a few hours.

b) If no backfeed is allowed at DT25, the instantaneous PV hosting capacity is capped by the minimum net load (≈ 25–50% of peak). PV above that will force curtailment or violate reverse-flow rules in those hours.

c) If limited backfeed is allowed (say, X% of peak), the headroom increases to min-load + X%.

- **Operational risk shifts, not disappears**

d) Thermal **risk** remains in the **evening block** (top ~15–20% of hours) where PV is near zero.

e) Voltage / reverse power risks cluster around **midday lows** (the 50%→25% tail).

- **Ramping:** The steep drop from the 100% plateau to ~75% and the midday valley means **sunset ramps** are still pronounced: PV falls quickly while load climbs toward the evening peak.
- **Losses and utilization:** PV lower daytime current and **reduces losses**
- for a large chunk of hours (the ~75% plateau), improving average transformer loading—but **utilization of nameplate capacity** is still dictated by the evening peak.

8.1.3 Baseline Power Flow Scenario (without solar injection)

Using all the above-mentioned data and information the baseline network model for the Porvorim Bazar feeder has been developed. The detailed computation has been explained in the section 'Developing/ twining the real network in PyPSA ' in the Annexure-1.

The results have been obtained considering the 5 days representative hourly load for the month of May. Figure 3 depicts the optimal power (P in MW) occurring at Porvorim Bazar feeder network for 11th May. Similarly, the reactive power (Q in MVAr) flow occurring on these 28 lines connecting the DTs of Porvorim Bazar feeder has been portrayed in figure 31. The total apparent power (S, in MVA) flow for 11th May loadings on Porvorim Bazar feeder has been shown in figure 32.

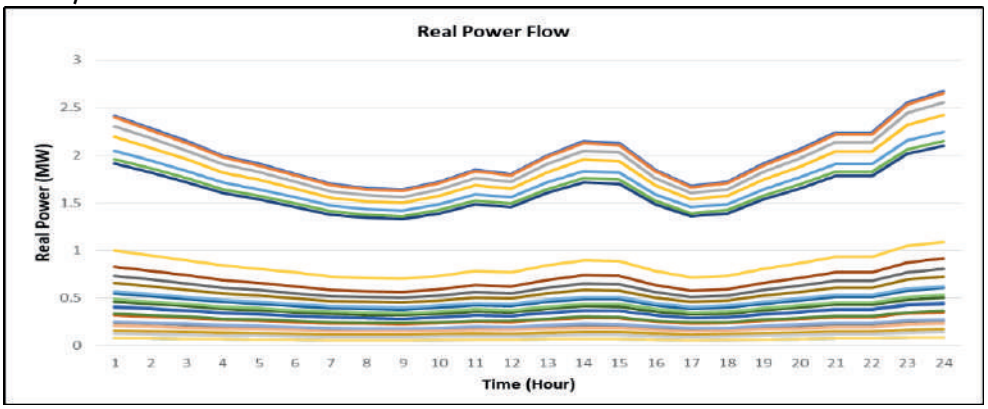


Figure 30: Real Power flow (MW) in 28 lines in Parvorim Bazar feeder on 11th May

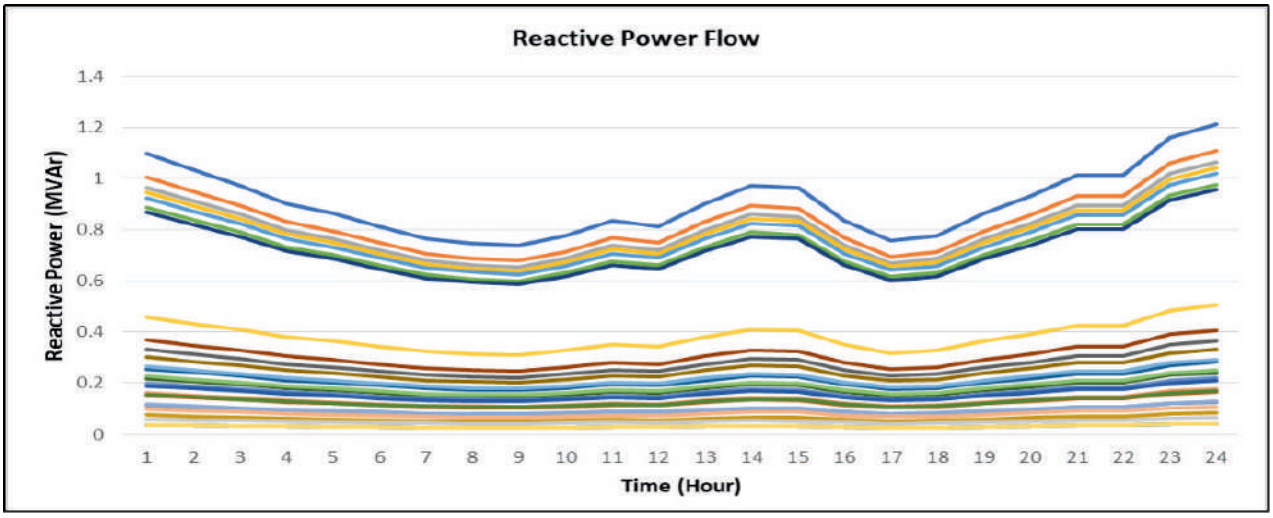


Figure 31: Reactive Power flow (MVAr) in 28 lines in Parvorim Bazar feeder on 11th May

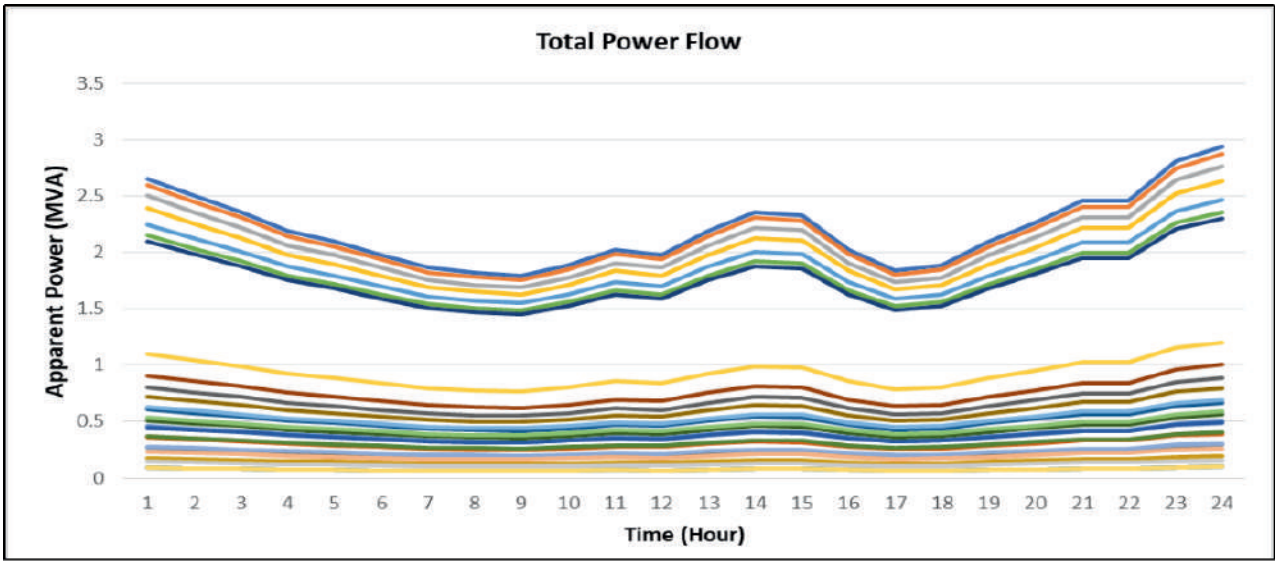


Figure 32: Apparent Power flow (MVA) in 28 line in Parvorim Bazar feeder on 11th May

The representative results for the voltage variation for PB_DT25, i.e Minguel Pinto DTC at both 11kV and 415V connecting points of the network has been depicted in figure 33 and figure 34 respectively.

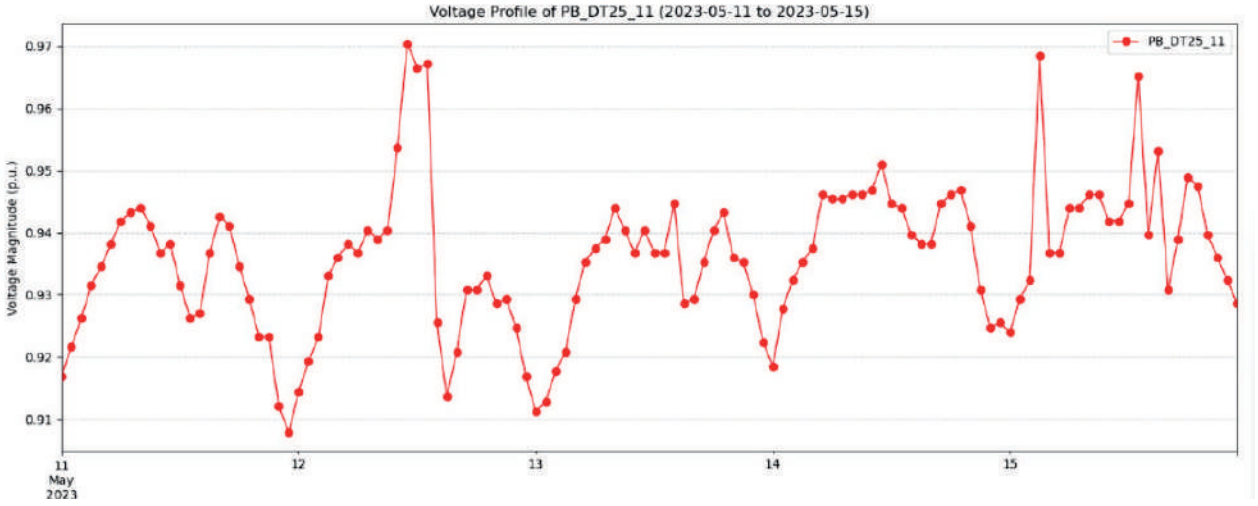


Figure 33: Voltage variation for PB_DT25 (MVA) of Parvorim Bazar feeder AT 11kV point

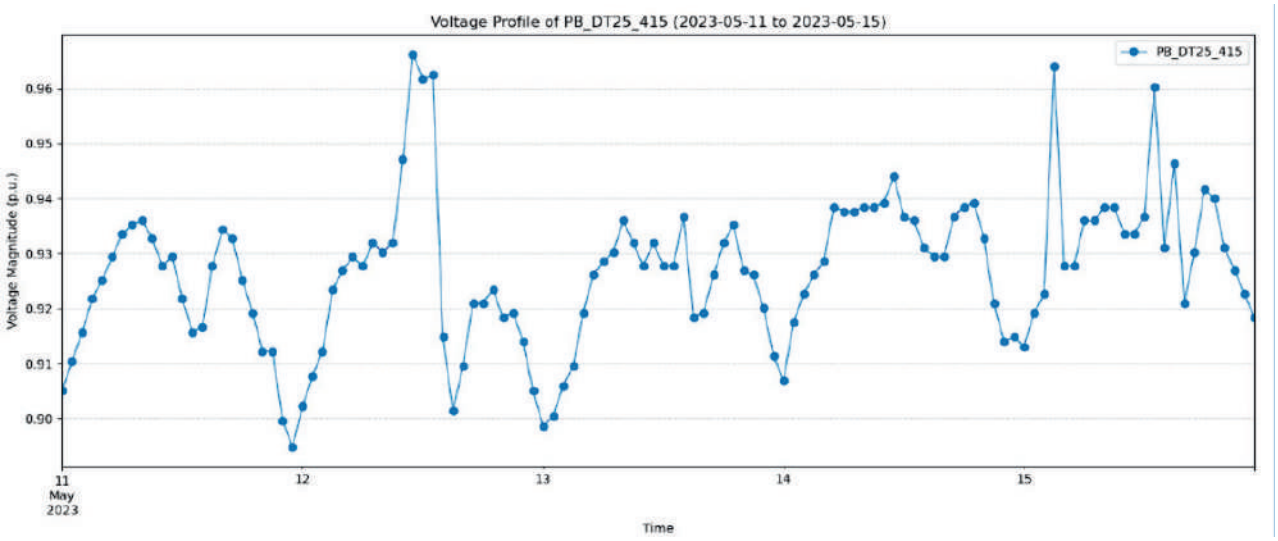


Figure 34: Voltage variation for PB_DT25 (MVA) of Parvorim Bazar feeder AT 415V point

As per CEA guidelines, consumer voltages are generally required to remain within ±6% of the nominal value. Distribution systems are typically designed to meet this standard. On the secondary side of distribution transformers (415 V), consumer voltages are therefore expected to stay within ±6% of the nominal value. For the primary side (11 kV), the same standard is usually targeted; however, practical considerations such as feeder length and technical losses may extend the acceptable variation to about ±10%. In this study, all recorded voltages were found to lie within these permissible limits.

Figure 35 depicts the line loadings for the Porvorim Bazar feeder. All the lines connecting to the DTs have an average load of 35%. However no overloaded lines have been found, for 5 days of May loading.

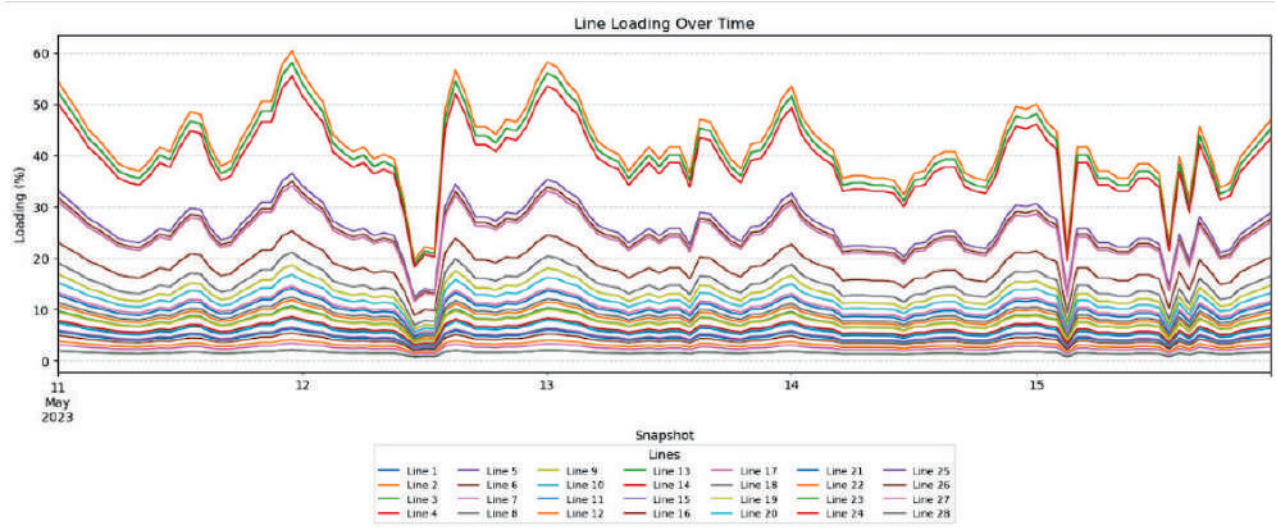


Figure 35: Feeder Loading for all 5 days of May (baseline scenario)

Figures 36 to 40 represent the transformer loading for 11th, 12th, 13th, 14th, and 15th May 2023, respectively, for all the transformers and DT comprising the Provorim Bazar network.

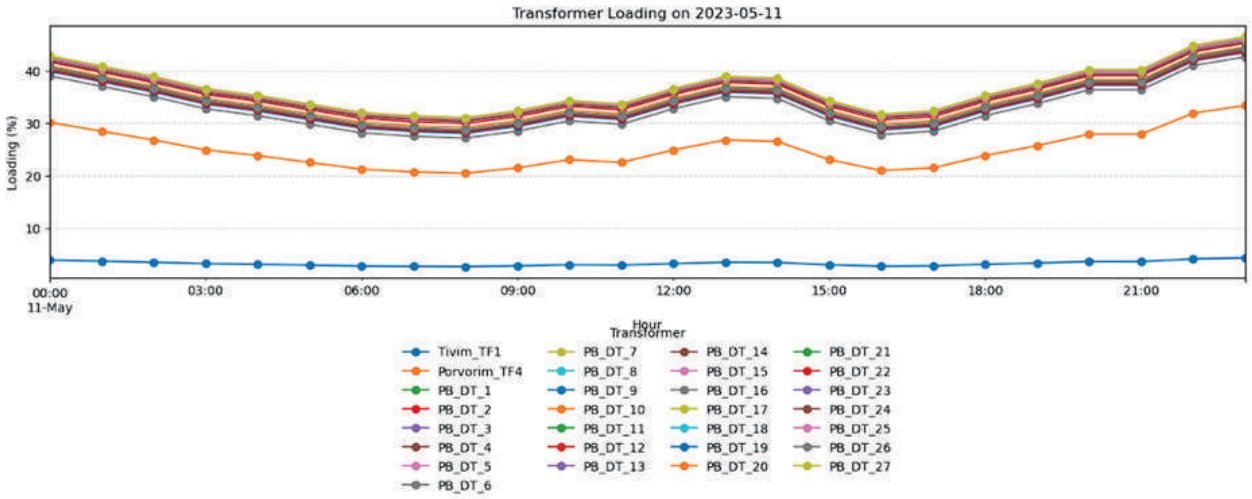


Figure 36: Transformer loading on 11th May(baseline)

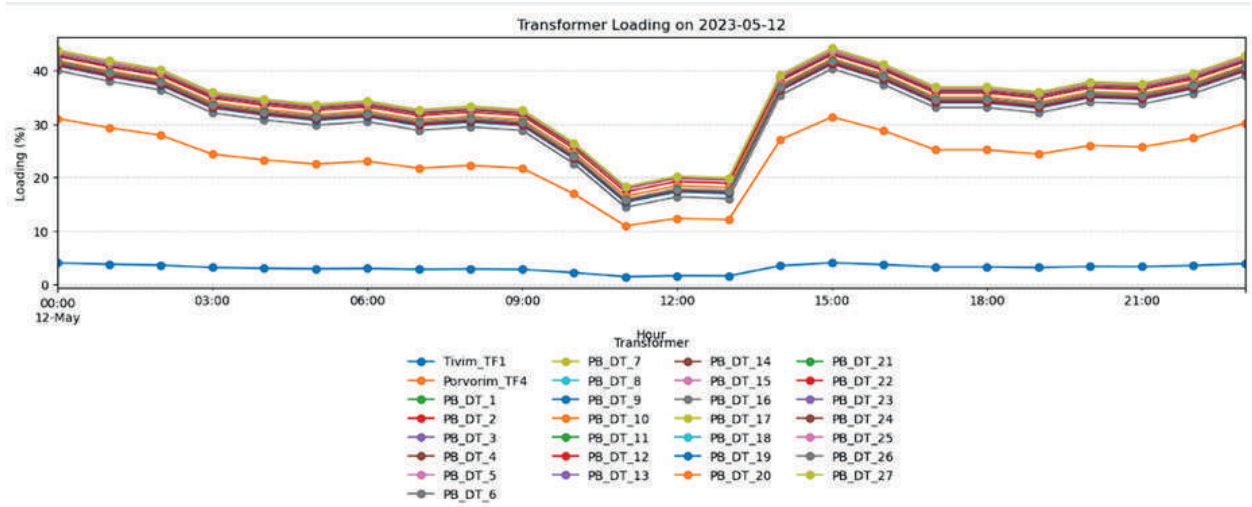


Figure 37: Transformer loading on 12th May(baseline)

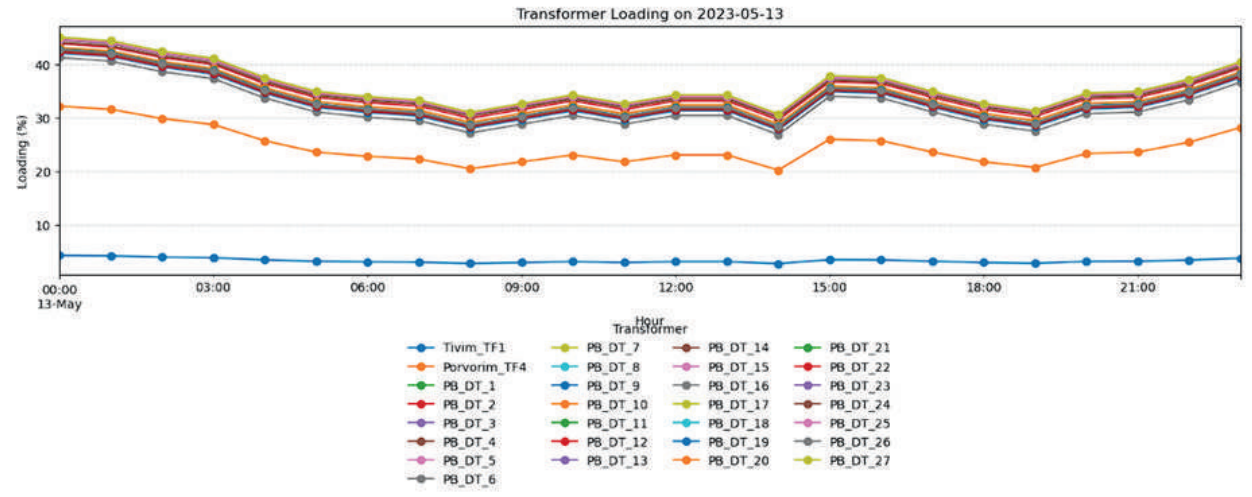


Figure 38: Transformer loading for on 13th May (baseline)

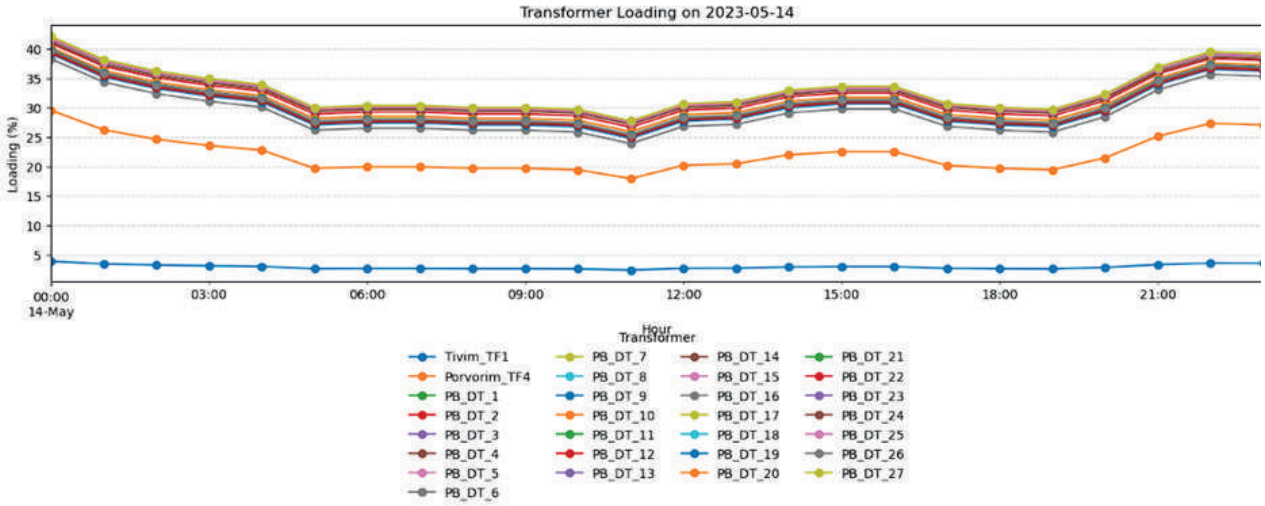


Figure 39: Transformer loading of 14th May(baseline)

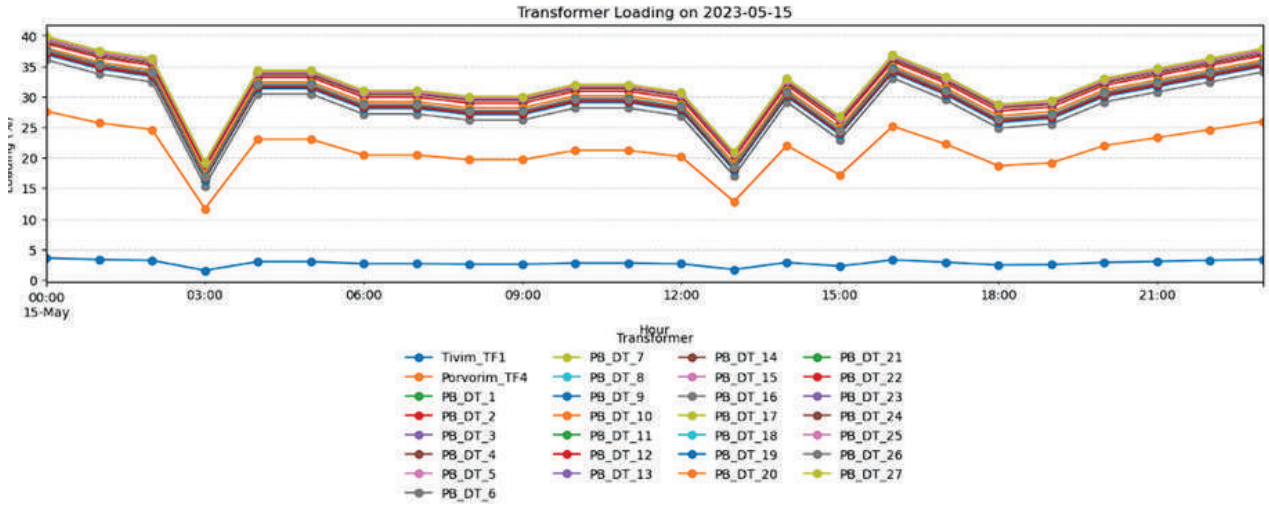


Figure 40: Transformer loading on 15th May (baseline)

The transformer loading for all the 27 DTs have been found to range within 10 to 40% on 11th and 15th May, while this range lies between 15 to 40% for other 3 days. Transformer loading remains comfortably within limits, averaging below 40%, suggesting sufficient capacity to accommodate additional demand or distributed generation if required. However, please note that, as the network has been isolated from the whole network of the state of Goa, hence the Tivim 220kV transformer is showing so less loading, which otherwise would have accounted all other loads connected with other different feeders.

8.1.4 Power Flow Analysis with solar injections

By using the same. ipynb program file, which was used for baseline scenario all the input files for the solar injecting scenario have been imported as PyPSA model. Further, with the same set of. ipynb program file for power flow and transformer and line/feeder loading have been run to understand the impacts of solar injecting capacities on these factors.

Fig 41 shows the line loading for all 5 days, when 30kW of solar was injected on PB_DT_25, i.e Minguel Pinto. It has been found that there was no significant change in line loadings, when solar

power injections were increased from 3kW to 5kW, 10kW and 30kW.

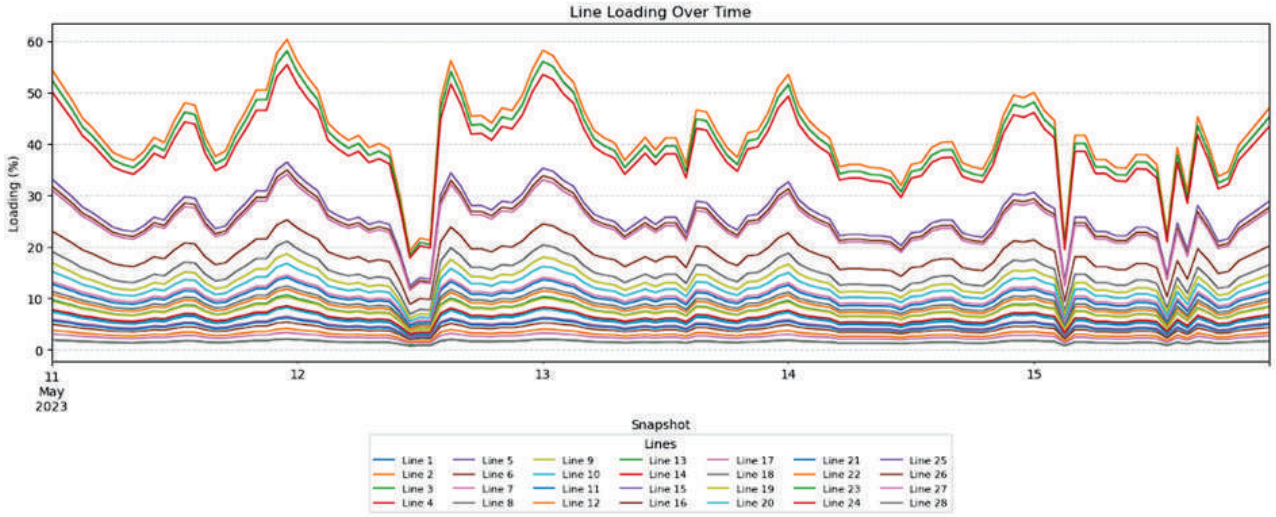


Figure 41: Feeder Loading for all 5 days of May(solar injected scenario)

The Loading of all the transformers and DTs have been computed. However, the analysis was done, based on the minimum loading occurring on the solar injected transformer (PB_DT_25) for all the different solar capacities. Among the 5 days of May loading, on solar injection the minimum loading of PB_DT_25, (Minguel Pinto) was found to occur on 12th May. Figure 42 represents the comparative percentage transformer loading on 12th May for baseline along with solar injected capacities of 3kW,5kW,10kW and 30kW.

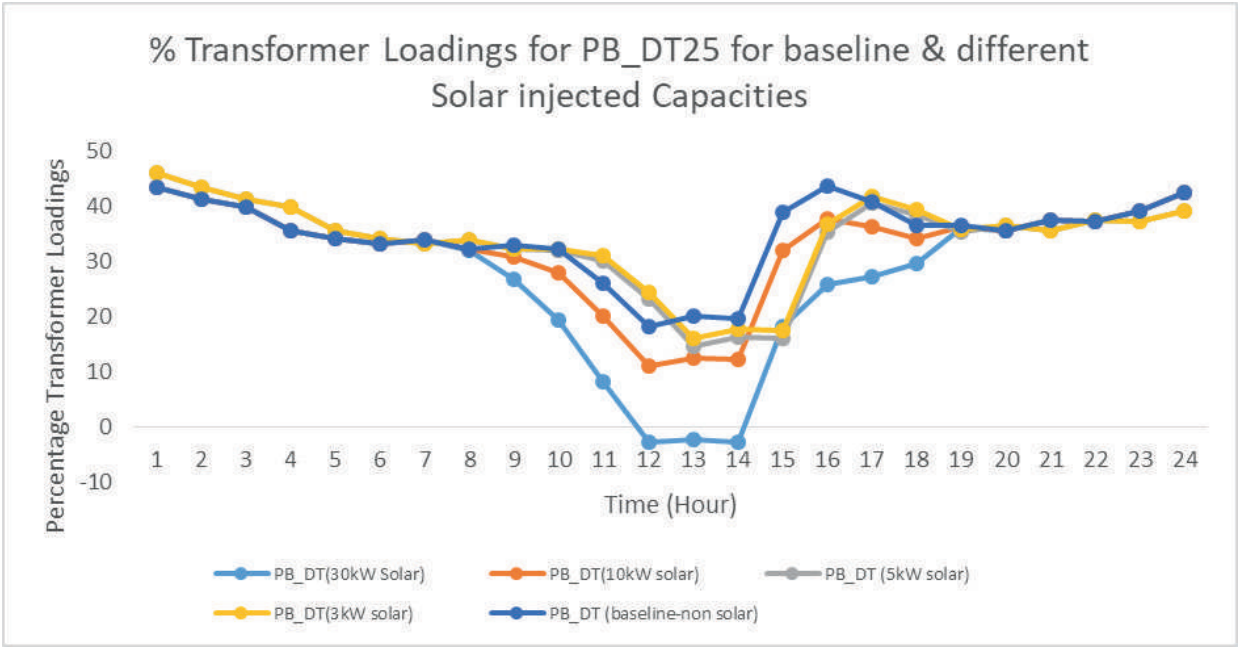


Figure 42: Comparative PB_DT25 Loading on 12th of May (with & without solar injection

Among the 5 days of May loading the minimum loading on the injected transformer, i.e PB_DT_25, (Minguel Pinto) has been observed as 16.05%. On 12th May at 11.00 hours when 3kW of solar were injected. 14.66% of minimum loading was recorded on 12th May at 11.00 hours, when 5kW solar capacity was injected.

When 10kW of solar were injected the transformer minimum loading were found to be 11.17% for that particular day and date. Negative loading has been noted on the solar hours both 12th and 15th May, when 30kW of solar was injected. However, the minimum loading was recorded on 12th may at 11 hours as -2.7%. while, on the other hand, at baseline scenario, i.e, when there was no solar injection, the loading of PB_DT_25 was recorded around 18% at the same hour of the same day. Negative loading signifies a reverse power flow on the grid, which may increase the loading condition of other interconnected DTs.

Though the minimum loading occurred on 12th May, the pattern of loading reduction resulting in reverse power flow has been observed for all 5 days. This analysis would suggest, that the maximum solar injecting capacity can be up to 25kW, or else the Minguel DT capacity can be increased from 100kV to 250 or above KVA. However, similar comparative loading has also been presented in figure 43 for all 5 days of May loading

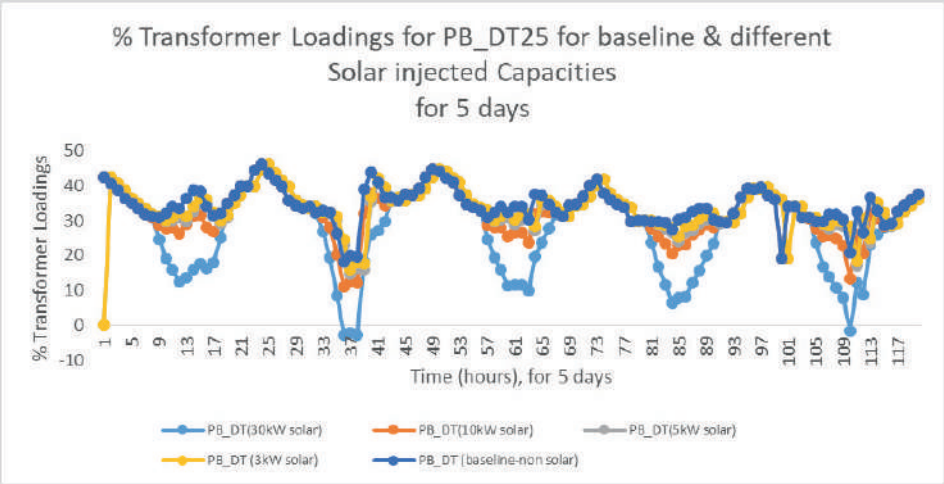


Figure 43: Comparative PB_DT25 Loading for all 5 days (with & without solar injection)

As voltage, is also an important factor to be noted for solar injection. However, not much deviation has been observed at PB_DT_25 when injecting solar capacities of 3kW,5kW,10kW and 30kW. A comparative voltage profile recorded at 415V point of PB_DT_25 has been portrayed below in figure 44.

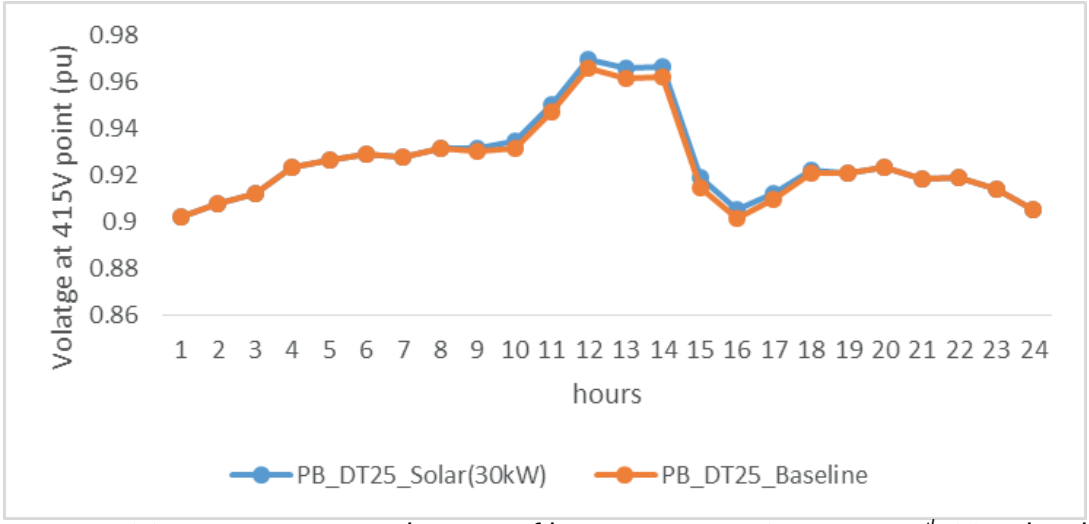


Figure 44: Comparative Voltage profile at PB_DT25 415V on 12th May load

A negligible increment on the voltage level was noted when 30kW of solar was injected in comparison to that of not injecting solar.

8.1.5 Summary findings of solar injection at DT level

Here is the head-to-head view of how much PV the DT25 (100 kVA) can host using MW load series (120 hours) and the provided solar profile (pu curve peaking at 0.745 around 12–13h). where treating 100 kVA ≈ 100 kW (pf≈1).

What the load looks like:

- Peak load: 40 kW (0.04 MW) ⇒ only ~40% of transformer nameplate.
- Minimum daylight load (when PV>0): 10 kW.

So, the constraint is reverse power (backfeed), not forward/thermal loading.

Hosting limits under two conditions:

a) Zero-export limit (no backfeed at any hour): $P_{PV,max} = min \frac{L(t)}{Pu(t)}$

Where L(t) is load in kW and pu(t) is the PV per-unit output at time (t). Using the 5-day load series (10–40 kW) and the solar profile (peak pu=0.745) Zero-export (no backfeed): P_(PV,max)≈14.4 ≈ 14.4 kW.

b) 10% backfeed allowed (≤ 10 kW backflow): $P_{PV,max,10\%} = min \frac{L(t)+10}{Pu(t)}$

If we allow 10% backfeed on a 100 kVA transformer (assume ≈ 10 kW export limit at PF≈1) then using the 5-day load series (10–40 kW) and the solar profile (peak pu=0.745) with 10% backfeed : P_(PV,max)≈ 28.7 kW.

The following table shows how the feeder behaves with various solar injections in the network which creates the net load profile and curtailment profile. This information is important for the feeder level Solar injection planning and capacity expansion.

Table 9: Behaviour of the network under different PV capacity injection

PV size	Max PV output (kW)	Min net load (kW)	Hours with backfeed (ZE rule)	Energy to curtail for ZE (kWh)	Hours >10 kW backfeed	Curtailment to meet 10% cap (kWh)	% of PV gen curtailed (10% cap)
3 kW	2.24	7.91	0	0.00	0	0.00	0.000%
5 kW	3.73	6.51	0	0.00	0	0.00	0.000%
10 kW	7.45	3.04	0	0.00	0	0.00	0.000%
30 kW	22.35	−10.88	5	18.81	1	0.88	0.109%

The Figure 45 below shows the time-series net load (kW) with un-curtailed PV for 3/5/10/30 kW alongside the base load. The dashed lines mark 0 kW (no export) and −10 kW (10% backfeed on a 100 kVA DT).

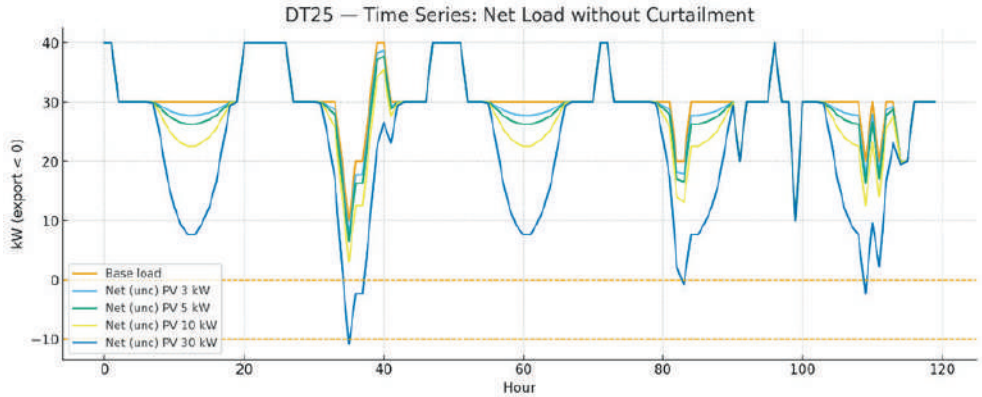


Figure 45: Time series net load without curtailment under different PV capacity

The analysis indicates that 3/5/10 kW never drive export, so curtailment = 0 under either policy. 30 kW pushes midday net below 0 (down to ~–11 kW). With Zero-Export, curtailment is ~18.8 kWh (≈3.4% of its PV energy). But with 10% back feed, curtailment drops to ~0.9 kWh (≈0.16%). From the daylight worst-case hour, the approximate hosting thresholds are:

- Zero-export limit ≈ 14.4 kW;
- 10% backfeed limit ≈ 28.7 kW

Figure 46 below further shows the load duration curves of the DT25 under varied solar injections of 3/5/10 and 30 kW. X-axis represents (Percent of Time Exceeded) hours sorted from highest net load at the left (0%) to the lowest at the right (100%). Y-axis (Transformer loading, % of 100 kVA) represents the net kVA seen by the 100 kVA transformer. The dashed line at 100% is its nameplate.

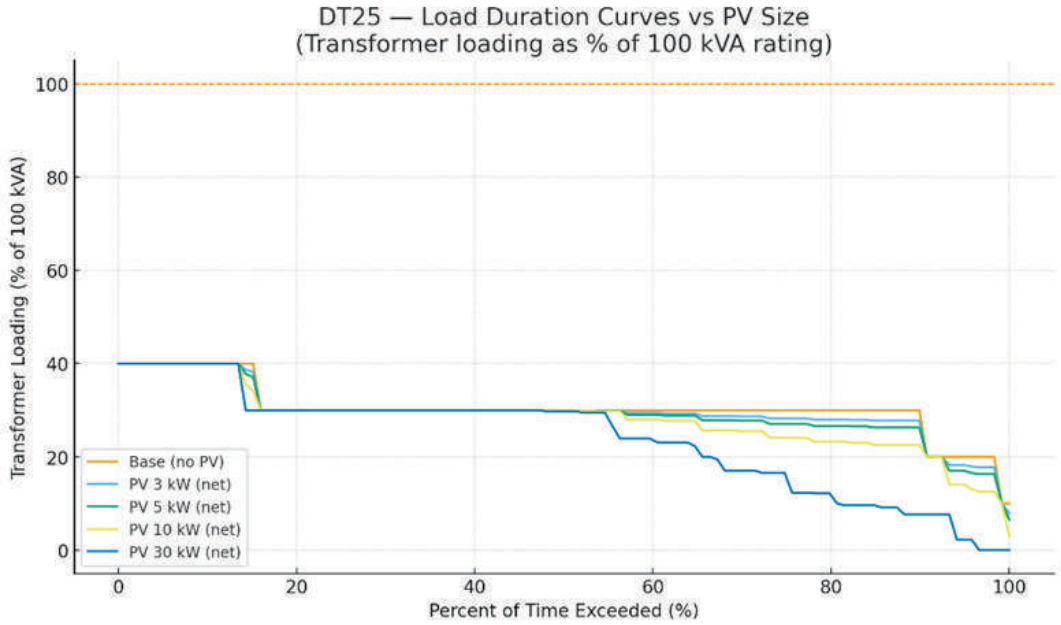


Figure 46: Time series net load under different PV capacity

After careful assessment of the LDCs it reveals that:

1. Peak stays unchanged by PV installation. At the extreme left, all curves sit around ~40% of rating (~40 kVA). DT's highest loads are in the evening/night, so daytime PV doesn't coincide with the true system peak. Even 30 kW PV barely moves the leftmost point.
2. PV carves down the middle of the curve (daylight hours). Between roughly 20–90% on the x-axis (most daylight hours), net loading drops in proportion to PV size:
   - 3 kW → small reduction (a few kVA)
   - 5 kW → modest reduction
   - 10 kW → clear midday relief
   - 30 kW → largest midday relief; the curve sits well below the base case over a wide span.

Light-load hours approach zero with large PV installation. At the far right (lowest net loads), the 30 kW curve dips toward 0–5% of rating, signalling frequent periods where PV ≈ load. If export is restricted, curtailment or storage would be needed here; if export is allowed, these hours will backfeed.

4. Thermal headroom is ample. Even without PV, the peak is only ~40% of the 100 kVA rating. Thermal capacity isn't the constraint for any of the modeled PV sizes; the binding constraints will be reverse power/voltage rise at low-load, high-PV hours.
5. Energy vs. peak. The area between each PV curve and the base curve represents energy offset. 30 kW delivers the most energy benefit but doesn't reduce the evening peak which indicates need of battery or demand shifting to push down the leftmost part of the LDC.

IN summary, all four PV sizes are thermally acceptable on DT25. Bigger PV gives more daytime relief and energy but creates more hours near zero/negative net load (export/curtailment risk). If we avoid backfeed, PV sizing should be tied to the minimum daytime load (we estimated ~14 kW) otherwise plan for export allowance or storage to capture the 30 kW benefit without curtailment.

8.2: Battery integrated Solar Uptake at 11kV level

Beside DT level scenarios, to showcase the uptake of solar potential and its impact on the existing electrical network at 11kV level, solar uptake scenario with and without has also been developed through the PyPSA.

8.2.1 Solar Capacity Addition without Storage

In this scenario, the existing electricity system is evaluated under current load conditions for May 2023, with the integration of an additional 2 GW of solar photovoltaic (PV) capacity. This installed solar potential is derived from the cumulative values listed in Table 8.

illustrates the optimal power demand mix determined through a least-cost optimization approach. Various power demand sources, including coal, hydro, wind, nuclear, biomass, and others, are depicted as stacked layers, showing their contributions to meeting the electricity demand over the selected time snapshots. The graphical output demonstrates a clear pattern wherein solar power demand significantly dominates during the daytime hours, as shown in figure 47. As solar availability increases with sunlight, the contribution from other conventional energy sources such as coal, biomass, and nuclear noticeably declines. This outcome is a result of the cost-optimal dispatch strategy, which prioritizes the use of cheaper and cleaner solar energy whenever available. Consequently, conventional sources are ramped down or held in reserve during periods of high solar output.

However, solar generation ceases entirely during non-solar hours, particularly at night and early morning. In these periods, the demand is predominantly met by dispatchable conventional sources like nuclear, biomass, and coal. These sources remain crucial in maintaining system stability and meeting peak demand without solar input. It is important to note that despite the substantial increase in installed solar capacity, its contribution is limited to daylight periods, which creates a temporal mismatch between energy generation and consumption patterns.
One of the key challenges emerging from this analysis is the system's dependence on conventional energy sources to fulfill evening and nighttime load requirements. When solar generation is unavailable

and conventional generation is insufficient to meet demand fully, distribution companies (DISCOMS) are compelled to procure additional electricity through short-term Power Purchase Obligations (PPOs) or Renewable Purchase Obligations (RPOs). These market-based procurements are often more expensive and subject to price volatility, thereby increasing the overall operational cost of the electricity supply.

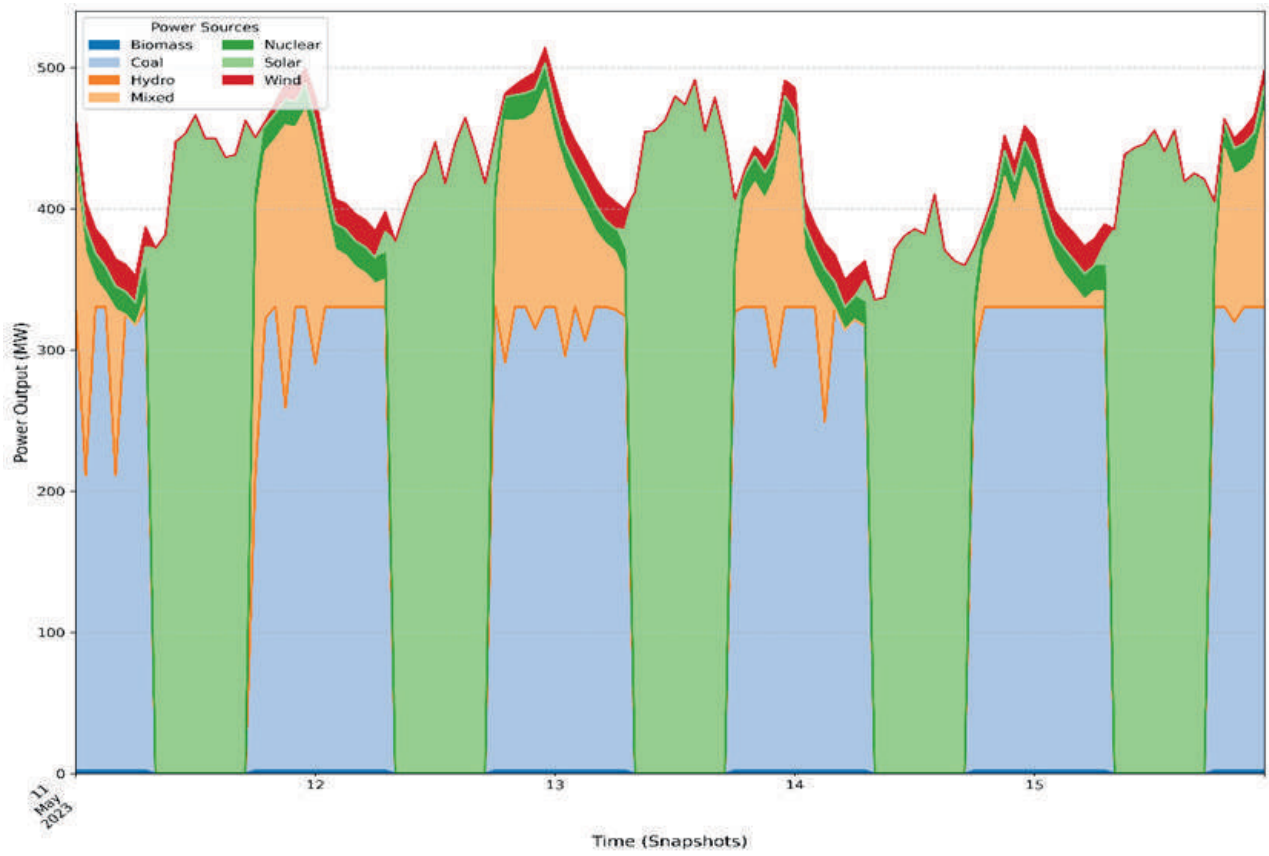


Figure 47: Optimal power demand with the integration of an additional 2 GW solar PV.

The findings from this scenario highlight a critical limitation of integrating large-scale solar capacity without a corresponding investment in energy storage systems. While solar generation helps reduce dependency on fossil fuels during the day, the lack of storage leads to underutilizing renewable potential and continued reliance on costlier and carbon-intensive sources during peak evening hours. This inefficiency underscores the need for storage solutions, such as battery energy storage systems (BESS), that can absorb excess solar power during the day and release it during times of high demand or solar unavailability. In summary, this analysis demonstrates that while solar PV can significantly reduce the operational cost and emissions of power demand during sunlight hours, its standalone deployment without storage support fails to address load requirements during non-solar periods. Therefore, integrating storage systems emerges as a necessary complement to ensure grid reliability, reduce curtailment, and optimize the electricity system's overall economic and environmental performance.

The impact of integrating 2 GW of solar PV into the existing electrical network was evaluated using load flow studies in PyPSA. Key performance indicators such as line loadings, voltage profiles, and transformer utilization were reassessed across multiple substations. Fig. 48 illustrates the results for the Anjuna substation, one of the locations identified as highly suitable for solar PV deployment. In comparison with the baseline scenario, no significant changes were observed in either the feeder line or transformer loading levels. This is primarily because the underlying demand profile remained unchanged between the pre- and post-solar cases. Consequently, despite the injection of solar generation, its spatial distribution and timing did not lead to a measurable reduction in line or transformer loadings at Anjuna.

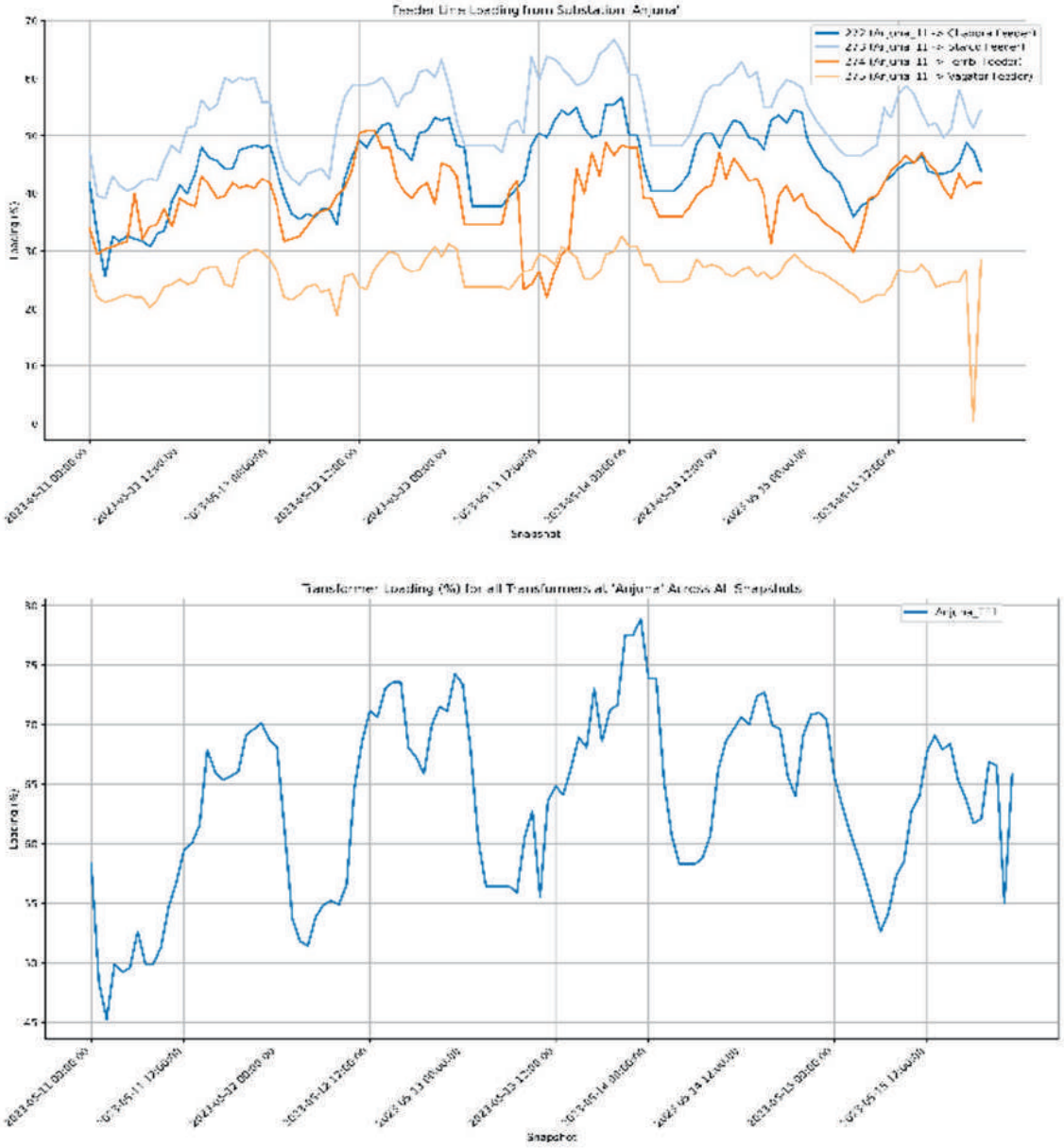


Figure 48: Line and transformer loading of Anjuna substation after incorporating 2 GW Solar

Moreover, Fig. 49 illustrates the bus voltage profile at the 33 kV Anjuna substation with and without solar injection on 11 May 2023. As shown, even with the integration of an additional 217.58 MW of installed solar PV capacity at the substation, the voltage remains well within the acceptable fluctuation limit of ±10%, indicating stable voltage performance despite the added generation. A noticeable voltage rise is observed during the solar generation hours (approximately 9:00 to 18:00), which can be attributed to active power injection from the solar PV systems. This localized generation reduces the net power drawn from the upstream grid, leading to an increase in voltage at the point of injection. This suggests that while solar PV can offset energy consumption, its grid impact is heavily influenced by its placement relative to load centers and the overall load flow characteristics of the network.

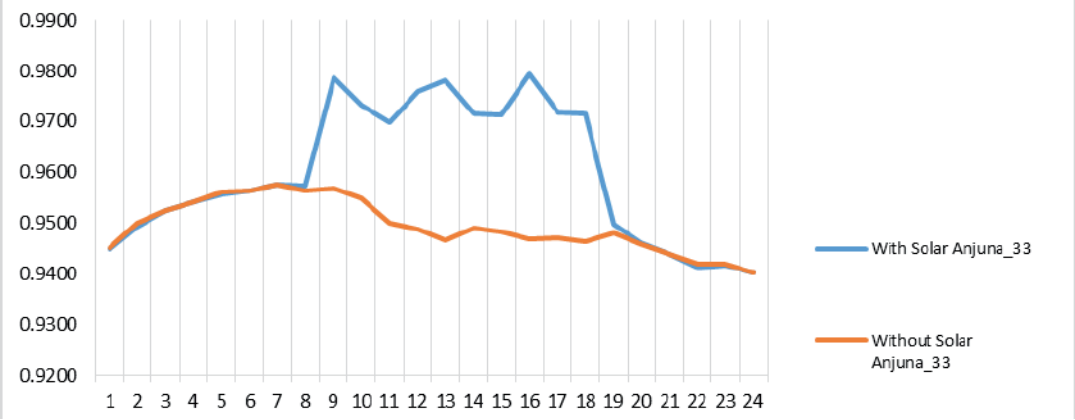


Figure 49: Voltage Profile at 33 kV Anjuna Substation with and without Solar PV Injection on 11 May 2023.

8.2.2 Solar capacity addition with battery storage at grid level

In this scenario, the existing electricity system is evaluated under current load conditions for May 2023 by integrating an additional 2 GW of solar photovoltaic (PV) capacity along with battery storage of equal capacity (2.11 GW/2.11 GWh). The detailed technical and economic parameters, including marginal and capital costs of the storage system, are provided in Table 9.

Table 10: Details of the Storage with cost in INR

Name of Storage	Installed Capacity	Connection Point	Max hours supported	Marginal cost (Rs)	Capital cost (Rs)	State of charge
Storage_1	217.58	Anjuna_33	6	3000	100000000	50
Storage_2	203.12	Benaulim_33	6	3000	100000000	50
Storage_3	141.43	Canacona_33	6	3000	100000000	50
Storage_4	233.47	Carmona_33	6	3000	100000000	50
Storage_5	430.04	KRC_33	6	3000	100000000	50
Storage_6	365.8	Nagoa_33	6	3000	100000000	50
Storage_7	358.07	Porvorim_33	6	3000	100000000	50
Storage_8	164.42	Saligao_33	6	3000	100000000	50

The optimal power demand mix under this configuration is illustrated in Fig. 50, while the battery dispatch profile and its corresponding state of charge (SOC) are depicted in Fig. 51.

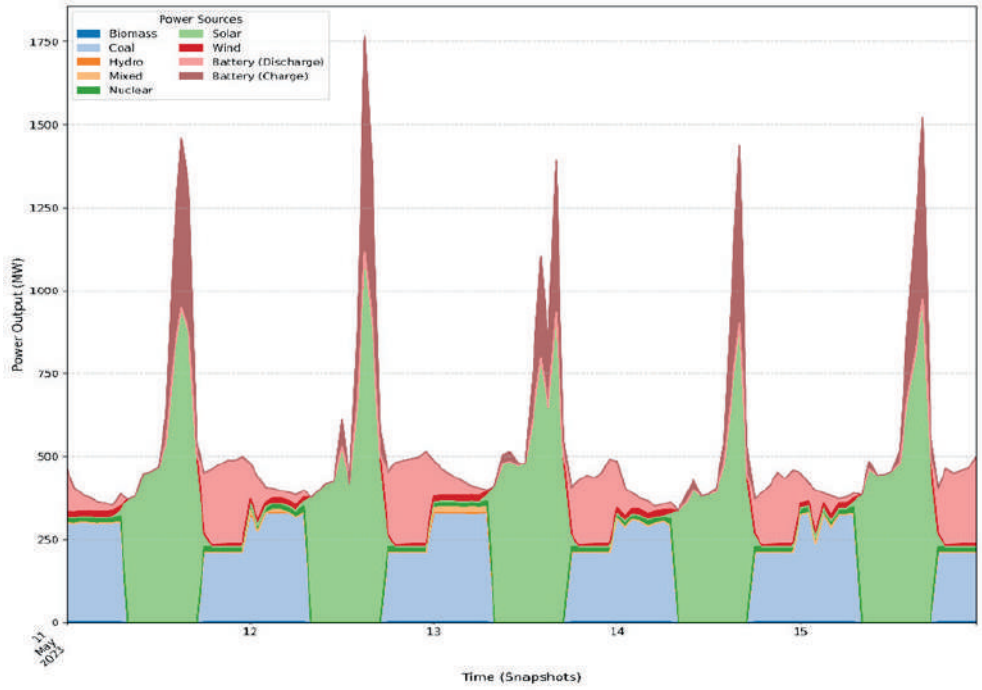


Figure 50: Optimal Generation mix for May 2023 load with 2 GW solar with storage

A comparison with the scenario without storage (shown in Figure 51) highlights several important operational and system-level benefits achieved through the integration of energy storage. Firstly, the inclusion of battery storage significantly enhances solar energy utilization. In the storage-less case, a substantial portion of mid-day solar generation is curtailed due to the lack of demand or flexibility to absorb this energy. However, with storage incorporated, the battery is charged during these peak solar hours—evident from the negative power values in the dispatch profile—thereby reducing curtailment and making better use of solar resources.

This stored solar energy is then discharged during the evening hours when solar output diminishes and demand rises, as shown by the positive power values in the dispatch curve. This strategic time-shifting of energy not only reduces the dependency on fossil fuel-based generation, especially coal, during evening peaks but also flattens coal dispatch throughout the day. Compared to the fluctuating coal and hydro output in the no-storage scenario, the generation mix with storage shows a more balanced and stable operation. Such smoothing of generation profiles contributes to reduced ramping stress on conventional units, improving operational efficiency and lowering fuel costs and emissions.

Moreover, the storage-enabled case greatly improves the system's ability to match generation with demand. The battery effectively acts as a buffer, charging when generation exceeds demand and discharging when demand exceeds generation. The SOC profile shows clear daily cycling, indicating that the battery is efficiently charged and

discharged across the simulation period. This results in a system that operates more economically and offers greater reliability and flexibility. In summary, adding storage leads to enhanced utilization of renewable energy, especially solar, reduces curtailment, flattens the dispatch of thermal units, and enables a better match between generation and load. These operational benefits, when compared with the system performance without storage, clearly demonstrate the value of integrating energy storage as a means to unlock the full potential of renewable investments and to transition toward a more resilient and sustainable power system.

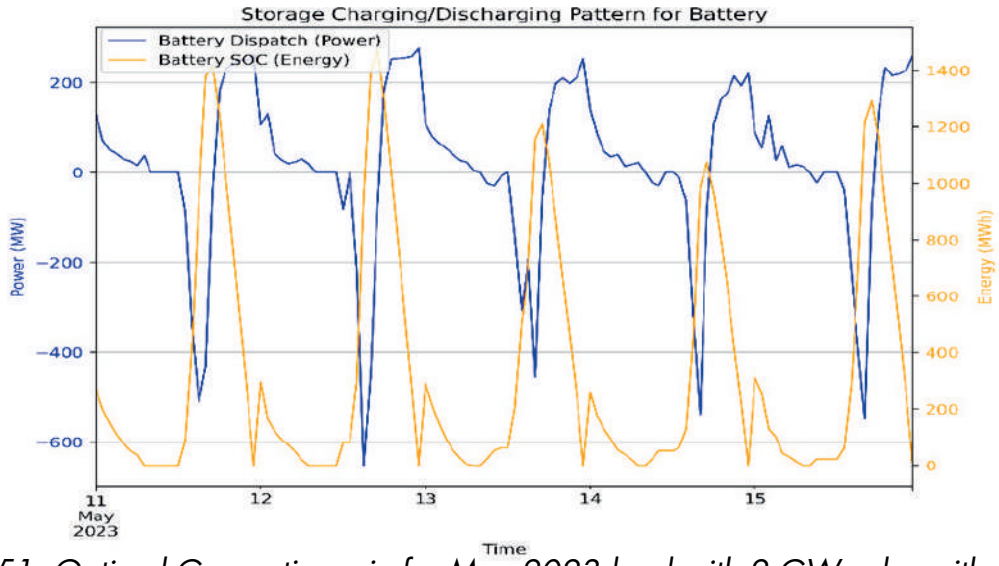


Figure 51: Optimal Generation mix for May 2023 load with 2 GW solar with storage

8.2.3 Solar capacity addition with battery storage at DT level

Here we have demonstrated the impacts of solar capacity injection at the DT level in a select feeder of Porvorim Bazar. Given the load profile of the feeder and the DT here is a straight, data-driven sizing for zero-export (no backfeed) with a 30 kW PV at DT25 (100 kVA) using the5-day hourly load (10–40 kW) and the solar profile.

Battery capacity assessment

For each hour t, the surplus that would backfeed is $S_t = \max(PV_{30,t} - L_t, 0)$

To eliminate backfeed we need:

- Energy capacity ≥ the largest daily sum $\sum S_t \, \Delta t \; (kWh)$
- Power rating ≥ the max hourly surplus $max(S_t) \; (kW)$

Battery Capacity

- Worst daily surplus energy (battery must absorb): ≈ 15.98 kWh (on 12-May).
- Max instantaneous surplus power: ≈ 12.35 kW (around midday when load dips to ~18 kW and PV ~22.35 kW).

Accounting for realistic usable capacity and losses (≈90% usable SoC window and ~90–95% RTE), the obtained battery capacity is as follows:

- Energy: ~20 kWh usable (nameplate ~22–24 kWh)
- Power (inverter/charge rate): ≥ 13 kW (recommend 15 kW for headroom)
- Implied charge C-rate: 12.35 kW / 20 kWh ≈ 0.62 C (well within common specs).

8.3 Summary of Case Study Findings:

We have summarized the major findings from the study under two sets of observations:

a) Baseline condition which indicates the current state of network operation and **b) solar injected state of operation and corresponding impacts.**

8.3.1 Baseline condition

Transformer loading

- Max loading is observer up to ~50%, hence no upsizing is required for the DTs of Porvorim Bazar. Loads can be increased at DT level.
- An operational target ≤80% for normal operation should be maintained to preserve thermal and aging margins.

Line loading

- Maximum loadings up to ~60% and average loading up to ~35% have been observed
- Mixed feeder is acceptable: although XLPE (≈356 A) has higher ampacity than ACSR (≈250 A), actual loading is driven by connected load, not conductor rating.
- Additional load can be connected provided section loadings remain ≤80%
- Evening voltage (see below) stays within limits, prefer new loads on XLPE sections or closer to DTs to limit upstream currents and voltage drop.

Voltage

- Borderline during evening peak, otherwise within ±10%.
- Verify tap/OLTC (on load tap changer) settings for evening profile, add/retune shunt capacitors or PF correction near peak-load pockets, and rebalance phases where needed. Re-check voltage drops after any new large connection.

8.3.2 Solar-injected Scenarios

Transformer loading

- Midday loading reduces reverse power occur on lightly loaded DTs, so DTs having higher connected load capacity should be considered for solar injection.
- Where reverse power is undesired apply DT-level export caps (static cap) can be added.
- Where reverse power is acceptable: ensure upstream coordination (see lines/protection) and continue to monitor kVA and temperature rise (still well below nameplate in your study).

Line loading

- Remains ≤60% max, and an average of 35%, so no thermal upgrade is needed.
- Reverse flow aggregates upstream; use the weakest section (ACSR 250 A) to set feeder-section export ceilings (operate ≤80% of section rating).
- If PV grows, consider time-of-day feeder reconfiguration (tie-switching) and phase balancing so no single phase/section becomes the backfeed path.

Voltage

- Observed compliance within the ±10% limit. Keep Volt-VAR/Volt-Watt on inverters with mild slopes to cushion cloud transients without unnecessary curtailment.
- Coordinate capacitor switching to avoid midday over-compensation when PV raises local voltage and reduces reactive demand, can be considered.

9.0 Conclusion & Recommendations



Addressing grid, policy, and participation challenges to accelerate Goa's transition toward a 100% renewable energy future

9.1 Conclusions

The State of Goa stands at a pivotal moment in its energy transition journey. This study, grounded in the Clean Energy Roadmap 2050, has thoroughly assessed Goa's renewable energy (RE) potential, evaluated the existing power infrastructure, and demonstrated viable pathways for scaling up RE capacity in an economically and technically optimized manner.

Using advanced spatial analysis through GIS and robust power system modeling via PyPSA, the project provided critical insights into the operational dynamics and bottlenecks of the state's 11 kV, 415 V and 33 kV networks. Seasonal loading profiles revealed that while transformer utilization averaged around 32%, certain feeders, especially during the summer, were operating at over 70% capacity, highlighting the need for grid reinforcement and localized upgrades.

The study explored RE potential comprehensively:

- Solar emerged as the primary candidate for expansion, with total estimated technical potential reaching up to 3 GW, including rooftop, floating, and agro-PV installations.
- Biomass offers an additional 200 MW of distributed potential, particularly valuable for rural and agricultural zones.
- Wind, while less exploited, presents up to 100 MW of site-specific capacity pending further validation.

The site suitability framework, using Multi-Criteria Decision Modelling (MCDM), identified the most promising substations and zones for RE uptake, taking into account technical, geographic, and infrastructural constraints. Eight substations, including KRC, Nagoa, and Porvorim, demonstrated the highest solar potential, and specific deployment strategies have been outlined.

Key challenges such as grid stability, regulatory complexity, and limited public-industrial participation were identified. Mitigation strategies emphasize smart grid deployment, financial incentives (like green bonds and VGF), streamlined RE policy, and improved stakeholder engagement. In conclusion, Goa possesses the technical resources, institutional frameworks, and planning tools necessary to transition toward a 100% renewable electricity system. The successful implementation of these recommendations requires:

- Immediate reinforcement of grid infrastructure.
- Acceleration of decentralized RE deployments.
- Policy innovations supporting Green Open Access and energy storage.
- Stronger collaboration between government, industry, and civil society.

With sustained commitment and phased investments, Goa has the opportunity to lead India's clean energy transformation while ensuring economic resilience, energy security, and environmental sustainability.

9.2 Recommendations

A major challenge in RE integration in Goa is maintaining grid stability and reducing the curtailment of RE power to reduce the cost of supply. High solar and wind energy penetration can lead to voltage fluctuations and frequency imbalances. Deploying smart grid technologies, such as advanced metering infrastructure and automated grid controls, can help mitigate these issues. Another challenge is the regulatory landscape, where complex permitting processes and financial disincentives for DISCOMs hinder RE adoption. Addressing these barriers requires policy streamlining, tariff restructuring, and financial incentives for RE investments. Furthermore, there is a need to increase public and industrial participation through awareness campaigns and incentives that encourage industries to transition to RE sources.

9.2.1 Grid Stability and Technical Challenge

A major challenge in RE integration is maintaining grid stability. High penetration of solar and wind energy can lead to voltage fluctuations and frequency imbalances, which may affect overall system reliability. Deploying smart grid technologies, such as advanced metering infrastructure, automated grid controls, and flexible AC transmission systems (FACTS), can help mitigate these issues. Enhancing real-time grid monitoring through digital twin technologies can improve grid adaptability to fluctuating RE supply. Practical measures could be as follows:

- **Peak-oriented measures:** Uptake demand response or TOU rates targeting the evening peak block to improve the energy utilization. It is important to consider west-tilted PV or community storage to shift energy towards peak.
- **Hosting capacity without curtailment:** keep aggregate PV such that PV_max ≤ minimum net load (+ allowed export); otherwise plan for smart-inverter curtailment at midday.
- **Storage for PV smoothing:** even 1–2 hours of storage sized to the midday headroom can mop up most of the tail (50→25% zone), cutting curtailment and easing sunset ramps.

9.2.2 Regulatory and Policy Barriers

The regulatory landscape poses significant challenges, as complex permitting processes and financial disincentives for DISCOMs hinder RE adoption. Many utilities have traditionally relied on thermal power, and shifting towards renewables requires regulatory clarity, streamlined approval processes, and updated tariff structures. Addressing these barriers requires policy streamlining, tariff restructuring, and financial incentives such as viability gap funding (VGF) to support RE investments. Furthermore, clear frameworks must be

established for integrating distributed generation sources into the existing grid.

9.2.3 Public and Industrial Participation

Encouraging participation from industries and the general public is crucial for the success of RE initiatives. Many industries remain hesitant to transition to renewable energy due to upfront costs and infrastructure challenges. To overcome this, awareness campaigns, financial incentives, and attractive financing mechanisms such as green loans should be introduced. Additionally, collaboration with private sector entities can foster innovation in RE adoption and investment.

9.2.4 Steps to increase RE share

In view of the comprehensive assessment of Goa's renewable energy potential and current power infrastructure, the following recommendations and next steps are proposed to support the state's transition toward a 100% RE-based power system by 2050:

A. Policy and Regulatory Interventions

- **Accelerate Implementation of Clean Energy Roadmap 2050:** Goa should formalize an annual RE capacity augmentation plan aligned with the CER 2050 targets. This includes setting district-level targets and ensuring coordination across urban, rural, and industrial sectors.
- **Enact Green Open Access and Net Metering Frameworks**: Policy mechanisms like Green Open Access should be fully operationalized to enable large consumers to directly procure RE. Simplified net metering regulations should be developed for rooftop solar, especially in commercial and residential sectors.
- **Establish RE-Zoning Guidelines:** Based on the GIS-MCDM site suitability analysis, the government should identify and notify Renewable Energy Zones (REZs) around high-potential substations such as Anjuna, Nagoa, and KRC, with streamlined clearances and grid access incentives.

B. Infrastructure Development

- **Invest in Grid Reinforcement and Smart Grid Technologies**: Expand capacity at stressed feeders (e.g., Agonda, Baga, Calangute) through line and transformer capacity upgrades and smart transformers. Deploy Advanced Metering Infrastructure (AMI) and remote monitoring tools to support dynamic RE integration.
- **Promote Battery Energy Storage Systems (BESS)**: The study indicates that BESS significantly enhances system flexibility and reduces curtailment. The state should introduce viability gap funding (VGF) or capital subsidies for distributed and substation-level storage systems.
- **Upgrade Load Forecasting and Grid Planning Tools**: Integrate real-time data analytics and weather forecasting into grid operations. Use open-source tools like PyPSA at the utility level for transparent and reproducible energy planning. Feeder level deployment of the Goa-PyPSA will be essential for smarter planning and investment to enhance RE generation in the State of Goa.

C. Deployment and Investment Strategies

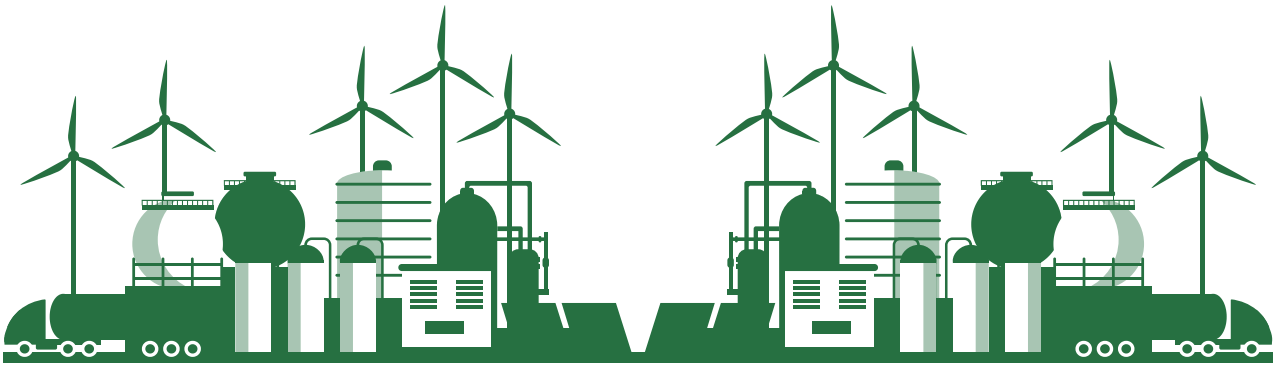
- Prioritize Distributed Solar (Rooftop, Agro, Floating): Incentivize rooftop PV in urban clusters and agro-PV in

rural pockets using performance-linked subsidies and capital grants. Accelerate floating solar pilots on water bodies like Carambolim and Salulim.

- **Facilitate Public-Private Participation (PPP)**: Create a project pipeline for private sector participation in RE deployment and storage projects. Establish a single-window platform to reduce bureaucratic delays for project approvals.
- **Leverage Carbon and Green Financing**: Tap into green bonds, international climate finance, and carbon credit markets to support RE projects and offset implementation costs.

D. Capacity Building and Awareness

- **Enhance Institutional and Human Capacity**: Organize training for DISCOMs, planners, and regulators on RE integration, storage, and demand-side management. Develop RE-focused curricula in technical institutes.
- **Community Engagement and Awareness Drives**: Launch awareness campaigns around rooftop solar, energy efficiency, and EV charging infrastructure to encourage public adoption.





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Annexure 1: Goa-Py-PSA Model Input Files

Goa-PyPSA Model Input Files: buses.csv

Based on these SLD diagrams, all the connecting components for Porvorim Bazar feeder (Tivim220/33kV SS, Porvorim 33/11 SS, and further 27 DT connected to Porvorim Bazar feeder) were entered in the buses.csv file. Figure A1-1 shows the snapshot of the mapping of the DTs done to build the buses network.

name	y	x	v_nom	type	carrier	osm_name	control
Tivim_220	15.63431	73.85829	220	Tivim substation	AC	Tivim_220	Slack
Tivim_33	15.63431	73.85829	33	Tivim substation	AC	Tivim_33	PV
Porvorim_33	15.53731	73.82693	33	Porvorim substation	AC	Porvorim_33	PV
Porvorim_11	15.53731	73.82693	33	Porvorim substation	AC	Porvorim_11	PV
PB_DT1_11	15.53731	73.82694	11	Porvorim Feeder	AC	PB_Feeder	PV
PB_DT1_415	15.53731	73.82694	0.415	Porvorim DT	AC	PB_DT	PQ
PB_DT2_11	15.54558	73.82039	11	Porvorim Feeder	AC	PB_Feeder	PQ
PB_DT2_415	15.54558	73.82039	0.415	Porvorim DT	AC	PB_DT	PQ
PB_DT3_11	15.54556	73.82036	11	Porvorim Feeder	AC	PB_Feeder	PQ
PB_DT3_415	15.54556	73.82036	0.415	Porvorim DT	AC	PB_DT	PQ
PB_DT4_11	15.54473	73.82038	11	Porvorim Feeder	AC	PB_Feeder	PQ
PB_DT4_415	15.54473	73.82038	0.415	Porvorim DT	AC	PB_DT	PQ
PB_DT5_11	15.5427	73.82168	11	Porvorim Feeder	AC	PB_Feeder	PQ
PB_DT5_415	15.5427	73.82168	0.415	Porvorim DT	AC	PB_DT	PQ
PB_DT6_11	15.54067	73.81918	11	Porvorim Feeder	AC	PB_Feeder	PQ
PB_DT6_415	15.54067	73.81918	0.415	Porvorim DT	AC	PB_DT	PQ

Figure A1-1: Porvorim Bazar Buses Network

Here, the first column defines the name of the component, which is user defined (generally given to understand that connecting point). Next, 2nd and 3rd collum indicates the longitude and latitude of the components. These geographical points were received from GED's shape files data. The 'type' column defines the component types. The 'carrier' column defines the type of network, i.e either DC or AC. The 'osm_name' column gives the names of the components while plotting the network using open street map. The 'control' column gives the bus type, such as, slack bus, PV/generator Bus, PQ/ Load bus.

Goa-PyPSA Model Input Files: lines.csv

Based on these data, the values for the parameters required for the lines.csv file have been calculated and used in the model as shown in the Figure A1-2 below

name	bus0	bus1	s_nom	r	x	length	s_nom_extendable	carrier
1	Tivim_33	Porvorim_33	36	0.964538	1.61625	15	TRUE	AC
2	Porvorim_11	PB_DT26_11	4.763	1.269237	0.02797	0.97	TRUE	AC
3	PB_DT26_11	PB_DT27_11	4.763	1.269237	0.02797	0.1	TRUE	AC
4	PB_DT27_11	PB_DT25_11	4.763	2.096787	0.0462	0.18	TRUE	AC
5	PB_DT25_11	PB_DT24_11	6.7635	0.0923	0.0142	0.24	TRUE	AC
6	PB_DT24_11	PB_DT23_11	6.7635	0.0923	0.0142	0.15	TRUE	AC
7	PB_DT23_11	PB_DT17_11	6.7635	0.0923	0.0142	0.64	TRUE	AC
8	PB_DT17_11	PB_DT21_11	4.763	2.096787	0.0462	0.1	TRUE	AC
9	PB_DT21_11	PB_DT20_11	4.763	2.096787	0.0462	0.1	TRUE	AC
10	PB_DT20_11	PB_DT19_11	4.763	2.096787	0.0462	0.1	TRUE	AC
11	PB_DT19_11	PB_DT18_11	4.763	2.096787	0.0462	0.29	TRUE	AC
12	PB_DT18_11	PB_DT14_11	4.763	2.096787	0.0462	0.15	TRUE	AC
13	PB_DT14_11	PB_DT22_11	4.763	2.096787	0.0462	0.28	TRUE	AC
14	PB_DT22_11	PB_DT16_11	4.763	2.096787	0.0462	0.15	TRUE	AC
15	PB_DT16_11	PB_DT15_11	4.763	2.096787	0.0462	0.03	TRUE	AC

Figure A1-2: Figure A1-2: Porvorim Bazar Buses Network

The 'name' column gives the name of the line. 'bus0' and 'bus1' columns are basically the from buses and to bus in between which the respective lines are connected. 's_nom' columns define the rating of the line in MVA. For a 3-phase line, the phase current is the conductor current, and the values have been calculated as shown in equation (1)

$$s_nom = 1.732 * voltage(33/11kV) * current(conductor\ current, in\ Amp)/1000$$

The 'r' and 'x' column refer to the resistance_p.u and reactance_p.u of the line. This has been calculated by the following equations 2, 3 and 4;

$$r = Resistance\ /\ Z_{base}$$

$$x = Reactance/Z_{base}$$

$$Z_{base} = V^2/s_nom$$

Here, e.g. for line 2: Z_{base} = 11*11/4.76 =45.04; r= 1.269/45.04 =0.0399, resistance for line 2 was taken from the data shown above.

Goa-PyPSA Model Input Files: transformers.csv

Among 27 transformers, 16 transformers were shown in transformer.csv file as shown below in figure A1-3.

name	bus0	bus1	s_nom	x_pu	r_pu	Voltage_level	type	s_nom_extendable
Tivim_TF1	Tivim_220	Tivim_33	63	0.011	0.005	220/33	63 MVA 220/33 kV	FALSE
Porvorim_TF4	Porvorim_33	Porvorim_11	8	0.011	0.008	33/11	8 MVA 33/11 kV	FALSE
PB_DT_1	PB_DT1_11	PB_DT1_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_2	PB_DT2_11	PB_DT2_415	0.12	0.01	0.01	11/0.415	0.12 MVA 11/0.415kV	FALSE
PB_DT_3	PB_DT3_11	PB_DT3_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_4	PB_DT4_11	PB_DT4_415	0.1	0.01	0.01	11/0.415	0.1 MVA 11/0.415kV	FALSE
PB_DT_5	PB_DT5_11	PB_DT5_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_6	PB_DT6_11	PB_DT6_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_7	PB_DT7_11	PB_DT7_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_8	PB_DT8_11	PB_DT8_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_9	PB_DT9_11	PB_DT9_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_10	PB_DT10_11	PB_DT10_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_11	PB_DT11_11	PB_DT11_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_12	PB_DT12_11	PB_DT12_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_13	PB_DT13_11	PB_DT13_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_14	PB_DT14_11	PB_DT14_415	0.1	0.01	0.01	11/0.415	0.1 MVA 11/0.415kV	FALSE
PB_DT_15	PB_DT15_11	PB_DT15_415	0.2	0.01	0.01	11/0.415	0.2 MVA 11/0.415kV	FALSE
PB_DT_16	PB_DT16_11	PB_DT16_415	0.63	0.01	0.01	11/0.415	0.63 MVA 11/0.415kV	FALSE

Figure A1-3: Porvorim Bazar transformer network

The 'name' column is the name given to those transformers and DTC/HTC. The column ' s_nom' is the capacity of the transformers in MVA, while 'voltage_level' indicates the primary/secondary voltages. These values have been directly taken from the figure 26 of section 8. The 'x' and 'r' are the series reactance and series resistance of the transformer. The values were taken from the PyPSA file based on their type (i.e rating in MVA and primary/secondary voltage). The values corresponding to the parameters defined in the transformers.type.csv file have also been taken from the pypsa documentation file.
[https://pypsa.readthedocs.io/en/stable/userguide/components.html#transformer-types]

"Goa-PyPSA Model Input Files: loads-p,q_set.csv"

Finally, the loads-p_set.csv and loads-q_set.csv files are prepared considering the feeder load as shown in figure 21 and from the load distribution as per SLD diagram in figure 24 from section 8.

The proportional current was first calculated as

$$I_{proportional} = Load\ of\ the\ DTC / Total\ Load\ of\ all\ the\ DTC * I_{peak}$$

(i.e for Limawado Iproportional = 200/5239*127=4.85). The proportional current calculated for every DTs have been shown below in the figure

Name of Feeder	DTC/HTC name	DT capacity in kVA	proportional current at DT point (considering peak current=127A)
11kV Porvorim Bazar Feeder	Limawado	200	4.85
11kV Porvorim Bazar Feeder	Damian De Goa	120	2.91
11kV Porvorim Bazar Feeder	Diagram HTC	200	4.85
11kV Porvorim Bazar Feeder	Alcon Hyundai	100	2.42
11kV Porvorim Bazar Feeder	Priority DTC	200	4.85
11kV Porvorim Bazar Feeder	Devashree V	200	4.85
11kV Porvorim Bazar Feeder	Devashree IV	200	4.85
11kV Porvorim Bazar Feeder	Devashree III	200	4.85
11kV Porvorim Bazar Feeder	Devashree II	200	4.85
11kV Porvorim Bazar Feeder	Devashree Enclave (9-9 market	200	4.85
11kV Porvorim Bazar Feeder	Devashree I	200	4.85
11kV Porvorim Bazar Feeder	Corporation Bank	200	4.85
11kV Porvorim Bazar Feeder	Norbert Gym Dtc	200	4.85
11kV Porvorim Bazar Feeder	Police Housing Society DTC	100	2.42
11kV Porvorim Bazar Feeder	20-point Socorro	200	4.85
11kV Porvorim Bazar Feeder	Alps Construction DTC	630	15.27
11kV Porvorim Bazar Feeder	Socorro Panch	200	4.85
11kV Porvorim Bazar Feeder	Karapurkar DTC	200	4.85
11kV Porvorim Bazar Feeder	VP Socorro HTC	239	5.79
11kV Porvorim Bazar Feeder	Prabhu Residency I	150	3.64
11kV Porvorim Bazar Feeder	Prabhu Residency II	200	4.85
11kV Porvorim Bazar Feeder	Govind Bhai Mori	200	4.85
11kV Porvorim Bazar Feeder	Clergy Home DTC	100	2.42
11kV Porvorim Bazar Feeder	Holy Family School DTC	200	4.85
11kV Porvorim Bazar Feeder	Minguel Pinto DTC 100	100	2.42
11kV Porvorim Bazar Feeder	Kamat Nagar	200	4.85
11kV Porvorim Bazar Feeder	Malita DTC	100	2.42
Total Load		**5239**	

Figure A1-4: Porvorim Bazar proportional currents based on DT capacity

Next, with the values of current (as mentioned is figure21 of section 8) has been digitalized as shown in figure below.

Time	Porvorim Bazar load (at 11kV :SS) MW	current at PB feeder (Amp)
5/11/2023 0:00	1.99	116
5/11/2023 1:00	1.89	110
5/11/2023 2:00	1.78	104
5/11/2023 3:00	1.66	97
5/11/2023 4:00	1.59	93
5/11/2023 5:00	1.51	88
5/11/2023 6:00	1.42	83
5/11/2023 7:00	1.39	81
5/11/2023 8:00	1.37	80
5/11/2023 9:00	1.44	84
5/11/2023 10:00	1.54	90
5/11/2023 11:00	1.51	88
5/11/2023 12:00	1.66	97
5/11/2023 13:00	1.78	104
5/11/2023 14:00	1.77	103
5/11/2023 15:00	1.54	90

Figure A1-5: Representative hourly load data of Provorim Bazar feeder

The Real Power (P), and reactive power (Q) at the Porvorim Bazar feeder have been computed as-

$$P = 1.732 * 11 * current * 0.9/1000 \text{ in MW}$$

$$Q = 1.732 * 11 * current * 0.43/1000 \text{ in MVAr}$$

For 1st 15 hours of 11th May load have been depicted below in figure.

Time	Porvorim Bazar load P_set at 11kV	current at PB feeder	Porvorim Bazar load Q_set at 11kV
11/5/2023 0:00	1.99	116	0.99
11/5/2023 1:00	1.89	110	0.94
11/5/2023 2:00	1.78	104	0.89
11/5/2023 3:00	1.66	97	0.83
11/5/2023 4:00	1.59	93	0.80
11/5/2023 5:00	1.51	88	0.75
11/5/2023 6:00	1.42	83	0.71
11/5/2023 7:00	1.39	81	0.69
11/5/2023 8:00	1.37	80	0.69
11/5/2023 9:00	1.44	84	0.72
11/5/2023 10:00	1.54	90	0.77
11/5/2023 11:00	1.51	88	0.75
11/5/2023 12:00	1.66	97	0.83
11/5/2023 13:00	1.78	104	0.89
11/5/2023 14:00	1.77	103	0.88
11/5/2023 15:00	1.54	90	0.77

Figure A1-6: 1st 15 hours of 11th May load

Next, considering this load profile at the feeder (11kV) level, the load profiles as every DT have been computed by a proportional factor.

Further, multiplying these proportional factors to the load profile at the feeder (figure: 1st 15 hours of 11th May load) we get the loads-p_set and loads-q_set for DTs.
Goa-PyPSA Model Input Files: generators.csv
The generator.csv file, generator-p_max_pu.csv loads.csv file and snapshot.csv are shown below in figures-

name	bus	p_nom	carrier	efficiency	p_nom_extendable
NTPC_G1	Tivim_220	50	Coal	0.26	FALSE

Figure A1-7: generator for Porvorim Bazar

name	bus	carrier
Limawado	PB_DT1_415	AC
Damian De Goa	PB_DT2_415	AC
Diagram HTC	PB_DT3_415	AC
Alcon Hyundai	PB_DT4_415	AC
Norbert Gym Dtc	PB_DT5_415	AC
Priority DTC	PB_DT6_415	AC
Devashree V	PB_DT7_415	AC
Devashree IV	PB_DT8_415	AC
Devashree III	PB_DT9_415	AC
Devashree II	PB_DT10_415	AC
Devashree Enclave (9-9 market	PB_DT11_415	AC
Devashree I	PB_DT12_415	AC
Corporation Bank	PB_DT13_415	AC
Police Housing Society DTC	PB_DT14_415	AC

Figure A1-8: representative generator_p_max_pu for Porvorim Bazar

name	bus	carrier
Limawado	PB_DT1_415	AC
Damian De Goa	PB_DT2_415	AC
Diagram HTC	PB_DT3_415	AC
Alcon Hyundai	PB_DT4_415	AC
Norbert Gym Dtc	PB_DT5_415	AC
Priority DTC	PB_DT6_415	AC
Devashree V	PB_DT7_415	AC
Devashree IV	PB_DT8_415	AC
Devashree III	PB_DT9_415	AC
Devashree II	PB_DT10_415	AC
Devashree Enclave (9-9 market	PB_DT11_415	AC
Devashree I	PB_DT12_415	AC
Corporation Bank	PB_DT13_415	AC
Police Housing Society DTC	PB_DT14_415	AC

Figure A1-9: representative loads for Porvorim Bazar

name	weightings
5/11/2023 0:00	1
5/11/2023 1:00	1
5/11/2023 2:00	1
5/11/2023 3:00	1
5/11/2023 4:00	1
5/11/2023 5:00	1
5/11/2023 6:00	1
5/11/2023 7:00	1
5/11/2023 8:00	1
5/11/2023 9:00	1
5/11/2023 10:00	1
5/11/2023 11:00	1
5/11/2023 12:00	1
5/11/2023 13:00	1
5/11/2023 14:00	1
5/11/2023 15:00	1

Figure A1-10: representative snapshot for Porvorim Bazar

The P_nom is the installed capacity given to the Tivim substation, which is based on the available generators' types at major 220kV substation as received from the PGCI (power grid corporation of India). The generator-p_max_pu.csv has been assigned equal weightage of dispatch for every hour. The snapshot.csv defines the hourly profile.

Developing/ twining the real network in PyPSA

After installing the PyPSA software, the input files defining the power system network of the Porvorim Bazar is being saved in the desired path or folder. Then, by using the. ipynb program file to input all the necessary data the baseline model for the Porvorim Bazar Section has been developed. A snapshot of the. ipynb program file is shown below in Figure

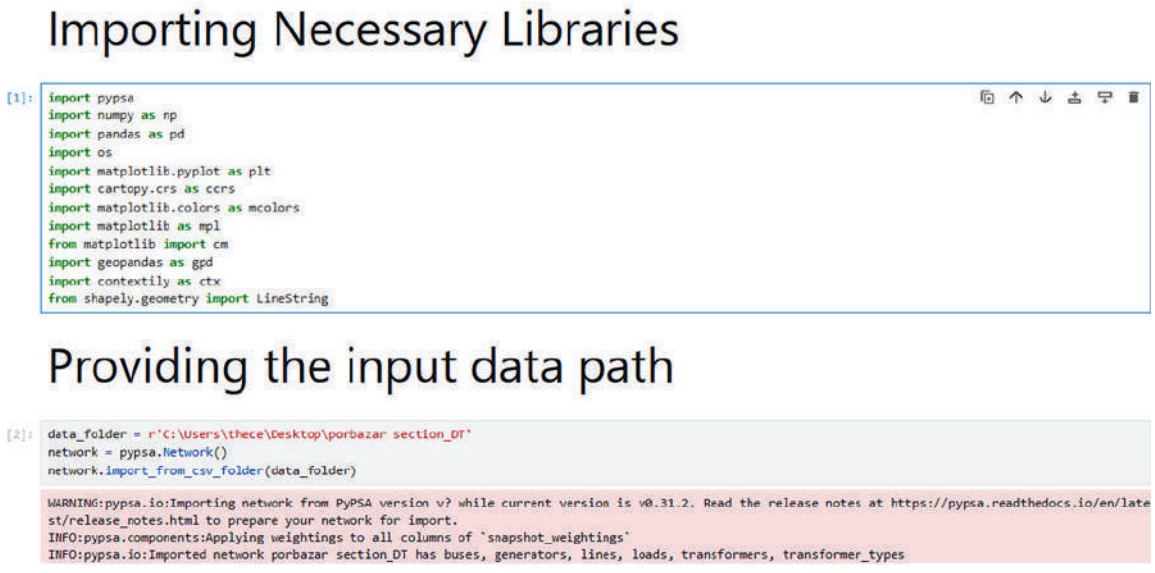


Figure A1-11: .ipynb program file to import the input files and simulate the model

After the network has been twinned, the power flow analysis was performed for the network and the results were analyzed in terms of real power flow P(MW), reactive power flow Q(MVA), the Voltages (pu) at the connecting points, the line loading and the transformer loading. The snapshots of the .ipynb program file for power flow and transformer and line/feeder loading has been shown below in the figure.

Non Linear Power Flow

```
network.generators_t.p_set = network.generators_t.p
```

```
network.pf()
```

Line Loading Calculations and Depictions

```
network.lines_t.p0
```

```
Power_line=network.lines_t.p0.abs()
# Define the output CSV file path
csv_filename_all_snapshots =os.path.join(data_folder,'output1', f'Power_line.csv')

# Save the collected data to a single CSV file
Power_line.to_csv(csv_filename_all_snapshots, index=True)

# Print confirmation
print(f"Line loadings saved to {csv_filename_all_snapshots}")
```

```
network.lines_t.q0
```

```
ReactivePower_line=network.lines_t.q0.abs()
# Define the output CSV file path
csv_filename_all_snapshots =os.path.join(data_folder,'output1', f'ReactivePower_line.csv')

# Save the collected data to a single CSV file
ReactivePower_line.to_csv(csv_filename_all_snapshots, index=True)

# Print confirmation
print(f"Line loadings saved to {csv_filename_all_snapshots}")
```

```
# Extract active and reactive power at the from-bus end
P = network.lines_t["p0"]   # DataFrame (snapshots × lines)
Q = network.lines_t["q0"]

# Compute apparent power magnitude
S0 = np.sqrt(P**2 + Q**2)

# Print first few values
print(S0.head())
```

```
line_loading_all = S0.abs().div(network.lines.s_nom, axis=1) * 100
# Example: plot first 5 lines across all snapshots
plt.figure(figsize=(14, 6))
line_loading_all.iloc[:, :28].plot(ax=plt.gca())

plt.xlabel("Snapshot")
plt.ylabel("Loading (%)")
plt.title("Line Loading Over Time")
plt.grid(True, linestyle="--", alpha=0.6)
plt.tight_layout()
plt.show()
```

```
# Calculate line loading (%) for chosen snapshot
hour_to_analyze = network.snapshots[20]  # Select the 21st snapshot

line_loading_final_hourly = (
    S0.abs().loc[hour_to_analyze].div(network.lines.s_nom) * 100
)

# Find overloaded lines (>100%)
overloaded_lines = line_loading_final_hourly[line_loading_final_hourly > 100]

print("Overloaded lines at", hour_to_analyze)
print(overloaded_lines)
```

Transformer Loading Calculation

```
network.transformers_t.p0
```

```
transformer_loading_final = (network.transformers_t.p0 / network.transformers.s_nom) * 100
# Define the output CSV file path
csv_filename_all_snapshots =os.path.join(data_folder,'output1', f'transformer_loading_final.csv')

# Save the collected data to a single CSV file
transformer_loading_final.to_csv(csv_filename_all_snapshots, index=True)
print(transformer_loading_final.head())
# Print confirmation
#print(f"Transformer loadings_final saved to {csv_filename_all_snapshots}")
```

```
day_to_plot = "2023-05-11"
transformer_loading_day = transformer_loading_final.loc[day_to_plot]

plt.figure(figsize=(14, 6))
transformer_loading_day.plot(ax=plt.gca(), marker='o')

plt.xlabel("Hour")
plt.ylabel("Loading (%)")
plt.title(f"Transformer Loading on {day_to_plot}")
plt.grid(True, linestyle="--", alpha=0.6)
plt.legend(title="Transformer")
plt.tight_layout()
plt.show()
```

Figure A1-12: .ipynb program file to run pf & compute line loading and transformer loading

Goa-PyPSA Model Input Files: Solar Scenario

The loads-p_set.csv and loads-q_set.csv files for solar scenario have been calculated in the similar manner as that of the baseline scenario. Here, the peak current was considered as 120A, which was peak among the solar hours for representative 5days of May.
The proportional current was first calculated as

$$I_{proportional} = Load\ of\ the\ DTC / Total\ Load\ of\ all\ the\ DTC\ *\ I_{peak}$$

(i.e for Limawado Iproportional = 200/5239*120=4.58).

Next, with the values of current from feeder load as shown in figure 21, P and Q at feeder level were calculated as per the equation given below:

$$P = 1.732 * 11 * current * 0.9/1000 \text{ in MW}$$

$$Q = 1.732 * 11 * current * 0.43/1000 \text{ in MVAr}$$

Next, considering this load profile at the feeder (11kV) level, the load profiles as every DT have been computed by a proportional factor.
Proportional factor= proportional current at that DT / The Peak Current.
Further, multiplying these proportional factors to the load profile at the we get the loads-p_set and loads-q_set for DTs.

In place of generator-p_max_pu.csv for solar scenario generator-p_set.csv file, has been prepared. The generator.csv and representative hourly generation for few hours of 11th May for generator-p_set.csv files have been shown in figures.

bus	p_nom	carrier	efficiency	p_nom_extendable
Tivim_220	50	Coal	0.26	FALSE
PB_DT25_415	0.05	Solar	0.26	TRUE

Figure A1-13: generator for Porvorim Bazar-solar scenario

name	Solar_DT1
5/11/2023 0:00	0
5/11/2023 1:00	0
5/11/2023 2:00	0
5/11/2023 3:00	0
5/11/2023 4:00	0
5/11/2023 5:00	0
5/11/2023 6:00	0
5/11/2023 7:00	0.00035
5/11/2023 8:00	0.01015
5/11/2023 9:00	0.0216
5/11/2023 10:00	0.0297
5/11/2023 11:00	0.0348
5/11/2023 12:00	0.03725
5/11/2023 13:00	0.03725
5/11/2023 14:00	0.034
5/11/2023 15:00	0.0295
5/11/2023 16:00	0.0224
5/11/2023 17:00	0.0115
5/11/2023 18:00	0.0009
5/11/2023 19:00	0
5/11/2023 20:00	0

Figure A1-14: representative generator_p_max_pu for Porvorim Bazar-solar scenario

In the generators.csv file, the solar generation has been injected at PB_DT25 (i.e Minguel Pinto DTC 100) at the load end, i.e 415V. Here the representative p_nom shown in the figure is 0.03MW, i.e 30kW. For the hosting capacity study, this p_nom value has to be change as per the installed capacity chosen. The hourly generation for solar has been recalculated for different installed capacities, as shown below in figure.

name	solar_pu	Solar_3kW	Solar_5kW	Solar_10kW	Solar_30kW
5/11/2023 0:00	0	0	0	0	0
5/11/2023 1:00	0	0	0	0	0
5/11/2023 2:00	0	0	0	0	0
5/11/2023 3:00	0	0	0	0	0
5/11/2023 4:00	0	0	0	0	0
5/11/2023 5:00	0	0	0	0	0
5/11/2023 6:00	0	0	0	0	0
5/11/2023 7:00	0.007	0.000021	0.000035	0.00007	0.00035
5/11/2023 8:00	0.203	0.000609	0.001015	0.00203	0.01015
5/11/2023 9:00	0.432	0.001296	0.00216	0.00432	0.0216
5/11/2023 10:00	0.594	0.001782	0.00297	0.00594	0.0297
5/11/2023 11:00	0.696	0.002088	0.00348	0.00696	0.0348
5/11/2023 12:00	0.745	0.002235	0.003725	0.00745	0.03725
5/11/2023 13:00	0.745	0.002235	0.003725	0.00745	0.03725
5/11/2023 14:00	0.68	0.00204	0.0034	0.0068	0.034
5/11/2023 15:00	0.59	0.00177	0.00295	0.0059	0.0295
5/11/2023 16:00	0.448	0.001344	0.00224	0.00448	0.0224
5/11/2023 17:00	0.23	0.00069	0.00115	0.0023	0.0115
5/11/2023 18:00	0.018	0.000054	0.00009	0.00018	0.0009
5/11/2023 19:00	0	0	0	0	0

Figure A1-15: representative generators-p_set for Porvorim Bazar-solar scenario

The 'Solar_DT1_pu' gives the solar generation in pu considering the Porvorim Bazar geographical location from the renewable ninja open-source data [https://www.renewables.ninja/]. This p.u hourly generations were multiplied by the solar injected capacity in MW. Here the 4 columns shows the hourly generation for 3kW, 5kW, 10kW and 30kW. These solar capacities were considered for conducting the solar hosting capacity study at Minguel DT of Porvorim Bazar feeder.

Annexure 2: Results for whole state of Goa upto 11kV

name	bus0	bus1	Max Loading (%)	name	bus0	bus1	Max Loading (%)	name	bus0	bus1	Max Loading (%)
1	Colvale_220	Tivim_220	64.49	51	Carmona_33	Velim_33	28.28	101	Nagoa_33	Candolim_33	68.87
2	Colvale_220	Tivim_220	64.49	52	Carmona_33	Leela Feeder	15.3	102	Nessai_33	Aquem_33	97.66
3	Colvale_220	Amona_220	78.97	53	Colony_33	Kundaim_33	31.75	103	Nessai_33	KRC_33	31.01
4	Colvale_220	Amona_220	78.97	54	Cuncolim SS_33	Canacona_33	16.56	104	Nessai_33	KRC_33	31.01
5	Amona_220	Ponda_220	33.44	55	Cuncolim SS_33	Canacona_33	39.86	105	Nessai_33	KRC_33	47.07
6	Amona_220	Ponda_220	40.56	56	Cuncolim SS_33	Canacona_33	39.86	106	Nessai_33	KRC_33	47.07
7	Amona_220	Ponda_220	40.56	57	Cuncolim_33	Cuncolim SS_33	91.27	107	Nessai_33	Navelim_33	7.09
8	Amona_220	Ponda_220	33.44	58	Cuncolim_33	Cuncolim SS_33	70.99	108	Nessai_33	Navelim_33	7.09
9	Ponda_220	Xeldem_220	98.31	59	Cuncolim_33	Velim_33	22.09	109	Ponda_33	Madkai_33	72.81
10	Xeldem_220	Cuncolim_220	49.46	60	Cuncolim_33	Velim_33	44.19	110	Ponda_33	Madkai_33	6.17
11	Tivim_110	Ponda_110	15.29	61	Dharbandora_33	Shigao_33	71.52	111	Ponda_33	Pale_33	90.57
12	Tivim_110	Kadamba_110	31.01	62	EDC_Patto_33	Altinho_33	39.88	112	Ponda_33	Pale_33	77.24
13	Kadamba_110	Ponda_110	15	63	EDC_Patto_33	Altinho_33	39.88	113	Ponda_33	Kundaim_33	95.15
14	Ponda_110	Verna_110	24.28	64	EDC_Patto_33	Altinho_33	39.88	114	Ponda_33	Kundaim_33	20.92
15	Ponda_110	Xeldem_110	4.29	65	EDC_Patto_33	Altinho_33	39.88	115	Ponda_33	Kundaim_33	49.62
16	Xeldem_110	Verna_110	26.82	66	Harbour_33	JSW Feeder	33.84	116	Ponda_33	Colony_33	6.3
17	Altinho_33	Campal_33	33.45	67	Kadamba_33	EDC_Patto_33	56.73	117	Ponda_33	Colony_33	6.38
18	Altinho_33	Campal_33	33.45	68	Kadamba_33	EDC_Patto_33	56.73	118	Ponda_33	Colony_33	6.38
19	Altinho_33	IT Hub Feeder	0.88	69	Kadamba_33	EDC_Patto_33	56.74	119	Ponda_33	Dharbandora_33	33.72
20	Altinho_33	Marriotts Feeder	8.66	70	Kadamba_33	EDC_Patto_33	56.74	120	Ponda_33	Shiroda_33	14.93
21	Amona_33	Corlim_33	97.4	71	Kadamba_33	Corlim_33	48.64	121	Ponda_33	Shiroda_33	14.93
22	Amona_33	Kundaim_33	72.52	72	Kadamba_33	Corlim_33	83.39	122	Ponda_33	Raia_33	69.82
23	Amona_33	Bicholim_33	67.47	73	Kadamba_33	Bambolim_33	94.36	123	Ponda_33	Raia_33	69.82
24	Amona_33	Sanquelim_33	30.96	74	Kadamba_33	Bambolim_33	94.36	124	Ponda_33	Bethora_33	22.25
25	Amona_33	Sanquelim_33	30.96	75	Kadamba_33	Bambolim_33	47.18	125	Ponda_33	Bethora_33	22.25
26	Amona_33	Valpoi_33	50	76	Kadamba_33	Nagali Hill_33	46.68	126	Ponda_33	Verna_33	60.82
27	Amona_33	Valpoi_33	52.52	77	Kadamba_33	Nagali Hill_33	46.68	127	Pontemol_33	Xelpem_33	3.25
28	Amona_33	Pale_33	36.49	78	Kadamba_SS_33	Harbour_33	22.96	128	Pontemol_33	Xelpem_33	4.65
29	Amona_33	Pale_33	34.57	79	Kadamba_SS_33	Harbour_33	22.96	129	Pontemol_33	Waddem_33	16.11
30	Amona_33	Sesa_Goa Feeder	66.51	80	Kadamba_SS_33	Bogda_33	23.73	130	Pontemol_33	Shigao_33	81.95
31	Amona_33	GEPL Feeder	82.62	81	Kadamba_SS_33	Bogda_33	23.73	131	Pontemol_33	Costi Feeder	0

32	Aquem_33	Monte Hill_33	44.16	82	Kadamba_SS_33	MPT-1 Feeder	7.95	132	Porvorim_33	Saligao_33	20.51
33	Aquem_33	Monte Hill_33	22.08	83	Kadamba_SS_33	MPT-2 Feeder	0	133	Porvorim_33	Saligao_33	20.56
34	Aquem_33	Monte Hill_33	22.08	84	Karaswada_33	Nachilona_33	7.87	134	Porvorim_33	Saligao_33	0.13
35	Aquem_33	KRC_33	31.45	85	KRC_33	Benaulim_33	15.61	135	Porvorim_33	Saligao_33	0.21
36	Aquem_33	KRC_33	31.45	86	KRC_33	Benaulim_33	15.61	136	Porvorim_33	Saligao_33	20.51
37	Bambolim_33	Pillar_33	31.99	87	KRC_33	Cuncolim SS_33	1.17	137	Porvorim_33	Saligao_33	20.56
38	Bambolim_33	Garrission Engineering Feeder	0	88	Kundaim_33	Madkai_33	28.7	138	Porvorim_33	Assembly Porvorim Feeder	58.76
39	Bambolim_33	GMC-I Feeder	14.19	89	Kundaim_33	Madkai_33	28.83	139	Raia_33	Fatorda_33	78
40	Bambolim_33	GMC-II Feeder	2.76	90	Mapusa_33	Anjuna_33	67.33	140	Raia_33	Fatorda_33	27.62
41	Benaulim_33	Carmona_33	8.23	91	Mapusa_33	Nagoa_33	36.74	141	Raia_33	Aquem_33	41.26
42	Benaulim_33	Carmona_33	8.23	92	Mapusa_33	Nagoa_33	36.74	142	Raia_33	Aquem_33	82.52
43	Corlim_33	Bicholim_33	63.89	93	Mapusa_33	Calangute_33	52.49	143	Saligao_33	Unichem 3-OH Feeder	19.09
44	Corlim_33	Bicholim_33	74.52	94	Mapusa_33	Calangute_33	52.49	144	Saligao_33	Unichem-UG-I Feeder	74.3
45	Canacona_33	Poinguinim_33	12.08	95	Nachilona_33	Porvorim_33	98.22	145	Saligao_33	Unichem-UG-II Feeder	15.59
46	Canacona_33	Poinguinim_33	12.08	96	Nachilona_33	Porvorim_33	42.74	146	Sancoale_33	Kadamba_SS_33	5.48
47	Candolim_33	Saligao_33	71.76	97	Bambolim_33	Nagali Hill_33	4.16	147	Sancoale_33	Kadamba_SS_33	5.48
48	Candolim_33	Saligao_33	71.76	98	Bambolim_33	Nagali Hill_33	12.75	148	Sancoale_33	Majorda_33	16.39
49	Candolim_33	FABR Feeder	13.94	99	Nagali Hill_33	Nagali-I Feeder	84.29	149	Sancoale_33	Majorda_33	16.38
50	Candolim_11	Highland Feeder	66.65	100	Nagali Hill_33	Nagali-II Feeder	86.59	150	Tivim_33	Pernem_33	60.04

Figure A2-1: Maximum Percentage Line loading for May (line 1 to line 150)

name	bus0	bus1	Max Loading (%)	name	bus0	bus1	Max Loading (%)	name	bus0	bus1	Max Loading (%)
151	Tivim_33	Pernem_33	80.05	201	Xeldem_33	Pontemol_33	49.13	251	Sancoale_11	Vasco-2 Feeder	22.77
152	Tivim_33	Tuem_33	4.21	202	Xeldem_33	Pontemol_33	7.15	252	Sanquelim_11	Amona Feeder	49.24
153	Tivim_33	Tuem_33	4.21	203	Xeldem_33	Xelpem_33	12.53	253	Sanquelim_11	Honda Feeder	26.37
154	Tivim_33	Mapusa_33	67.09	204	Xeldem_33	Xelpem_33	12.53	254	Sanquelim_11	Poriem Feeder	0

155	Tivim_33	Mapusa_33	70.99	205	Xeldem_33	Cuncolim_33	62.6	255	Sanquelim_11	Sanquelim Feeder	30.68
156	Tivim_33	Mapusa_33	46.5	206	Xeldem_33	Cuncolim_33	62.6	256	Sanquelim_33	GIM Feeder	0
157	Tivim_33	Mapusa_33	87.37	207	Xeldem_33	Cuncolim_33	62.6	257	Sanquelim_33	Podocem Feeder	0
158	Tivim_33	Mapusa_33	87.37	208	Xeldem_33	Cuncolim_33	62.6	258	Altinho_11	Alcon Feeder	40.29
159	Tivim_33	Karaswada_33	5.58	209	Xeldem_33	Rivona_33	13.05	259	Altinho_11	Cabo Feeder	28.9
160	Tivim_33	Karaswada_33	5.58	210	Xeldem_33	Aquem_33	41.63	260	Altinho_11	Campal Feeder	29.61
161	Tivim_33	Karaswada_33	5.58	211	Xeldem_33	Aquem_33	41.63	261	Altinho_11	Circuit House Feeder	15.97
162	Tivim_33	Nachilona_33	68.28	212	Nagali Hill_11	Vasant Vihar Feeder	0	262	Altinho_11	Fire Station Feeder	2.28
163	Tivim_33	Nachilona_33	68.25	213	Nagali Hill_11	Taleigao Feeder	25.6	263	Altinho_11	Inox Feeder	24
164	Tivim_33	Porvorim_33	30.06	214	Nagali Hill_11	Adraar Feeder	41.25	264	Altinho_11	Lydia Garden Feeder	33.43
165	Tivim_33	Porvorim_33	11	215	Nagali Hill_11	Alto-Nagali Feeder	12.8	265	Altinho_11	Manoshanti Feeder	11.92
166	Tivim_33	Bicholim_33	45.96	216	Nagali Hill_11	NIO Feeder	0	266	Altinho_11	National Feeder	27.38
167	Tivim_33	Bicholim_33	45.96	217	Nagali Hill_11	Status Feeder	15.65	267	Altinho_11	Tonca Miramar Feeder	92.25
168	Tivim_33	Sal_33	20.55	218	Nagali Hill_11	BSNL Feeder	5.69	268	Amona_11	Maina Feeder	0
169	Tivim_33	Sal_33	20.55	219	Nagali Hill_11	Caranzalem Feeder	44.1	269	Amona_11	Marcel Feeder	72.84
170	Tivim_33	AWW Feeder	7	220	Nagali Hill_11	Manipal Feeder	18.49	270	Amona_11	Navelim Feeder	55.04
171	Tivim_33	Mahindra Feeder	1.75	221	Nagali Hill_11	Market Nagali Feeder	0	271	Amona_11	Pissurlem_IDC Feeder	26.76
172	Tuem_33	Mandrem_33	0	222	Nagali Hill_11	Raj Bhavan Feeder	0	272	Anjuna_11	Chapora Feeder	32.72
173	Tuem_33	Mandrem_33	0	223	Nagali Hill_11	Oitiyant Feeder	5.69	273	Anjuna_11	Starco Feeder	38.55
174	Verna_33	Sancoale_33	22.09	224	Bambolim_11	Chimbel Feeder	21.6	274	Anjuna_11	Tembi Feeder	29.42
175	Verna_33	Sancoale_33	22.1	225	Bambolim_11	Dona_Paula Feeder	29.88	275	Anjuna_11	Vagator Feeder	18.77
176	Verna_33	Kadamba_SS_33	49.3	226	Bambolim_11	Green_Velley Feeder	30.92	276	Aquem_11	Aquem_Baixo Feeder	9.89
177	Verna_33	Kadamba_SS_33	49.3	227	Bambolim_11	Merces Feeder	25.3	277	Aquem_11	Gogol HB Feeder	36.02

178	Verna_33	Majorda_33	19.97	228	Bambolim_11	MES Feeder	34.02	278	Aquem_11	Khareband I Feeder	29.17
179	Verna_33	Majorda_33	19.97	229	Bambolim_11	Santa_Cruz Feeder	15.24	279	Aquem_11	Khareband II Feeder	23.84
180	Verna_33	Fatorda_33	52.94	230	Bambolim_11	Sirdao Feeder	10.65	280	Aquem_11	Malbhat Feeder	30.18
181	Verna_33	Fatorda_33	87.24	231	Pillar_11	Agassion Feeder	17.01	281	Aquem_11	Margao I Feeder	2.79
182	Verna_33	Fatorda_33	58.16	232	Pillar_11	Batim Feeder	32.4	282	Aquem_11	Margao III Feeder	26.38
183	Verna_33	Coca-Cola Feeder	56.36	233	Pillar_11	Neusa Feeder	13.91	283	Aquem_11	Rumdamol Feeder	26.89
184	Verna_33	PWD Feeder	7.5	234	Saligao_11	Betim Feeder	23.84	284	Benaulim_11	Colva Feeder	43.12
185	Verna_33	Microlab Feeder	89.98	235	Saligao_11	Cable_Industry Feeder	37.03	285	Benaulim_11	Benaulim Feeder	32.87
186	Verna_33	Finolex Feeder	70.64	236	Saligao_11	Gauravaddo Feeder	49.72	286	Benaulim_11	Mobor Feeder	0
187	Verna_33	Lupin Feeder	23.68	237	Saligao_11	Industry_OH Feeder	32.97	287	Benaulim_11	Varca Feeder	40.58
188	Verna_33	Cipla Feeder	5.33	238	Saligao_11	Navy Feeder	33.97	288	Benaulim_11	Trinity Feeder	18.41
189	Verna_33	Molbios Feeder	10.97	239	Saligao_11	Nerul Feeder	47.18	289	Benaulim_11	Colva Express Feeder	34.85
190	Verna_33	Birla Feeder	73.84	240	Saligao_11	Pilerne Feeder	29.38	290	Benaulim_11	Betal Batim I Feeder	36.04
191	Verna_33	Watson Feeder	95.5	241	Saligao_11	Saligao Feeder	18.77	291	Bethora_11	Bethora_Industria l Feeder	33.84
192	Benaulim_33	Ramada Feeder	34.58	242	Saligao_11	Shervani Feeder	85.96	292	Bethora_11	Bonbag Feeder	28.18
193	Xeldem_33	Nessai_33	30.8	243	Saligao_11	Candolim Church Feeder	0	293	Bethora_11	Nirankal Feeder	30.53
194	Xeldem_33	Nessai_33	23.96	244	Sancoale_11	Cansaulim Feeder	15.64	294	Bethora_11	Shiroda Feeder	5.4
195	Xeldem_33	Nessai_33	72.51	245	Sancoale_11	College Feeder	13.04	295	Bicholim_11	Advalpal Feeder	8.69
196	Xeldem_33	Nessai_33	33.02	246	Sancoale_11	Cortalim Feeder	17.62	296	Bicholim_11	Assonora Feeder	48.19
197	Xeldem_33	Nessai_33	41.07	247	Sancoale_11	Industrial Sancoale Feeder	18.98	297	Bicholim_11	Bordem Feeder	23.59
198	Xeldem_33	Cuncolim SS_33	88.41	248	Sancoale_11	Sesa_Goa Sancoale Feeder	13.04	298	Bicholim_11	City Feeder Feeder	50.22
199	Xeldem_33	Pontemol_33	28.33	249	Sancoale_11	Tata Feeder	21.78	299	Bicholim_11	IDC Feeder	19.02
200	Xeldem_33	Pontemol_33	17.71	250	Sancoale_11	Vasco-1 Feeder	26.73	300	Bicholim_11	Karapur Feeder	23.59

Figure A2-2: Maximum Percentage Line loading for May (line 151 to line 300)

name	bus0	bus1	Max Loading (%)	name	bus0	bus1	Max Loading (%)	name	bus0	bus1	Max Loading (%)
301	Bicholim_11	Kudchirem Feeder	31.22	351	Corlim_11	Mollar Feeder	0	401	Kundaim_11	Cuncolim Kundaim Feeder	48.61
302	Bicholim_11	Ladphem Feeder	0.53	352	Corlim_11	New Ind. Feeder	40.37	402	Kundaim_11	Kundaim Ind I Feeder	65.16
303	Bicholim_11	Lamgao Feeder	18.26	353	Corlim_11	Old Goa Feeder	33.43	403	Kundaim_11	Kundaim Ind II Feeder	72.02
304	Bicholim_11	Mayem Feeder	31.75	354	Corlim_11	Old Ind. Feeder	12.86	404	Kundaim_11	Kundaim Ind III Feeder	72.45
305	Bicholim_11	Narva Feeder	24.34	355	Corlim_11	Carambolim Feeder	47.57	405	Kundaim_11	Kundiam Feeder	45.18
306	Bicholim_11	Pilgao Feeder	25.4	356	Corlim_11	Kadamba Feeder	40.89	406	Madkai_11	Industry I Feeder	73.4
307	Bogda_11	Antartica Feeder	20.51	357	Cuncolim SS_11	Balli Feeder	22.42	407	Madkai_11	Industry II Feeder	47.96
308	Bogda_11	Brahmasthal Feeder	27.93	358	Cuncolim SS_11	Chinchinim Feeder	4.11	408	Madkai_11	Madkai Feeder	12.72
309	Bogda_11	Harbour Feeder	8.98	359	Cuncolim SS_11	Cuncolim Feeder	42.47	409	Madkai_11	Undir Feeder	31.71
310	Bogda_11	Head land Feeder	9.37	360	Cuncolim SS_11	IDC I Feeder	29.22	410	Madkai_11	Karanzal Feeder	10.91
311	Bogda_11	Masjid Feeder	14.06	361	Cuncolim SS_11	IDC II Feeder	42.47	411	Majorda_11	Nuvem Feeder	37.79
312	Calangute_11	Caculo Feeder	0	362	Cuncolim SS_11	Patem Feeder	26.49	412	Majorda_11	Duguem Feeder	33.99
313	Calangute_11	Kamat Feeder	0	363	Cuncolim SS_11	Dharmapur Feeder	20.32	413	Majorda_11	Utorda Feeder	19.53
314	Calangute_11	Maria Rosa Feeder	41.09	364	Dharbandora_11	Bondla Feeder	24.68	414	Majorda_11	Ramesh hotel Feeder	5.58
315	Calangute_11	Mark_Memorial Feeder	9.38	365	Dharbandora_11	Dabal Feeder	32.97	415	Majorda_11	Majorda Feeder	40.08
316	Calangute_11	Post_Office Feeder	47.18	366	Dharbandora_11	Dharbandoda Feeder	15.59	416	Majorda_11	Arrsoim Feeder	20.53
317	Calangute_11	Shivam Feeder	35.97	367	Dharbandora_11	Sonarbag Feeder	38.67	417	Mandrem_11	Ashvem Feeder	0
318	Calangute_11	Tivai Feeder	0	368	EDC_Patto_11	Bal Bharti Feeder	23.59	418	Mandrem_11	Mandrem Feeder	0

319	Calangute _11	Weena Feeder	33.96	369	EDC_Patto_11	Central Library Feeder	25.37	419	Mandrem_11	Khalsawada Feeder	0
320	Campal_11	Adarsh Feeder	33.74	370	EDC_Patto_11	Ginger Feeder	23.59	420	Mandrem_11	New Wada Feeder	0
321	Campal_11	City Campal Feeder	0.51	371	EDC_Patto_11	Kanaka Feeder	17.76	421	Mandrem_11	Palyem Feeder	0
322	Campal_11	Ideal Feeder	25.85	372	EDC_Patto_11	Neuginagar Feeder	26.89	422	Mapusa_11	Guirim Feeder	0
323	Campal_11	Indoor Stadium Feeder	50.58	373	EDC_Patto_11	Old Busstand Feeder	27.39	423	Mapusa_11	Khorlim Feeder	0
324	Campal_11	La Campala Feeder	31.45	374	EDC_Patto_11	Patto Plaza Feeder	9.89	424	Mapusa_11	Althinho Feeder	0
325	Campal_11	Market Feeder	27.9	375	EDC_Patto_11	Printing Press Feeder	4.31	425	Mapusa_11	Parra Feeder	0
326	Campal_11	St.Inez Feeder	28.66	376	EDC_Patto_11	Ribandar Feeder	22.32	426	Mapusa_11	Market Mapusa Feeder	37.47
327	Canacona_33	BHARAT HOTEL Feeder	8.83	377	EDC_Patto_11	Vidhyut Bhavan Feeder	22.57	427	Mapusa_11	Anjuna Feeder	73.06
328	Canacona_11	Shristhal Feeder	36.53	378	Fatorda_11	Ambaji Feeder	0	428	Mapusa_11	Assagao Feeder	86.73
329	Canacona_11	Agonda feeder	40.65	379	Fatorda_11	Borda I Feeder	50.73	429	Mapusa_11	Sodim Feeder	66.37
330	Canacona_11	Palolem Feeder	42.36	380	Fatorda_11	Borda II Feeder	0.25	430	Mapusa_11	Siolim Feeder	55.16
331	Canacona_11	Gaodongrim Feeder	14.2	381	Fatorda_11	Chowgule Fatorda Feeder	43.63	431	Mapusa_11	Housing Board Feeder	13.27
332	Canacona_11	Gulem Feeder	3.55	382	Fatorda_11	Fatorda Feeder	47.18	432	Mapusa_11	Industry Feeder	23.76
333	Candolim_11	Condolim Feeder	74.47	383	Fatorda_11	Gogol Feeder	50.73	433	Mapusa_11	Karaswada Feeder	24.95
334	Candolim_11	Singuerim Feeder	65.13	384	Fatorda_11	Old _Market Feeder	37.54	434	Mapusa_11	City Mapusa Feeder	20.39
335	Candolim_11	Ximer Feeder	50.7	385	Harbour_11	Mangoor Feeder	42.87	435	Mapusa_11	PWD Mapusa Feeder	21.78
336	Candolim_11	Tarcar Feeder	0	386	Harbour_11	Vasco City Feeder	51.56	436	Mapusa_11	Dhuler Feeder	29.3
337	Candolim_11	Kamat Candolim Feeder	0	387	Kadamba_SS_11	Airport Feeder	43.77	437	Monte Hill_11	Adarsh Monte Hill Feeder	30.69
338	Carmona_11	Zalor Feeder	20.03	388	Kadamba_SS_11	Church Feeder	0	438	Monte Hill_11	GVN I Feeder	66.71

339	Carmona_11	Zanoth Interlink Feeder	24.85	389	Kadamba_SS_11	City Kadamba Feeder	47.96	439	Monte Hill_11	GVN II Feeder	10.15
340	Carmona_11	Xirro Interlink Feeder	7.61	390	Kadamba_SS_11	New_Vaddem Feeder	79.91	440	Monte Hill_11	Hari Mandir I Feeder	18.26
341	Carmona_11	Mobor Interlink Feeder	17.24	391	Kadamba_SS_11	Vaddem_Lake Feeder	43.17	441	Monte Hill_11	Hari Mandir II Feeder	30.44
342	Colony_11	Bazar Feeder	24.08	392	Karaswada_11	Sattadhar Feeder	50.43	442	Monte Hill_11	Lohiya I Feeder	40.33
343	Colony_11	Curti Feeder	0	393	Karaswada_11	ACOI Feeder	40.35	443	Monte Hill_11	Lohiya II Feeder	0
344	Colony_11	Farmagudi Feeder	30.42	394	Karaswada_11	Industrial Kara Feeder	42.15	444	Monte Hill_11	Mutt Feeder	9.13
345	Colony_11	Khadpabandh Feeder	43.1	395	Karaswada_11	Spice Goa Feeder	5.76	445	Nachilona_11	Aldona Cable Feeder	27.34
346	Colony_11	Ponda I Feeder	45.13	396	KRC_11	Mandopa Feeder	33.06	446	Nachilona_11	Aldona O.H Feeder	11.01
347	Colony_11	Rajiv Gandhi K/M Feeder	17.75	397	KRC_11	MES KRC Feeder	51.86	447	Nachilona_11	Bastora Feeder	30.32
348	Corlim_11	Diwar Feeder	48.86	398	KRC_11	Navelim_OH Feeder	32.87	448	Nachilona_11	Moira Feeder	40.37
349	Corlim_11	Kumbharjua Feeder	26.49	399	Kundaim_11	Marcel Kundaim Feeder	61.3	449	Nachilona_11	Pomburfa Feeder	43.76
350	Corlim_11	Dhulapi Feeder	41.66	400	Kundaim_11	Mardol Feeder	57.44	450	Nagoa_11	Para Feeder	36.02

Figure A2-3: Maximum Percentage Line loading for May (line 301 to line 450)

name	bus0	bus1	Max Loading (%)	name	bus0	bus1	Max Loading (%)	name	bus0	bus1	Max Loading (%)
451	Nagoa_11	Agarwada Feeder	40.99	494	Pontemol_11	Panchwadi Feeder	79.02	536	Tivim_11	Colvale Feeder	40.37
452	Nagoa_11	Calangute Feeder	38.99	495	Pontemol_11	Town-1 Feeder	27.9	537	Tivim_11	Power_Grid Feeder	36.36
453	Nagoa_11	Dharwadkar Feeder	34.63	496	Pontemol_11	Town-2 Feeder	19.28	538	Tivim_11	Ind_Estate_UG1 Feeder	40.7

454	Nagoa_11	Nagao Feeder	21.19	497	Porvorim _11	Audit Feeder	23.72	539	Tivim_11	Ind_Estate_UG2 Feeder	32.69
455	Nagoa_11	Sanqwadi Feeder	28.15	498	Porvorim _11	Chogum Feeder	6.66	540	Tivim_11	Ind_Estate_OH Feeder	65.72
456	Nagoa_11	Mainbhatt Feeder	36.15	499	Porvorim _11	Devashri Feeder	23.34	541	Tivim_11 0	Binani Feeder	4.75
457	Nagoa_11	Baga Feeder	37.47	500	Porvorim _11	Gurudwara Feeder	37.54	542	Valpoi_1 1	City Valpoi Feeder	23.33
458	Nagoa_11	Arpora Feeder	38.15	501	Porvorim _11	Highland Porvorim Feeder	34.75	543	Valpoi_1 1	Dabose Feeder	6.64
459	Nagoa_11	Sauntawada Feeder	38.42	502	Porvorim _11	Housing Board Porvorim Feeder	24.1	544	Valpoi_1 1	Thana Feeder	11.13
460	Navelim_1 1	Davolim Feeder	21.78	503	Porvorim _11	Malim Feeder	25.94	545	Valpoi_1 1	Nagargao Feeder	15.43
461	Nessai_11	Chandor Feeder	95.55	504	Porvorim _11	Porvorim Bazar Feeder	11.09	546	Valpoi_1 1	Bhironda Feeder	36.87
462	Nessai_11	Goa Carbon Feeder	90.25	505	Porvorim _11	Pundalik Nagar Feeder	49.46	547	Valpoi_1 1	Saleli Feeder	15.23
463	Nessai_11	Industrial State Feeder	26.38	506	Porvorim _11	RND Feeder	37.17	548	Velim_11	Assolna Feeder	37.06
464	Nessai_11	Paroda Feeder	53.98	507	Porvorim _11	Salai Feeder	0	549	Velim_11	Betul Feeder	37.06
465	Pale_11	Barazan Feeder	50.96	508	Porvorim _11	Sangolda Feeder	33.48	550	Velim_11	Cumbeabhat Feeder	37.06
466	Pale_11	Kothambi Feeder	10.15	509	Porvorim _11	Socorro Feeder	25.96	551	Velim_11	Dramapur Feeder	37.06
467	Pale_11	Nanus Feeder	29.64	510	Porvorim _11	Torda Feeder	24.1	552	Velim_11	Chinchinim Velim Feeder	37.06
468	Pale_33	Vagus Feeder	0	511	Raia_11	Curtorim Feeder	57.78	553	Verna_11	Cortalim_OH Feeder	0.91
469	Pale_33	Sonshi Feeder	0	512	Raia_11	Loutolim Feeder	18.9	554	Verna_11	Smartlink Feeder	37.36
470	Pernem_11	Nagzar Feeder	35.14	513	Raia_11	Rachol Feeder	3.83	555	Verna_11	Industrial Verna Feeder	53.04
471	Pernem_11	Torse Feeder	34.43	514	Raia_11	Raia Feeder	38.7	556	Verna_11	Lokmat Feeder	38.6
472	Pernem_11	Dhargal Feeder	69.57	515	Raia_11	Santemol Feeder	29.7	557	Verna_11	Cortalim_UG Feeder	2.34
473	Pernem_11	Sawalwada Feeder	32.68	516	Sal_11	Sal Feeder	37.57	558	Verna_11	Herald Feeder	64.38
474	Pernem_11	City Pernem Feeder	23.98	517	Sal_11	Kasarpal Feeder	42.34	559	Verna_11	Verna Feeder	35.51
475	Pernem_11	WRD Feeder	10.48	518	Sal_11	Mencurem Feeder	12.17	560	Verna_11	Jordan Feeder	57.38

476	Pernem_11	Keri Feeder	23.04	519	Sal_11	Ibrampur Feeder	37.57	561	Verna_11	IFB Feeder	23.35
477	Poinguinim_11	Khotigao Feeder	22.57	520	Rivona_11	Colamba Feeder	0	562	Verna_11	Nagoa Feeder	30.44
478	Poinguinim_11	Link Line Feeder	12.68	521	Rivona_11	Sulcorna Feeder	0	563	Waddem_11	Bhati Feeder	47.41
479	Poinguinim_11	Marli tirwal feeder	0	522	Rivona_11	Maina Rivona Feeder	22.37	564	Waddem_11	Netravali O/H Feeder	33.19
480	Poinguinim_11	Poinguinim Feeder	5.83	523	Shigao_11	Collem Feeder	10.15	565	Waddem_11	Netravali U/G Feeder	0
481	Poinguinim_11	Loliem Feeder	14.46	524	Shigao_11	Dhat Feeder	28.58	566	Waddem_11	Kurpem U/G Feeder	0
482	Ponda_11	Curti Ponda Feeder	17.25	525	Shigao_11	Mollem Feeder	17.62	567	Xeldem_11	Quepem Feeder	0
483	Ponda_11	Durbhat Feeder	6.59	526	Shiroda_11	Torla_Paz Feeder	10.18	568	Xeldem_11	Xelvona Feeder	0
484	Ponda_11	Opa Feeder	9.38	527	Shiroda_11	Borlim Feeder	27.98	569	Xeldem_11	Rivona Feeder	0
485	Ponda_11	Savoiverem Feeder	10.72	528	Shiroda_11	Shiroda_Bazar Feeder	13.99	570	Xeldem_11	Assolda Feeder	0
486	Ponda_11	Shantinagar Feeder	8.62	529	Tuem_11	Ashvem Teum Feeder	0.6	571	Xeldem_11	Bansai Feeder	0
487	Ponda_11	Usgao Feeder	7.49	530	Tuem_11	Industry Tuem Feeder	0.25	572	Xelpem_11	Sanguem Feeder	71.12
488	Pontemol_11	Bansai Pontemol Feeder	17.25	531	Tuem_11	Tuem Feeder	10.61	573	Xelpem_11	Dando Feeder	7.56
489	Pontemol_11	Dabal Pontemol Feeder	63.21	532	Tuem_11	Morjim Feeder	0.51	574	Xelpem_11	Ponsamol Feeder	52.15
490	Pontemol_11	Hodar Feeder	10.15	533	Tuem_11	Mandrem Teum Feeder	0.04	575	Xelpem_11	Barazan Xelpem Feeder	7.16
491	Pontemol_11	IDC Pontemol Feeder	30.44	534	Tivim_11	Sirsaim Feeder	25.69	576	Xelpem_11	Malkarne Feeder	9.1
492	Pontemol_11	Kakoda Feeder	21.05	535	Tivim_11	Tivim_Village Feeder	36.03				
493	Pontemol_11	Kalay Feeder	17.76								

Figure A2-4: Maximum Percentage Line loading for May (line 451 to line 576)

name	type	bus0	bus1	Max Loading (%)	name	type	bus0	bus1	Max Loading (%)	name	type	bus0	bus1	Max Loading (%)
Altinho_TF1	20 MVA 33/11 kV	Altinho_33	Altinho_11	29.02	Kadamba_TF3	40 MVA 110/33 kV	Kadamba_110	Kadamba_33	31.63	Porvorim_TF1	6.3 MVA 33/11 kV	Porvorim_33	Porvorim_11	65.7
Altinho_TF2	20 MVA 33/11 kV	Altinho_33	Altinho_11	29.02	Kadamba_TF4	40 MVA 110/33 kV	Kadamba_110	Kadamba_33	31.63	Porvorim_TF2	10 MVA 33/11 kV	Porvorim_33	Porvorim_11	62.08
Amona_TF1	50 MVA 220/33 kV	Amona_220	Amona_33	58.73	Kadamba_SS_TF1	6.3 MVA 33/11 kV	Kadamba_SS_33	Kadamba_SS_11	47.27	Porvorim_TF3	10 MVA 33/11 kV	Porvorim_33	Porvorim_11	62.08
Amona_TF2	50 MVA 220/33 kV	Amona_220	Amona_33	58.73	Kadamba_SS_TF2	6.3 MVA 33/11 kV	Kadamba_SS_33	Kadamba_SS_11	47.27	Porvorim_TF4	8 MVA 33/11 kV	Porvorim_33	Porvorim_11	64.2
Amona_TF3	6.3 MVA 33/11 kV	Amona_33	Amona_11	78.66	Kadamba_SS_TF3	6.3 MVA 33/11 kV	Kadamba_SS_33	Kadamba_SS_11	47.27	Raia_TF1	6.3 MVA 33/11 kV	Raia_33	Raia_11	60.1
Anjuna_TF1	10 MVA 33/11 kV	Anjuna_33	Anjuna_11	78.88	Karaswada_TF1	10 MVA 33/11 kV	Karaswada_33	Karaswada_11	30.69	Raia_TF2	10 MVA 33/11 kV	Raia_33	Raia_11	56.79
Aquem_TF1	6.3 MVA 33/11 kV	Aquem_33	Aquem_11	45.25	Karaswada_TF2	10 MVA 33/11 kV	Karaswada_33	Karaswada_11	30.69	Rivona_TF	3.15 MVA 33/11 kV	Rivona_33	Rivona_11	61.51
Aquem_TF2	10 MVA 33/11 kV	Aquem_33	Aquem_11	42.76	KRC_TF1	10 MVA 33/11 kV	KRC_33	KRC_11	72.7	Sal_TF1	6.3 MVA 33/11 kV	Sal_33	Sal_11	26.26
Aquem_TF3	10 MVA 33/11 kV	Aquem_33	Aquem_11	42.76	Kundaim_TF1	10 MVA 33/11 kV	Kundaim_33	Kundaim_11	73.9	Sal_TF2	6.3 MVA 33/11 kV	Sal_33	Sal_11	26.26
Bambolim_TF1	6.3 MVA 33/11 kV	Bamboli m_33	Bamboli m_11	41.47	Kundaim_TF2	10 MVA 33/11 kV	Kundaim_33	Kundaim_11	73.9	Saligao_TF1	6.3 MVA 33/11 kV	Saligao_33	Saligao_11	54.38
Bambolim_TF2	10 MVA 33/11 kV	Bamboli m_33	Bamboli m_11	39.19	Madkai_TF1	6.3 MVA 33/11 kV	Madkai_33	Madkai_11	45.04	Saligao_TF2	6.3 MVA 33/11 kV	Saligao_33	Saligao_11	54.38
Bambolim_TF3	10 MVA 33/11 kV	Bamboli m_33	Bamboli m_11	39.19	Madkai_TF2	6.3 MVA 33/11 kV	Madkai_33	Madkai_11	45.04	Saligao_TF3	10 MVA 33/11 kV	Saligao_33	Saligao_11	51.39
Benaulim_TF1	6.3 MVA 33/11 kV	Benaulim_33	Benaulim_11	59.34	Majorda_TF1	6.3 MVA 33/11 kV	Majorda_33	Majorda_11	51.93	Saligao_TF4	10 MVA 33/11 kV	Saligao_33	Saligao_11	51.39
Benaulim_TF2	10 MVA 33/11 kV	Benaulim_33	Benaulim_11	56.07	Majorda_TF2	10 MVA 33/11 kV	Majorda_33	Majorda_11	49.07	Sancoale_TF1	6.3 MVA 33/11 kV	Sancoale_33	Sancoale_11	45.24
Benaulim_TF3	10 MVA 33/11 kV	Benaulim_33	Benaulim_11	56.07	Mandrem_TF1	10 MVA 33/11 kV	Mandrem_33	Mandrem_11	0	Sancoale_TF2	6.3 MVA 33/11 kV	Sancoale_33	Sancoale_11	45.24
Bethora_TF1	6.3 MVA 33/11 kV	Bethora_33	Bethora_11	41.37	Mandrem_TF2	10 MVA 33/11 kV	Mandrem_33	Mandrem_11	0	Sancoale_TF3	6.3 MVA 33/11 kV	Sancoale_33	Sancoale_11	45.24
Bethora_TF2	6.3 MVA 33/11 kV	Bethora_33	Bethora_11	41.37	Mapusa_TF1	10 MVA 33/11 kV	Mapusa_33	Mapusa_11	48.3	Sancoale_TF4	10 MVA 33/11 kV	Sancoale_33	Sancoale_11	42.75
Bicholim_TF1	6.3 MVA 33/11 kV	Bicholim_33	Bicholim_11	62.24	Mapusa_TF2	10 MVA 33/11 kV	Mapusa_33	Mapusa_11	48.3	Sanquelim_TF1	10 MVA 33/11 kV	Sanquelim_33	Sanquelim_11	49.04

Bicholim_TF2	6.3 MVA 33/11 kV	Bicholim_33	Bicholim_11	62.24	Mapusa_TF3	10 MVA 33/11 kV	Mapusa_33	Mapusa_11	48.3	Shigao_TF1	6.3 MVA 33/11 kV	Shigao_33	Shigao_11	41.1
Bicholim_TF3	6.3 MVA 33/11 kV	Bicholim_33	Bicholim_11	62.24	Mapusa_TF4	6.3 MVA 33/11 kV	Mapusa_33	Mapusa_11	51.12	Shiroda_TF1	6.3 MVA 33/11 kV	Shiroda_33	Shiroda_11	55.52
Bogda_TF1	6.3 MVA 33/11 kV	Bogda_33	Bogda_11	45.86	Mapusa_TF5	8 MVA 33/11 kV	Mapusa_33	Mapusa_11	49.95	Tivim_TF1	40 MVA 110/33 kV	Tivim_110	Tivim_33	37.21
Bogda_TF2	6.3 MVA 33/11 kV	Bogda_33	Bogda_11	45.86	Monte-Hill_TF1	6.3 MVA 33/11 kV	Monte Hill_33	Monte Hill_11	53.27	Tivim_TF10	50 MVA 110/33 kV	Tivim_110	Tivim_33	37.21
Calangute_TF1	20 MVA 33/11 kV	Calangute_33	Calangute_11	21.22	Monte-Hill_TF2	6.3 MVA 33/11 kV	Monte Hill_33	Monte Hill_11	53.27	Tivim_TF2	50 MVA 110/33 kV	Tivim_110	Tivim_33	37.21
Calangute_TF2	20 MVA 33/11 kV	Calangute_33	Calangute_11	21.22	Monte-Hill_TF3	10 MVA 33/11 kV	Monte Hill_33	Monte Hill_11	50.33	Tivim_TF3	50 MVA 110/33 kV	Tivim_110	Tivim_33	37.21
Campal_TF1	20 MVA 33/11 kV	Campal_33	Campal_11	29.22	Nachilona_TF1	6.3 MVA 33/11 kV	Nachilona_33	Nachilona_11	77.57	Tivim_TF4	100_MVA 220/110 kV	Tivim_220	Tivim_110	31.83
Campal_TF2	10 MVA 33/11 kV	Campal_33	Campal_11	29.86	Nachilona_TF2	6.3 MVA 33/11 kV	Nachilona_33	Nachilona_11	77.57	Tivim_TF5	100_MVA 220/110 kV	Tivim_220	Tivim_110	31.83
Canacona_TF1	6.3 MVA 33/11 kV	Canacona_33	Canacona_11	64.23	Nagali Hill_TF1	10 MVA 33/11 kV	Nagali Hill_33	Nagali Hill_11	35.02	Tivim_TF6	100_MVA 220/110 kV	Tivim_220	Tivim_110	31.83
Canacona_TF2	6.3 MVA 33/11 kV	Canacona_33	Canacona_11	64.23	Nagali Hill_TF2	10 MVA 33/11 kV	Nagali Hill_33	Nagali Hill_11	35.02	Tivim_TF7	63 MVA 220/33 kV	Tivim_220	Tivim_33	67.68
Carmona_TF1	6.3 MVA 33/11 kV	Carmona_33	Carmona_11	61.51	Nagali Hill_TF3	8 MVA 33/11 kV	Nagali Hill_33	Nagali Hill_11	36.21	Tivim_TF8	10 MVA 33/11 kV	Tivim_33	Tivim_11	63.79
Colony_TF1	6.3 MVA 33/11 kV	Colony_33	Colony_11	57.92	Nagoa_TF1	8 MVA 33/11 kV	Nagoa_33	Nagoa_11	75.82	Tivim_TF9	10 MVA 33/11 kV	Tivim_33	Tivim_11	63.79
Colony_TF2	10 MVA 33/11 kV	Colony_33	Colony_11	54.73	Nagoa_TF2	6.3 MVA 33/11 kV	Nagoa_33	Nagoa_11	77.59	Tuem_TF1	6.3 MVA 33/11 kV	Tuem_33	Tuem_11	5.44
Candolim_TF1	10 MVA 33/11 kV	Candolim_33	Candolim_11	50.19	Nagoa_TF3	10 MVA 33/11 kV	Nagoa_33	Nagoa_11	73.32	Tuem_TF2	6.3 MVA 33/11 kV	Tuem_33	Tuem_11	5.44
Candolim_TF2	6.3 MVA 33/11 kV	Candolim_33	Candolim_11	53.11	Nagoa_TF4	10 MVA 33/11 kV	Nagoa_33	Nagoa_11	73.32	Tuem_TF3	8 MVA 33/11 kV	Tuem_33	Tuem_11	5.32
Candolim_TF3	8 MVA 33/11 kV	Candolim_33	Candolim_11	51.9	Navelim_TF1	20 MVA 33/11 kV	Navelim_33	Navelim_11	4.72	Valpoi_TF1	6.3 MVA 33/11 kV	Valpoi_33	Valpoi_11	53.48
Corlim_TF1	10 MVA 33/11 kV	Corlim_33	Corlim_11	57.74	Navelim_TF2	20 MVA 33/11 kV	Navelim_33	Navelim_11	4.72	Valpoi_TF2	6.3 MVA 33/11 kV	Valpoi_33	Valpoi_11	53.48
Corlim_TF2	6.3 MVA 33/11 kV	Corlim_33	Corlim_11	61.11	Nessai_TF1	6.3 MVA 33/11 kV	Nessai_33	Nessai_11	54.98	Velim_TF1	6.3 MVA 33/11 kV	Velim_33	Velim_11	42.06
Corlim_TF3	10 MVA 33/11 kV	Corlim_33	Corlim_11	57.74	Nessai_TF2	6.3 MVA 33/11 kV	Nessai_33	Nessai_11	54.98	Velim_TF2	6.3 MVA 33/11 kV	Velim_33	Velim_11	42.06
Cuncolim SS_TF1	10 MVA 33/11 kV	Cuncolim SS_33	Cuncolim SS_11	36.16	Pale_TF1	6.3 MVA 33/11 kV	Pale_33	Pale_11	59.33	Verna_TF1	50 MVA 110/33 kV	Verna_110	Verna_33	31.22

Cuncolim SS_TF2	10 MVA 33/11 kV	Cuncolim SS_33	Cuncolim SS_11	36.16	Pernem_TF1	6.3 MVA 33/11 kV	Pernem_33	Pernem_11	91.72	Verna_TF2	50 MVA 110/33 kV	Verna_110	Verna_33	31.22
Cuncolim SS_TF3	6.3 MVA 33/11 kV	Cuncolim SS_33	Cuncolim SS_11	38.27	Pernem_TF2	6.3 MVA 33/11 kV	Pernem_33	Pernem_11	91.72	Verna_TF3	40 MVA 110/33 kV	Verna_110	Verna_33	31.22
Cuncolim SS_TF4	6.3 MVA 33/11 kV	Cuncolim SS_33	Cuncolim SS_11	38.27	Pilar_TF1	6.3 MVA 33/11 kV	Pillar_33	Pillar_11	33.1	Verna_TF4	40 MVA 110/33 kV	Verna_110	Verna_33	31.22
Cuncolim_TF1	50 MVA 220/33 kV	Cuncolim_220	Cuncolim_33	54.41	Pilar_TF2	6.3 MVA 33/11 kV	Pillar_33	Pillar_11	33.1	Verna_TF5	10 MVA 33/11 kV	Verna_33	Verna_11	52.36
Cuncolim_TF2	50 MVA 220/33 kV	Cuncolim_220	Cuncolim_33	54.41	Poinguinim_TF1	6.3 MVA 33/11 kV	Poinguinim_33	Poinguinim_11	50.62	Verna_TF6	10 MVA 33/11 kV	Verna_33	Verna_11	52.36
Cuncolim_TF3	50 MVA 220/33 kV	Cuncolim_220	Cuncolim_33	54.41	Ponda_TF1	40 MVA 110/33 kV	Ponda_110	Ponda_33	29.7	Verna_TF7	6.3 MVA 33/11 kV	Verna_33	Verna_11	55.42
Dharbandoda_TF1	6.3 MVA 33/11 kV	Dharbandora_33	Dharbandora_11	88.46	Ponda_TF10	40 MVA 110/33 kV	Ponda_110	Ponda_33	29.7	Verna_TF8	8 MVA 33/11 kV	Verna_33	Verna_11	54.15
EDC_Patto_TF1	10 MVA 33/11 kV	EDC_Patto_33	EDC_Patto_11	38.1	Ponda_TF2	30 MVA 110/33 kV	Ponda_110	Ponda_33	29.7	Waddem_TF1	3.15 MVA 33/11 kV	Waddem_33	Waddem_11	50.62
EDC_Patto_TF2	20 MVA 33/11 kV	EDC_Patto_33	EDC_Patto_11	37.28	Ponda_TF3	100_MVA 220/110 kV	Ponda_220	Ponda_110	28.94	Xelpem_TF1	40 MVA 110/33 kV	Xeldem_110	Xeldem_33	29.09
Fatorda_TF1	6.3 MVA 33/11 kV	Fatorda_33	Fatorda_11	46.69	Ponda_TF4	100_MVA 220/110 kV	Ponda_220	Ponda_110	28.94	Xeldem_TF1	40 MVA 110/33 kV	Xeldem_110	Xeldem_33	29.09
Fatorda_TF2	6.3 MVA 33/11 kV	Fatorda_33	Fatorda_11	46.69	Ponda_TF5	100_MVA 220/110 kV	Ponda_220	Ponda_110	28.94	Xeldem_TF2	100_MVA 220/110 kV	Xeldem_220	Xeldem_110	27.8
Fatorda_TF3	6.3 MVA 33/11 kV	Fatorda_33	Fatorda_11	46.69	Ponda_TF6	63 MVA 220/33 kV	Ponda_220	Ponda_33	57.63	Xeldem_TF3	100_MVA 220/110 kV	Xeldem_220	Xeldem_110	27.8
Fatorda_TF4	10 MVA 33/11 kV	Fatorda_33	Fatorda_11	44.12	Ponda_TF7	50 MVA 220/33 kV	Ponda_220	Ponda_33	57.63	Xeldem_TF4	50 MVA 220/33 kV	Xeldem_220	Xeldem_33	55.88
Harbour_TF1	6.3 MVA 33/11 kV	Harbour_33	Harbour_11	34.43	Ponda_TF8	30 MVA 33/11 kV	Ponda_33	Ponda_11	7.27	Xeldem_TF5	10 MVA 33/11 kV	Xeldem_33	Xeldem_11	0
Harbour_TF2	6.3 MVA 33/11 kV	Harbour_33	Harbour_11	34.43	Ponda_TF9	6.3 MVA 33/11 kV	Ponda_33	Ponda_11	8.11	Xeldem_TF6	6.3 MVA 33/11 kV	Xeldem_33	Xeldem_11	0
Kadamba_TF1	40 MVA 110/33 kV	Kadamba_110	Kadamba_33	31.63	Pontemol_TF1	10 MVA 33/11 kV	Pontemol_33	Pontemol_11	48.44	Xeldem_TF7	6.3 MVA 33/11 kV	Xelpem_33	Xelpem_11	75.12
Kadamba_TF2	40 MVA 110/33 kV	Kadamba_110	Kadamba_33	31.63	Pontemol_TF2	10 MVA 33/11 kV	Pontemol_33	Pontemol_11	48.44					

Figure A2-5: Maximum Percentage Transformer loading for May





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