Enabling Carbon Minimal World!

Resource Adequacy Planning for the State of Maharashtra – Modeling Approaches and Results

Prepared By

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Enabling Carbon Minimal World!

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Abbreviations

APPC:	Average Power Procurement Cost
APR:	Annual Performance Review
ARR:	Annual Revenue Requirement
ARIMA:	Auto-Regressive Integrated Moving Average
BESS:	Battery Energy Storage Systems
CAGR:	Compound Annual Growth Rate
CC:	Capacity Crediting
CEA:	Central Electricity Authority
CERC:	Central Electricity Regulatory Commission
DERs:	Distributed Energy Resources
DLs:	Distribution Licensees
EENS:	Expected Energy Not Served
ELCC:	Expected Load Carrying Capability
EPS:	Electricity Power Survey
ESS:	Energy Storage Systems
EVs:	Electric Vehicles
FoR:	Forum of Regulators
LOLP:	Loss of Load Probability
LT-DRAP:	Long-Term Distribution Resource Adequacy Plan
LT-NRAP:	Long-Term National Resource Adequacy Plans
MERC:	Maharashtra Electricity Regulatory Commission
MoD:	Merit Order Dispatch
MoP:	Ministry of Power
MSLDC:	Maharashtra State Load Dispatch Centre
NENS:	Normalized Energy Not Served
NLDC:	National Load Dispatch Centre
NEP:	National Electricity Plan
PRM:	Planning Reserve Margin
PSP:	Pumped Storage Hydro
PUShP:	Portal for Utility Statistics for Health of Power Distribution
RA:	Resource Adequacy
RAR:	Resource Adequacy Requirement
RE:	Renewable Energy
RPO:	Renewable Purchase Obligation
RTC:	Round-The-Clock
SERC:	State Electricity Regulatory Commissions
SLDC:	State Load Dispatch Centres
ST-DRAP:	Short-Term Distribution Resource Adequacy Plan
ST-NRAP:	Short-Term National Resource Adequacy Plans
STOA:	Short Term Open Access
STU:	State Transmission Utilities
UPS:	Uninterruptible Power Supply
vRE:	variable Renewable Energy

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1. Introduction

India has set five ambitious clean energy targets for its economy, also known as five nectar elements or "Panchamrit", as follows:

1. Reach non-fossil energy capacity of 500 GW by 2030.
2. Meet 50 percent of its energy requirements from renewable energy (RE) by 2030.
3. Reduce the total projected carbon emissions by one billion tonnes from now onwards till 2030.
4. Reduce the carbon intensity of its economy by less than 45 percent by 2030.
5. Achieve the target of Net Zero by 2070.

Between FY15 and November 2024, RE (including hydro) capacity increased around five times from 40 GW to almost 205 GW[1], supplying nearly 23% of the total electricity generated as November 2024[2]. Various studies suggest a significant increase in share of RE in the next 10 years. Karnataka, Maharashtra, Rajasthan, Gujarat, and Tamil Nadu stand out as RE-rich states in India, collectively possessing around 50% of total RE installed capacity.

1.1. Background

Maharashtra boasts of 20,621 MW of installed RE capacity, including 8,989 MW of solar and 5,216 MW of wind as of December 2024[3]. It has a total potential of 166 GW, underlining its pivotal role in India's RE landscape and in achieving India's clean energy aspirations.

As Maharashtra embarks on this transition, its electricity sector faces several challenges, such as:

- Intermittency at multiple levels (day/night, seasonal etc.)
- Unavailability during peak demand periods
- Increased ramping from conventional plants
- Creation of "duck curve" situations

Such a fast-evolving grid with ever increasing RE penetration requires adoption of measures of resource adequacy (RA) which would include flexible resources (storage, load shift etc.). RA involves the planning of generation and transmission resources to reliably meet the projected demand in compliance with specified reliability standards for serving the load with an optimal generation mix. It also provides the tools to determine whether there are enough resources and, if not, what type of resource is needed to meet reliability needs and how to contract these capacities. At the same time, any surplus resulting in the analysis would facilitate the trading of the same with other constituents ensuring optimal capacity utilization.

Well-designed system planning and RA frameworks, coordinated with state-level resource planning and procurement and supported by market mechanism, are critical to scaling RE deployment with less curtailment and less financial and operational stress on conventional assets. System planning and RA analysis can help facilitate capacity sharing, increasing the utilization of existing generation assets.

Further, ensuring sufficient firm capacity on the grid is crucial to meet the load reliably. Procuring thermal capacity without considering RE or flexible resources can lead to an oversized system and higher costs. Therefore, system simulation studies and optimization are essential to meet ramping needs and load curves cost-effectively.

Key measures to address resource adequacy challenges include the implementation of demand-side management (DSM) strategies and load-shifting mechanisms. Load shifting helps optimize electricity consumption patterns by encouraging consumers to shift demand from peak periods to times of surplus generation, enhancing system reliability. Additionally, accurate demand forecasting and flexible generation resources play a crucial role in balancing supply and demand. These measures collectively strengthen the power system's ability to maintain reliability and meet electricity demand, especially with the increasing share of variable renewable energy (vRE) in the generation mix.

1 NPP Dashboard

2 NPP Dashboard

3 MNRE

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1.2. Objectives & Scope

RA is being implemented by various states across India as per the mandate of the Ministry of Power (MoP), which requires State Electricity Regulatory Commissions (SERCs) to notify Regulations and states to ensure their effective implementation. Given the criticality of RA in power sector planning, while also recognizing that it is a relatively new concept, this initiative was undertaken to conduct detailed studies and organize a capacity-building workshop for Maharashtra.

The workshop covered all aspects of RA, providing state agencies and utilities with the necessary training and material to facilitate a successful implementation. A separate report has been prepared documenting the workshop proceedings, while this report focuses on the detailed RA modeling studies.

This study aims to undertake "**Resource Adequacy Planning – Modeling Approaches and Results**" for the state of Maharashtra. By applying energy modeling and optimization techniques, it aims to demonstrate an optimal and cost-effective resource mix through FY34 that meets projected demand and also maintains reliability standards. It seeks to help Maharashtra maximize its RE potential and serve as a scalable, sustainable model for other RE-rich states in India.

To achieve this objective, the following key activities have been undertaken:

- **Data Collection**: Gathering, consolidating, and validating data related to hourly demand profiles, future peak and energy projections, existing and contracted resources with their technical and financial parameters, hourly RE generation profiles, and RPO targets.
- **System Configuration**: Setting up and configuring the collected inputs.
- **Simulations and Iterations**: Running simulations through FY34 to check outputs such as capacity expansion, dispatch, storage characteristics, system cost, as well as reliability metrics of net energy not served and loss of load probability.
- **Output Analysis and Inferences**: Analyzing output parameters to draw conclusions on meeting RPO targets, required RE and storage, operational reliability, planning reserve margin (PRM), cost of generation/system, and average power procurement cost (APPC).

1.3. Structure of the Report

This report is structured into six main chapters as follows:

Chapter 2 provides an overview of the demand and supply scenario in Maharashtra.

Chapter 3 explores the concept of RA in detail, emphasizing its role in planning of generation and transmission resources to meet projected demand reliably. It covers key features, guiding principles, and key steps in RA framework.

Chapter 4 provides an overview of Maharashtra Electricity Regulatory Commission (Framework for Resource Adequacy) Regulations, 2024 covering key steps, roles and responsibilities, and timelines.

Chapter 5 presents an overview of various tools and methodologies that can be applied for RA studies and also gives an insight into the modeling approach undertaken for this study.

Chapter 6 outlines the key input assumptions used in this modeling study, from existing and contracted resources with their technical and financial characteristics, RPO requirements, hourly solar and wind generation profiles, hourly demand profile, demand projections, stochastics etc.

Chapter 7 covers key outputs and outcomes derived from the energy modeling study. It highlights year-on-year (YoY) trends in installed capacity and generation, battery energy storage requirements, average hourly generation patterns, unserved and dump energy metrics, reliability indicators, and APPC. These findings offer a comprehensive view of the future energy landscape and the performance of Maharashtra's power system under RA framework.

Chapter 8 presents a high-level synthesis of RA study published by Central Electricity Authority (CEA) for the Maharashtra, to provide the state with a comprehensive set of pathways for its future development.

Chapter 9 provides concluding remarks.

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2. Maharashtra State Overview

Maharashtra, located in Western India, is the 3rd largest state both by area and by population[4]. It boasts of a vibrant economy with a projected Gross State Domestic Product (GSDP) of ₹ 40,44,251 crore for FY24, reflecting an 11% growth over FY23[5] which highlights its economic strength and progress. It is a key player in India's industrial and technological landscape, home to numerous major public sector industries and renowned research institutions.

Figure 1: Map of Maharashtra[6]

Maharashtra's strategic coastal location and strong industrial base have contributed to the expansion of its power sector, meeting the energy needs of both industrial, residential, agricultural, commercial and institutional consumers. Its power mix is diverse, including thermal, hydro, solar, and wind power plants, underscoring its commitment to sustainable energy. Innovative policies and cutting-edge technologies have positioned Maharashtra at the forefront of India's green energy transition. Through continuous innovation and collaborative efforts, the power sector continues to advance, aiming to fulfil the growing energy demands of its population while paving the way towards a more sustainable and prosperous future.

2.1. Demand Scenario

Maharashtra saw a peak demand of 31,178 MW in the month of April in FY24, which was a 14.8% increase from FY23. Its total energy requirement in FY24 was 2,06,398 MUs. The following Figure 2 shows the monthly peak demand for FY24:

4 UIDAI; List of states and union territories of India by area - Wikipedia

5 RBI

6 Maps of India – Maharashtra

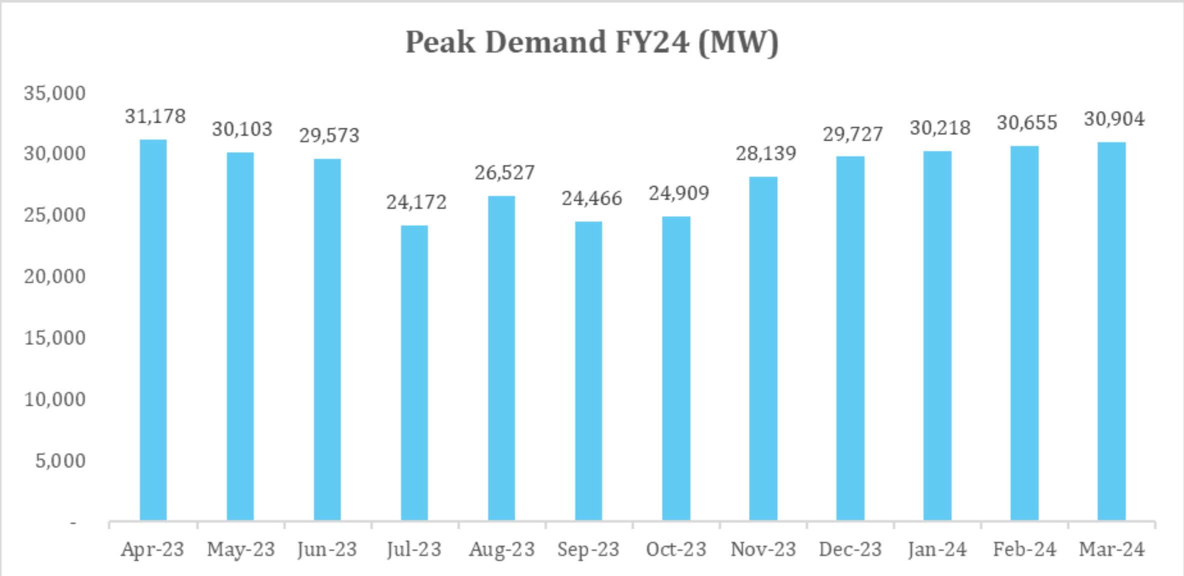

Figure 2: Maharashtra Month-wise Peak Demand of FY24[7]

The actual energy requirements over the past three years consistently surpassed the projections outlined in CEA's 20th Electric Power Survey (EPS) while the actual peak demand followed closely. Table 1 below provides a detailed comparison of actual and EPS projections:

Table 1: Actual v/s EPS Peak Demand and Energy Requirement[8]

Year	Energy Requirement (MUs)		Peak Demand (MW)	
	20th EPS	Actual	20th EPS	Actual
FY22	1,72,818	1,72,823	28,083	28,075
FY23	1,83,777	1,86,573	30,203	30,935
FY24	1,91,499	2,06,398	31,495	31,178

2.2. Supply Scenario

Maharashtra's energy landscape is characterized by a diverse mix of energy sources As of FY24, coal had an installed capacity of 23,444 MW, contributing 58% to the total installed capacity. On the other hand, RE contributed 37% (including hydro) to the total installed capacity, with 5,226 MW of wind and 3,710 MW of solar[9]. This RE-rich resource mix underscores Maharashtra's commitment to sustainability and a transition towards cleaner and more resilient power generation. On the generation side, as of FY24, coal makes up 79% of the total generation, with RE contributing 16%. The following Figure 3 shows Maharashtra's installed capacity mix:

7 Received from state

8 20th EPS, Received from state

9 Received from state

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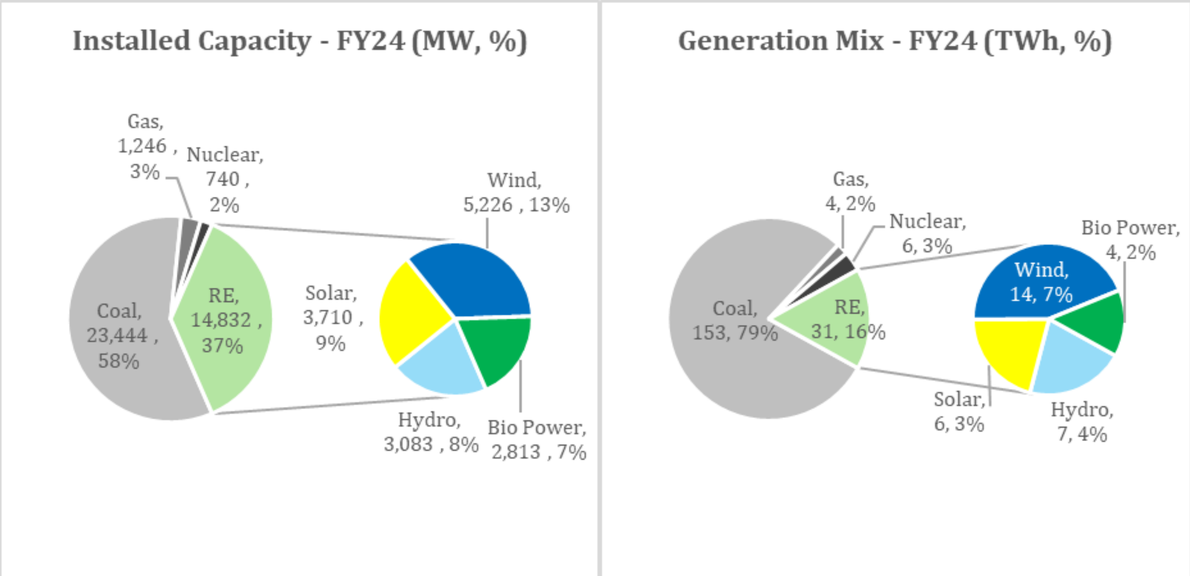

Figure 3: Installed Capacity[10] & Generation Mix[11] of Maharashtra for FY24

Given the rapidly growing demand and increasing share of renewable energy (RE), Maharashtra is set to remain a leading state in RE. Therefore, it is crucial for Maharashtra to prepare for vRE and its associated challenges by implementing RA. The following chapter provides an overview of RA, highlighting its key aspects and the reliability metrics involved.

10 Received from state

11 Received from state

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3. Resource Adequacy: A New Paradigm

Resource Adequacy (RA) entails the planning of generation and transmission resources for reliably meeting the projected demand in compliance with specified reliability standards for serving the load with optimum generation mix. This would also facilitate the scaling of RE while considering the need, inter alia, for flexible resources, storage systems for energy shift, and demand response measures for managing the intermittency and variability of RE sources. RA analysis provides the tools to determine whether there are enough resources and, if not, what type of resource is needed to meet reliability needs and contract these capacities. At the same time, any surplus resulting from the analysis would facilitate the trading of the same with other entities ensuring optimal capacity utilization.

3.1. Why do we need Resource Adequacy (RA)?

The evolving power sector necessitates a robust and adaptive framework to ensure resource adequacy and grid reliability. Several critical factors highlight the need for RA:

1. **Transition to RE:** The energy sector is undergoing an aggressive shift towards RE sources like solar and wind. While these sources are clean and sustainable, they introduce challenges such as intermittency and variability, which can disrupt grid stability. A reliable planning framework is essential to effectively integrate RE while ensuring consistent power supply.
2. **Changing grid dynamics:** With the rise of RE, conventional thermal power plants are now required to operate more flexibly, frequently ramping up or down to balance vRE generation. Additionally, modern grids experience bidirectional power flows due to distributed energy resources like rooftop solar. This complexity necessitates a more dynamic and resilient planning approach.
3. **Diverse energy mix and emerging demand drivers:** India's energy mix is becoming increasingly diverse and variable, with contributions from coal, gas, nuclear, hydro, and renewables. Simultaneously, new demand drivers such as electric vehicles (EVs), data centers, green hydrogen production, and solar technologies are reshaping energy consumption patterns. Climate and weather variability also significantly impact energy demand and renewable generation, requiring adaptive planning tools to account for these fluctuations. This has introduced a dual variability in both supply and demand, presenting a new phenomenon that needs to be effectively addressed for ensuring grid reliability and stability.
4. **Coincident peak challenges:** One significant challenge is managing coincident peak demands, where the combined peak demand of multiple states exceeds the national peak. For example, individual state peaks may occur at different times, creating complexities in resource allocation, capacity sharing, and transmission planning. Without proper coordination, this can lead to either resource under-utilization or excessive capacity additions. Addressing these challenges requires a structured approach like RA to align state and national grid planning effectively.
5. **Limitations of current demand forecasting:** Existing forecasting methods, such as those based on the Compound Annual Growth Rate (CAGR), are insufficient to capture the dynamic and region-specific changes in demand patterns. This can result in either underestimation or overestimation of resource requirements, leading to inefficiencies.
6. **Planning gaps and lack of synergy:** A significant challenge in the current energy planning framework is the disconnect between long-term planning, as outlined in the National Electricity Plan (NEP), and short-term planning, as reflected in the Load Generation Balance Report (LGBR). This misalignment results in inadequate coordination between capacity addition, transmission infrastructure development, and overall resource planning. Such gaps can lead to inefficiencies, delays in project implementation, and insufficient infrastructure to support growing energy demands. Ultimately, this lack of synergy poses a risk to grid stability, especially as the power system evolves to accommodate higher shares of renewable energy and more complex operational requirements. Addressing this disconnect is critical to ensuring a resilient, and reliable electricity grid.
7. **Grid reliability and security:** Ensuring grid stability under all conditions, especially during stress scenarios, requires a forward-looking framework. As the power system becomes more complex and interconnected, RA plays a vital role in maintaining grid security and meeting demand reliably.

3.2. Key Features of RA

- **Tool for resource assessment**: RA provides framework to evaluate the adequacy of the existing resource mix and identify gaps in capacity.
- **Addressing coincident peak challenges:** RA specifically addresses the complexities of coincident peaks, ensuring that capacity planning accounts for both state-level and national-level peak demands. By optimizing resource sharing among states and aligning resource planning, it avoids overbuilding or underutilization.
- **Shared responsibility:** RA encourages collaboration between states, utilities, grid operators, regulators, and other stakeholders, enabling efficient sharing of generation capacity and reducing costs.
- **Maximizing resource utilization:** RA focuses on increasing the utilization of existing infrastructure, reducing waste, and enhancing cost-effectiveness.
- **Transmission and capacity alignment:** Transmission infrastructure often lags behind capacity additions, creating bottlenecks. RA emphasizes synchronized planning to ensure transmission systems can support new capacity efficiently.

Implementing RA helps stakeholders ensure a reliable balance of supply and demand, maintain grid security, and optimize resource utilization. It also provides a forward-looking perspective, enabling power systems to adapt to emerging challenges, including fluctuating demand, resource availability, and system stress.

3.3. Guiding Principles of RA

Figure 4: Guiding Principles of RA

Ensuring RA in power systems requires a structured approach guided by key principles that balance reliability, cost-efficiency, and adaptability. These guiding principles provide a comprehensive framework for addressing capacity shortfalls while fostering sustainable energy solutions. Below is an elaboration on the critical aspects of RA:

1. **Assessment of RA**
   A thorough and comprehensive assessment of RA involves quantifying the size, frequency, duration, and timing of potential capacity shortfalls. This detailed evaluation is essential to design effective resource solutions.
   - **Size:** Identifying the magnitude of the capacity gap during peak and off-peak periods helps prioritize investments and procurement strategies.
   - **Frequency:** Understanding how often capacity shortages occur enables system operators to plan for recurring events and avoid over-provisioning.
   - **Duration:** The length of time a shortfall persists directly impacts the type of resources required, such as fast-ramping capabilities or long-duration storage.

- **Timing:** The seasonal, daily, or hourly nature of shortfalls provides insights into resource alignment with demand patterns, allowing for more precise capacity planning.

By systematically assessing these parameters, utilities can tailor their resource portfolios to address gaps effectively without overbuilding infrastructure.

2. **Static vs. Dynamic Approaches**

The traditional static approach of designing systems to meet peak demand using a fixed Planning Reserve Margin (PRM) is becoming outdated in today's dynamic energy landscape. Modern RA planning requires a shift toward dynamic methodologies that better reflect evolving grid conditions.

- **Dynamic RA Planning:** Dynamic RA planning, based on the established RA guidelines, produces a dynamic PRM (Planning Reserve Margin) that satisfies reliability requirements and accommodates contingencies.
- **Scenario-Based Analysis:** Dynamic approaches leverage scenario modeling to simulate various future outcomes, ensuring the system remains reliable under diverse conditions.

3. **Resource Diversity**

The diversity of energy resources plays a pivotal role in achieving optimal and least-cost resource adequacy. Each resource type brings unique capabilities that contribute to system stability and flexibility.

- **Renewable Resources:** Solar and wind offer clean, cost-effective energy but require complementary resources due to their variability.
- **Energy Storage:** Battery storage systems provide critical support by balancing short-term fluctuations and enhancing grid stability.
- **Demand Response:** Demand-side management helps align consumption with resource availability, reducing peak load pressures.
- **Flexible Generation:** Conventional plants with flexible ramping capabilities support the integration of intermittent resources.

By strategically combining diverse resources, planners can create a balanced portfolio that maximizes system efficiency while minimizing costs and emissions

4. **Sharing of Resources**

Isolated planning and operation of resources can lead to overcapacity and inefficient operations. A collaborative approach to resource sharing is essential for reducing overall system costs and enhancing regional reliability.

3.4. Key Steps in RA

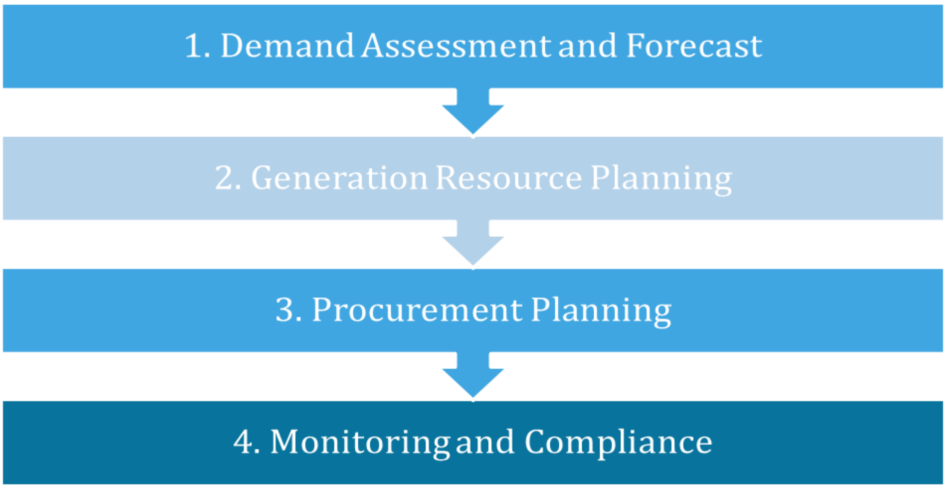

Figure 5: Key Steps in RA

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Below are the steps in RA:

1. **Demand Assessment and Forecasting:**
   - Purpose: Forecast peak demand (MWs) and energy requirement (MUs) over short (1 year), medium (5 years), and long-term (10 years) horizons considering various input parameters.
   - Prevailing Practices:
     - Current Methods: Non-uniform and simplistic across discoms and states, often relying on CAGR-based calculations.
     - Need for Scientific Approach: An analytical approach with detailed hourly resolution is essential for realistic planning, considering demand drivers such as electric vehicles (EVs), distributed energy resources (DERs), and weather changes.
   - Methodology:
     - Use weather data, historical consumption, categories of consumer, econometric data, policies, and other drivers.
     - Distribution licensees should conduct hourly demand assessment and forecasting for rolling short-term and medium-term horizons, using the latest Electricity Power Survey (EPS) as a base.
     - State Transmission Utilities (STU) and State Load Dispatch Centres (SLDC) should aggregate forecasts and submit state-level short-term and medium-term forecasts to the Central Electricity Authority (CEA) and National Load Dispatch Centre (NLDC).
2. **Generation Resource Planning:**
   - **Capacity Crediting (CC):**
     - Definition: CC represents the amount of power a resource can provide during peak hours.
     - Methodology:
       - Top Demand Hours: Capacity credit is estimated by averaging a generator's historical contribution during peak demand hours. The number of peak hours considered may vary by region.
       - Top Net Load Hours: Focuses on system stress when high demand coincides with low renewable generation. Net load, calculated as total demand minus renewable generation, is used as a better proxy for system stress. Capacity credit is averaged during these critical hours.
       - Expected Load Carrying Capability (ELCC): A detailed method using hourly demand and generation data, incorporating random generator outages based on historical and expected conditions.
   - **Planning Reserve Margin (PRM):**
     - Definition: PRM is the percentage of resources available over the peak demand to ensure reliability.
     - Metrics: Loss of Load Probability (LOLP) and Expected Energy Not Served (EENS) are used to gauge reliability.
   - **RA Requirement and Allocation:**
     - Calculate RA requirements based on forecasted demand, existing resources (discounted by their capacity credit), and PRM. Optimize these requirements at the national/regional level and allocate them down to states and demand-serving entities.
     - Formulations:
       - State Peak with PRM: RA Requirement = State Peak (1 + PRM)
       - Regional Peak with PRM: RA Requirement = Coincident Peak Demand (1 + PRM)
3. **Procurement Planning:**
   - **Procurement Resource Mix:**
     - Objective: Identify the resource mix to meet RA requirements and Renewable Purchase Obligations (RPO), ensuring reliability and avoiding stranded assets by using optimization and least-cost energy modelling techniques.
   - **Procurement Type and Tenure:**
     - Objective: Ensure the type and duration of procurement contracts
   - **Capacity Trading/Sharing Constructs:**

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- Objective: To optimize resource utilization and minimize costs

4. **Monitoring and Compliance:**
   - Objective: Develop an overarching framework to ensure smooth implementation of the RA framework.
   - Components: Monitoring and reporting, verification and regulatory oversight, and treatment for shortfalls in short-term and medium-term compliance.

3.5. Reliability Metrics[12]

To ensure a reliable power system, various reliability metrics are employed to assess the adequacy of generation resources. These metrics quantify the system's ability to meet demand under normal and contingency conditions. Below is a detailed explanation of the key reliability metrics:

1. **Loss of Load Probability (LoLP)** measures the likelihood that electricity demand may exceed available generation capacity at any given time during the year. It serves as a key indicator of supply shortages due to insufficient capacity or unexpected outages. A typical reliability target for LoLP is less than 0.2%, meaning that the risk of supply inadequacy is acceptable only for a very small portion of the year. This metric is critical for planning the balance between supply and demand to minimize load shedding risks.
2. **Expected Energy Not Served (EENS)** quantifies the total energy shortfall (in megawatt-hours) that is anticipated over a year due to supply inadequacies. Unlike LoLP, which measures the probability of a shortfall, EENS captures its severity by estimating the amount of unmet demand.
3. **Normalized Energy Not Served (NENS)** builds on EENS by normalizing the energy shortfall against the system's total demand, providing a percentage-based measure of reliability. A system is generally considered reliable if NENS remains below 0.05%, indicating that only a very small fraction of total demand is unmet. NENS is particularly useful for comparing reliability across systems with varying sizes and demand profiles.
4. **Planning Reserve Margin (PRM)** represents the percentage of additional generation capacity maintained above the system's peak demand. This buffer ensures reliability during unexpected events, such as generator outages or demand surges. While higher PRMs improve system reliability, they also increase costs, necessitating a careful balance to achieve optimal performance. PRM serves as an essential planning tool to account for uncertainties and maintain system resilience.

RA plays a pivotal role in ensuring the reliability of power systems, especially in an era of increasing renewable energy integration and evolving grid dynamics. The detailed analysis of RA not only highlights its importance but also underscores the necessity of comprehensive planning to address challenges like intermittency, coincident peak demands, and grid reliability.

Building on this foundational understanding, the following sections delve into the specifics of Maharashtra's approach to RA, guided by its recently introduced Resource Adequacy Regulations, 2024. These regulations align with national directives and aim to establish a robust framework for resource planning.

[12] CEA Guidelines: RA Framework

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4. MERC RA Regulations

The Maharashtra Electricity Regulatory Commission (MERC) has notified Framework for Resource Adequacy Regulations, 2024 (referred as MERC RA Regulations in this report) in alignment with the national directives to ensure a reliable, cost-effective, and sustainable electricity supply in the state. These Regulations aim to enhance power system reliability by optimizing resource planning and addressing the challenges posed by the evolving energy landscape.

4.1. Background

Background and Legislative Framework

The Resource Adequacy framework derives its legal foundation from the Electricity Act, 2003, which empowers the Ministry of Power (MoP), Government of India, to issue amendments and rules for the effective regulation of the power sector. As part of this mandate:

- The Electricity (Amendment) Rules, 2022, issued by the MoP on 29th December 2022, provided the legal provisions for developing a Resource Adequacy Planning Framework.
- Under Rule 16(1) of these Rules, the MoP, in consultation with the Central Electricity Authority (CEA), issued the Guidelines for Resource Adequacy Planning Framework for India on 28th June 2023.
- Rule 16(2) further mandates State Electricity Regulatory Commissions (SERCs) to frame state-specific Resource Adequacy regulations based on the MoP guidelines and any model regulations prepared by the Forum of Regulators (FoR).

To facilitate uniformity and effective implementation, the Forum of Regulators developed a set of Model Regulations for the Resource Adequacy Framework, published in June 2023. These model regulations provided the foundation for state commissions to develop tailored frameworks suited to their unique grid conditions and demand-supply dynamics.

Adoption of Resource Adequacy in Maharashtra

In compliance with the national directives and model regulations, the Hon'ble Maharashtra Electricity Regulatory Commission (MERC) issued the MERC Framework for Resource Adequacy Regulations, 2024, through its notification on 21st June 2024.

Regulatory Implications and Compliance

The regulations require:

- Distribution Licensees (DLs): To submit long-term and short-term resource adequacy plans in accordance with the framework.
- System Operators (SLDCs/STUs): To assess resource adequacy compliance and identify gaps in capacity or infrastructure.
- Coordination with Regional and National Frameworks: To align state-level planning with the national framework and ensure compliance with central guidelines.

The MERC regulations are expected to serve as a model for other states, demonstrating a proactive approach to modernizing power system planning and fostering energy security for all stakeholders.

In the following sub-sections key chapters from MERC Chapter is covered.

- Demand Assessment and Forecasting
- Generation Resource Planning
- Power Procurement Planning
- Monitoring and Compliance
- Roles and Responsibilities

4.2. Demand Assessment and Forecasting

Effective demand assessment and forecasting is a cornerstone of Resource Adequacy (RA) planning. Accurate and detailed demand projections help ensure a balance between supply and demand, reduce system inefficiencies, and enhance reliability. This chapter outlines the methodologies, responsibilities, and considerations involved in long-term, medium-term, and short-term demand forecasting.

4.2.1. Long-term and Medium-term Demand Forecast

Importance of Demand Forecasting

Demand forecasting serves as the foundation for RA planning. It involves short-term, medium-term, and long-term projections, each with distinct requirements:

- Short-Term Forecasts: Hourly or sub-hourly assessments of demand are necessary to manage real-time grid operations. These forecasts rely on granular data, including consumer behavior and weather patterns.
- Medium-Term Forecasts: Hourly load assessments identify seasonal and annual demand trends, providing critical insights for operational planning.
- Long-Term Forecasts: Monthly peak and off-peak load assessments, along with category-wise energy forecasts, are crucial for infrastructure development and policy implementation.

Responsibilities of Distribution Licensees

Distribution licensees are tasked with demand forecasting within their control areas, including partial open-access consumers. Their key responsibilities include:

- Providing category-wise consumption and assessed data (e.g., agricultural, domestic) to the State Transmission Utility (STU) and the Maharashtra State Load Dispatch Centre (MSLDC).
- Submitting historical consumption data by April 21 each year in a prescribed format.

Methodologies for Load Forecasting

Licensees must adopt robust methodologies, including:

- Quantitative Approaches: Compounded Average Growth Rate (CAGR), trend analysis, and econometric modeling.
- Advanced Techniques: Artificial Intelligence (AI) and Machine Learning (ML), including Artificial Neural Networks (ANN) and Auto-Regressive Integrated Moving Average (ARIMA).
- Hybrid Models: Combining multiple methodologies for improved accuracy, including probabilistic modeling for various scenarios (e.g., most probable, business-as-usual, aggressive).

Refinement and Validation

Licensees must conduct statistical analyses to select the most reliable forecasting model, using metrics such as standard deviation and R-square values. The forecasts must be validated through historical load data and refined based on load research outcomes.

Adjustments to Demand Forecasts

Forecasts must incorporate adjustments for evolving energy trends and policy impacts. Key factors include:

- Energy Efficiency and Conservation: Impact of measures such as Demand-Side Management (DSM) and energy-saving programs.
- Distributed Energy Resources (DERs): Contributions from renewable generation, rooftop solar, and storage systems.
- Policy Influences: Effects of initiatives like 24x7 supply, electrification programs, and the National Hydrogen Mission.
- Technological Shifts: Growing adoption of electric vehicles (EVs) and changes in consumption patterns.

Separate trajectories must be developed for each policy, considering economic, demographic, and regulatory influences. Distribution licensees should also account for consumer migration and open-access consumption.

4.2.2. Short-term Demand Forecasting and State Aggregation

Hourly and Sub-hourly Forecasting

Short-term demand forecasts require hourly or sub-hourly assessments using advanced tools and a historical database. Distribution licensees must factor in demand response, time-of-use policies, and load-shifting measures to refine projections.

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State-Level Aggregation

MSLDC aggregates demand forecasts from distribution licensees, incorporating load diversity and seasonal variations to prepare state-level projections. These aggregated forecasts are submitted to the Authority, NLDC, and RLDC by May 31 each year.

Rolling Forecasts and Operational Planning

Licensees must produce short-term (1-year) and medium-term (5-year) rolling forecasts, updated annually. These forecasts provide insights into operational requirements and ensure alignment with state-level plans.

4.3. Generation Resource Planning

This chapter outlines the critical steps and methodologies for generation resource assessment and planning. It emphasizes the importance of capacity crediting, planning reserve margins, and resource adequacy to meet forecasted demand.

4.3.1. Key Contours and Steps in Generation Resource Planning

- Components of Generation Resource Planning:
  - Capacity crediting of generation resources.
  - Assessment of planning reserve margin (PRM).
  - Resource adequacy requirement and allocation for control areas.
- Mapping of Existing and Upcoming Resources:
  - Distribution licensees must document all contracted resources (existing, upcoming, and retiring) in MW for both the long-term and medium-term.
  - Detailed characteristics of generating units, such as heat rate, auxiliary consumption, ramp rates, capacity utilization factors, and transmission plans, must be included.
- Incorporation of System Constraints:
  - Consider penalties for unmet demand, forced outages, spinning reserves, and compliance with emission norms and grid codes.
- Planning Reserve Margin (PRM):
  - PRM ensures excess generation capacity for reliability. The value is based on reliability indices like Loss of Load Probability (LOLP) and Normalized Energy Not Served (NENS).
  - PRM values must align with guidelines from the Authority or the Commission.

4.3.2. Capacity Crediting of Generation Resources

- Computation of Capacity Credit (CC):
  - A net load-based approach is used for determining CC factors, particularly for wind, solar, and hybrid renewable energy (RE) resources.
  - Steps include:
    - Analyzing gross and net load duration curves.
    - Summing RE capacity and generation for the top 250 load hours.
    - Deriving the CC factor as the ratio of generation to installed capacity for these hours.
  - Average CC factors over five years are used for resource planning.
- Resource-Specific CC Factors:
  - Hydro: Based on water availability and plant type (run-of-the-river vs. storage).
  - Thermal: Based on fuel availability and outage data.
  - Storage: Derived using the net load approach or prescribed methodologies.
- Coordination with System Operators:
  - Distribution licensees share CC computations with MSLDC.
  - MSLDC consolidates state-specific CC factors for submission to the Authority and other entities.

4.3.3. Assessment of Planning Reserve Margin (PRM)

- PRM is expressed as a percentage of peak load. It accounts for reliability targets, including LOLP and NENS, ensuring adequate planning for future demand.

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- Planning Reserve Margin (PRM) factor (for example, 10%) shall be based on the reliability indices in terms of Loss of Load Probability (LOLP, for example, 0.2%) and Normalized Energy Not Served (NENS, for example, 0.05%) as may be specified by the Authority or by the Commission

4.3.4. Resource Adequacy Requirement (RAR) and Allocation

- Resource Gap Analysis:
  - Distribution licensees identify gaps by subtracting resource adequacy plans from demand forecasts.
  - Sensitivity and scenario analyses are conducted for accuracy.
- Development of Adequacy Plans:
  - Medium-Term (MT) and Short-Term (ST) Distribution Resource Adequacy Plans are developed and updated annually.
- National and State-Level Plans:
  - Long-Term National Resource Adequacy Plan (LT-NRAP):
    - Establishes PRM and optimal generation mix for the next decade.
  - Short-Term National Resource Adequacy Plan (ST-NRAP):
    - Provides a one-year outlook, including maintenance schedules and project status.
  - States derive their RAR from national allocations, coordinated by STU/MSLDC.
- Contracting Mix for RAR:
  - Long-term contracts must meet at least 70% of RAR, medium-term 20%, and short-term contracts address the remainder.
  - Day-Ahead Market (DAM) purchases are excluded from RAR compliance.
- Regulatory Oversight:
  - MT and ST plans are subject to Commission approval by September each year, ensuring alignment with national frameworks and scenarios.

4.4. Power Procurement Planning

Procurement planning involves identifying the optimal power procurement resource mix, determining the modalities for procurement type and tenure, and engaging in capacity trading or sharing. These efforts aim to minimize the risk of resource shortfall while avoiding stranded capacity or contracted generation.

4.4.1. Procurement of Resource Mix

Optimal Resource Mix

Distribution licensees must adopt least-cost modeling and optimization techniques to identify an optimal procurement resource mix that ensures smooth integration of renewable energy (RE) while meeting reliability standards.

- Short-term (ST-DRAP) and medium-term (MT-DRAP) plans require Commission approval.
- Long-term (LT-DRAP) plans are for consistency with national frameworks.

Renewable Energy Procurement

- RE procurement should comply with MERC's Renewable Purchase Obligation (RPO) Regulations, 2019, and its amendments.
- Wind, Solar PV, Wind-Solar Hybrid, and Round-the-Clock (RTC) generation procurement should follow Ministry of Power guidelines.

Energy Storage

- Distribution licensees must plan for battery energy storage systems (BESS) and pump storage projects (PSP) based on MT-DRAP outcomes.

Procurement Sources

- Power can be procured from sources such as state and central generating stations, IPPs, CPPs, RE plants, bilateral agreements, power exchanges, and other approved platforms.
- Short-term and medium-term procurement should be conducted through DEEP and PUShP portals.

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4.4.2. Procurement Type and Tenure

Prioritization of In-State Resources

- Priority must be given to available in-state capacity before considering inter-state procurement.
- Transmission constraints and costs must be factored into decisions, with STU/SLDC publishing available transmission corridors for planning.

Power Procurement Plan Requirements

- Plans must include demand forecasts, electricity supply estimates, and quality/reliability standards.
- Measures for energy efficiency, conservation, and demand-side management should be included.
- New sources of procurement should align with state and national policies.

Resource Adequacy Plans (RAR):

- 100% tie-up must be demonstrated for the first year and at least 90% for the second year.
- Distribution licensees must annually update their MT-DRAP and submit it by the specified deadlines.

4.4.3. Sharing of Capacity

Short-Term Sharing

- Distribution licensees must utilize intra-state capacity optimally through competitive sharing or trading mechanisms.
- Extra available capacity must be declared on a shared portal accessible to stakeholders.

Compliance

- Contracted capacity details must be submitted to MSLDC and STU for verification.
- Procurement strategies should align with aggregated state-level plans.

4.4.4. Approval of Power Purchase Agreements (PPA)

Mandatory Approvals

- New capacity arrangements, long/medium-term PPAs, and amendments require prior Commission approval.
- An updated list of existing PPAs must be submitted alongside the Resource Adequacy plan.

4.4.5. Variation in Power Purchase

Additional Procurement Exemptions

- Distribution licensees may enter into additional agreements due to unanticipated demand increases, supply failures, or costlier existing sources.
- Emergency short-term agreements for grid stability or exigencies are allowed, with details submitted to the Commission within 45 days.

4.5. Monitoring and Compliance

This section describes the monitoring, compliance, and enforcement mechanisms for resource adequacy, including reporting requirements, non-compliance charges, and the roles of the STU and MSLDC.

4.5.1. Monitoring and Reporting

- STU and MSLDC will communicate the state-aggregated capacity shortfall to the Commission by 15th September each year.
- Distribution licensees must commit to additional capacities based on MT-DRAP and ST-DRAP, with the Commission approving RA plans by 30th September annually.

4.5.2. Non-Compliance and Charges

- Distribution licensees must meet RA requirements; shortfalls will incur non-compliance charges.

- Charges will be 1.1 times the Marginal Capacity Charge or 1.25 times the Average Capacity Charge, as approved by the Commission.
- These charges cannot be recovered through the licensee's ARR.

4.5.3. Enforcement of Compliance

- MSLDC will levy and collect non-compliance charges from defaulting distribution licensees.

4.6. Roles and Responsibilities and Timelines

This section describes data sharing, timeline, and transparency requirements for resource adequacy, including data reporting, publication of information, and the establishment of dedicated cells.

4.6.1. Data Sharing

- Distribution licensees must maintain and share data related to demand forecasting, consumer profiles, energy efficiency initiatives, and 10 years of historical consumption data.
- MSLDC and STU will aggregate data for state-level and national assessments.

4.6.2. Key Timelines

- 30th April: Distribution licensees submit demand forecasts to MSLDC.
- 31st May: MSLDC submits state-level forecasts to the Authority and NLDC.
- 31st August: MT-DRAP and ST-DRAP exercises are completed.
- 15th September: STU and MSLDC communicate capacity shortfall to the Commission.
- 31st January: State-level aggregated plans submitted to RLDC/NLDC.

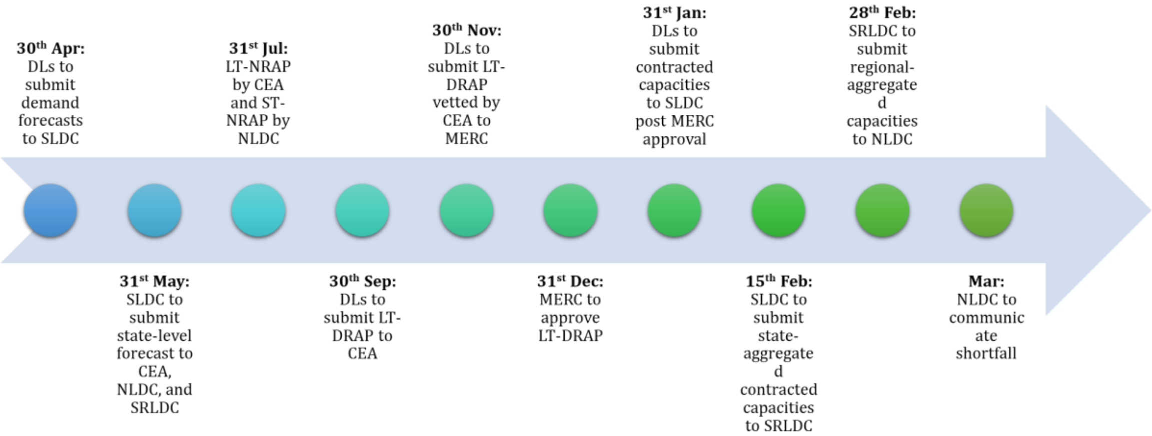

Figure 6: RA Implementation Timelines

4.6.3. Transparency and Publication

- Power procurement/sale data must be published on websites within 45 days.
- MSLDC must publish the monthly Merit Order Dispatch (MoD) stack, including per-unit variable costs.

4.6.4. Dedicated Cells

Distribution licensees must establish:

- A planning cell for Resource Adequacy within three months of the regulation's enforcement.
- A real-time management cell for intra-day and short-term power procurement.

Guidelines for these cells must be framed and shared with the Commission within 45 days of enforcement.

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5. Modeling Tools & Approaches

The following section outlines various tools and methodologies that can be applied for undertaking Resource Adequacy (RA) studies. With a primary objective of minimizing total system costs while ensuring the reliability and adequacy of the power system, this section provides an in-depth exploration of the principles guiding the modeling process.

5.1. Modeling Tools[13]

For comprehensive modeling, a variety of tools are available, each with its own unique capabilities. These tools are generally divided into three main categories: Capacity Expansion Models, Production Cost Models, and Generation Resource Adequacy Models. Each category has a specific function, depends on particular inputs, and produces distinct outputs.

1) **Capacity Expansion Models**
The primary focus of capacity expansion models is to guide decisions about future investments in power generation and transmission infrastructure. These models evaluate various factors, such as projected demand growth, available and planned generation assets, and evolving regulatory frameworks. By analyzing cost trends, fuel availability, and technological advancements, these models help stakeholders identify the optimal mix of investments. In addition to determining where new capacity is needed, they also help identify which existing assets may need to be retired, ensuring a cost-effective and sustainable energy supply.
2) **Production Cost Models**
Production cost models are designed to simulate the real-time operations of the power grid. These models analyze the performance of the power system under different conditions, factoring in demand patterns, fuel prices, and operational constraints. By considering elements such as network topology and regulatory policies, they offer insights into key operational metrics. These include the generation dispatch stack, system congestion, and the associated costs. Additionally, they assess the impact of renewable energy curtailments, emissions, and system reliability by measuring the potential loss of load.
3) **Generation Resource Adequacy Models**
Ensuring the availability of sufficient resources to meet demand is the focus of generation resource adequacy models. These tools analyze the system's capability to handle various scenarios, including unexpected outages and variable renewable energy generation. Using inputs such as demand profiles, network data, and outage statistics, these models calculate key adequacy metrics. Metrics such as Loss of Load Expectation (LOLE), Loss of Load Probability (LOLP), and Expected Energy Not Served (EENS) provide a comprehensive view of the system's reliability.

The tools which are capable of doing all the above objectives are:

- Open Source:
    - GridPath
- Commercial
    - BID3
    - Plexos
    - PowerSIMM Planner

PLEXOS has been used in the RA study for Maharashtra presented in this report.

5.2. Modeling Philosophy

Detailed optimization modeling ensures that critical aspects of system operations are captured accurately. It allows for the simulation of different scenarios, testing whether the energy demand balance is achieved on an hourly or sub-hourly basis under varying conditions. Randomness in generation patterns, particularly for RE sources, as well as that in load patterns is incorporated using stochastic techniques, ensuring that system reliability is assessed against real-world uncertainties. This level of analysis offers a

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more complete understanding of resource adequacy and helps in identifying the most efficient and reliable pathways for capacity expansion.

A capacity build model minimizes the total system cost to meet system load considering technical limits of generation, and a production cost model solves the optimal power flow formulation by taking into consideration generation limits and operational constraints such as ramp rates, technical minimum and transmission limits.

PLEXOS is an industry standard tool used in various applications such as Long-Term Capacity Expansion Planning, Production Cost Modeling, Transmission Planning Analysis, Demand Modeling, System Security and Adequacy, Ancillary Services and Energy Co-Optimization, Optimally Times Maintenance etc.

PLEXOS has been used to assess the pathway for clean energy investments such that CEA's reliability standards are met from FY25 to FY34 for the state of Maharashtra. The model minimizes total generation cost (fixed plus variable) for the entire system, including existing and new generation capacity.

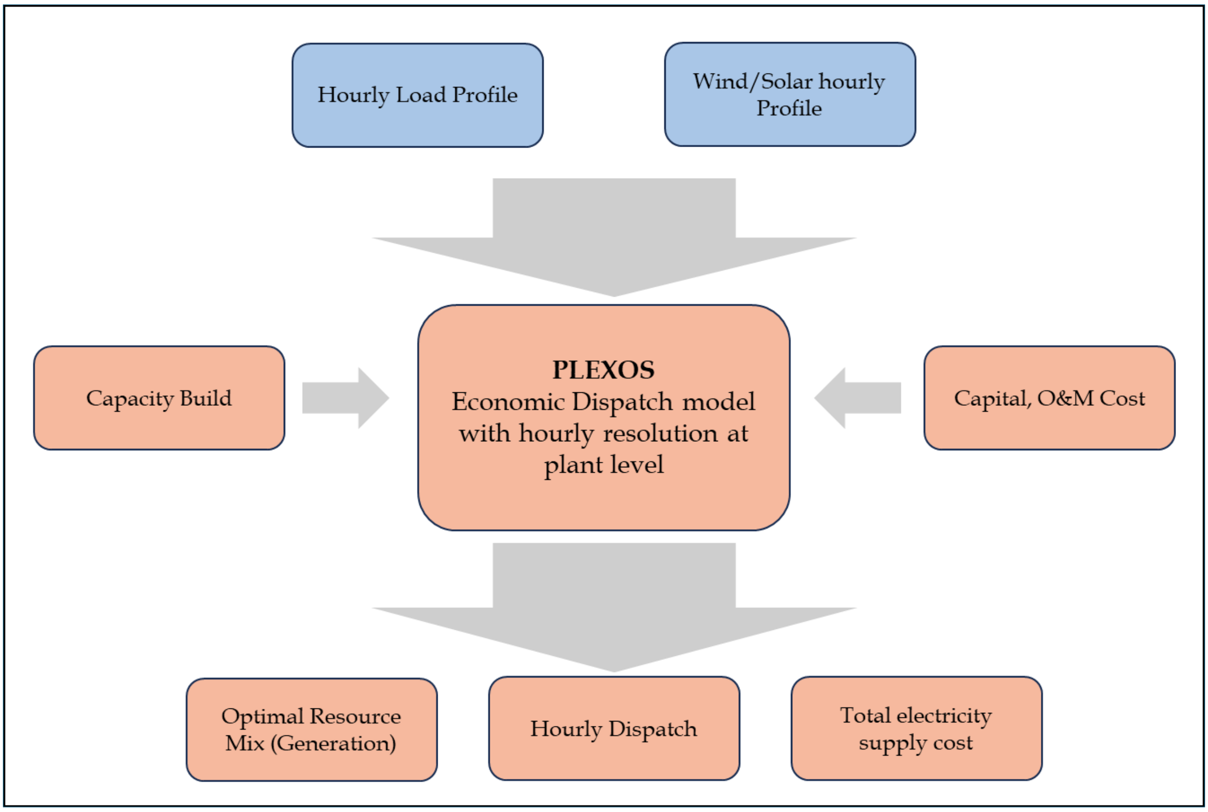

Figure 7: Modeling Philosophy

5.2.1. State Model Configuration

Configuration of the model in PLEXOS typically includes detailed representations of the state's power generation facilities, demand profiles, and RE integration as follows:

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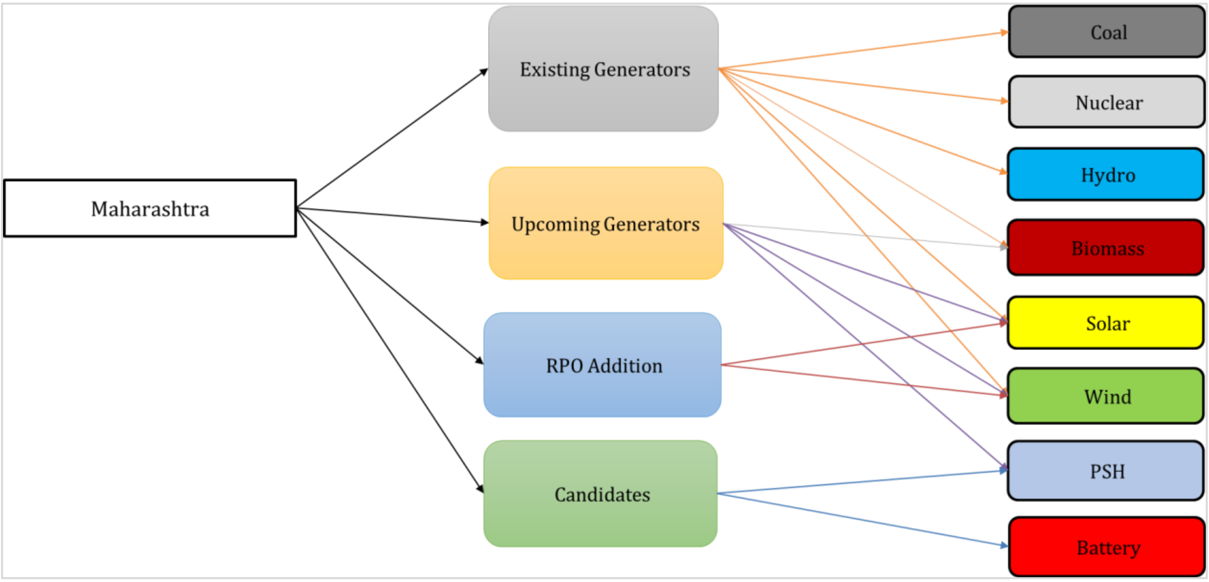

Figure 8: Maharashtra State Model Configuration in PLEXOS

5.2.2. Stage-wise Modeling

This flowchart outlines the steps involved in PLEXOS for evaluating capacity expansion and assessing YOY hourly dispatch outcomes. It emphasizes reliability criteria and ensures that the model's results align with specific standards or requirements.

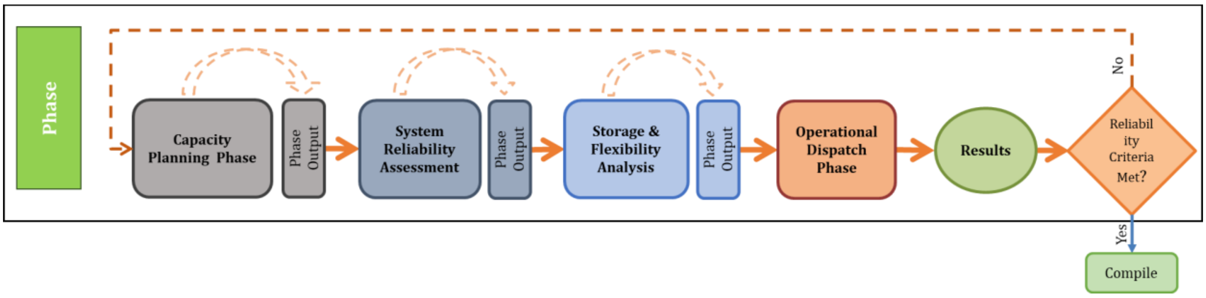

Figure 9: PLEXOS Stage-wise Modeling

1. **LT (Long Term Phase): Capacity Planning Phase**
   The objective of this phase is to assess and plan the capacity expansion of the energy system, focusing on developing an optimized resource mix and strategizing the buildout of additional generation capacity to meet future energy demands. Key activities include capacity expansion modeling to identify the necessary growth in generation capacity, resource mix optimization to balance the integration of RE sources with cost-effectiveness, and system buildout planning to outline timelines and prioritize projects for implementation.
2. **PASA (Projected Assessment of System Adequacy): System Reliability Assessment**
   The focus of this phase is to enhance the reliability of the power system by addressing maintenance schedules, system reliability metrics, and outage modeling. This involves developing and optimizing maintenance schedules to minimize disruptions to energy supply, evaluating reliability metrics such as LoLP to assess the system's ability to meet demand under various scenarios, and simulating potential outages to evaluate their impacts on system stability and reliability.
3. **MT (Medium Term): Storage & Flexibility Analysis**
   This phase aims to evaluate medium-term operational decisions, with a focus on storage solutions and system flexibility. It involves analyzing the system's ability to adapt to variations in demand and supply, particularly with the growing integration of renewable energy. The optimization of energy storage systems is prioritized to effectively balance load and generation. Scenario analysis is conducted to assess the effectiveness of various storage dispatch strategies.

4. **ST (Short Term): Operational Dispatch Phase**
   The final phase involves evaluating hourly dispatch results, with a focus on YoY variations to ensure the operational model meets predefined reliability criteria. This includes developing precise hourly models to simulate the dispatch of generating plants and assessing the outcomes against reliability standards.
5. **Results & Feedback Loop**
   At the conclusion of the operational dispatch phase, the system's reliability is evaluated against established criteria. If the criteria are not met, the framework employs an iterative feedback loop to revisit earlier phases. This ensures continuous improvement and alignment with reliability and sustainability goals.

Having outlined the various RA approaches and the modeling philosophy employed in the development of a least-cost optimization model using PLEXOS, the subsequent chapter delves into the specifics of monthly peak demand, daily load profiles, and solar and wind input profiles, and other inputs providing a comprehensive foundation for the detailed modeling and analysis that follows.

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6. Input Assumptions for Maharashtra RA Modeling

This section outlines the input data, stochastic simulation techniques, and resource-specific assumptions used to carry out RA modeling and assess system reliability for Maharashtra.

6.1. Solar & Wind Input Profiles

Figure 10 illustrates the monthly average solar and wind profiles for Maharashtra, featuring an average Capacity Utilization Factor (CUF) of 20% and 30% respectively. Based on the availability of the data, FY24 solar and wind profiles were used as a basis for future projections. In addition, simulations include stochastic variations in both demand and solar and wind profiles that introduce randomness in renewable energy generation.

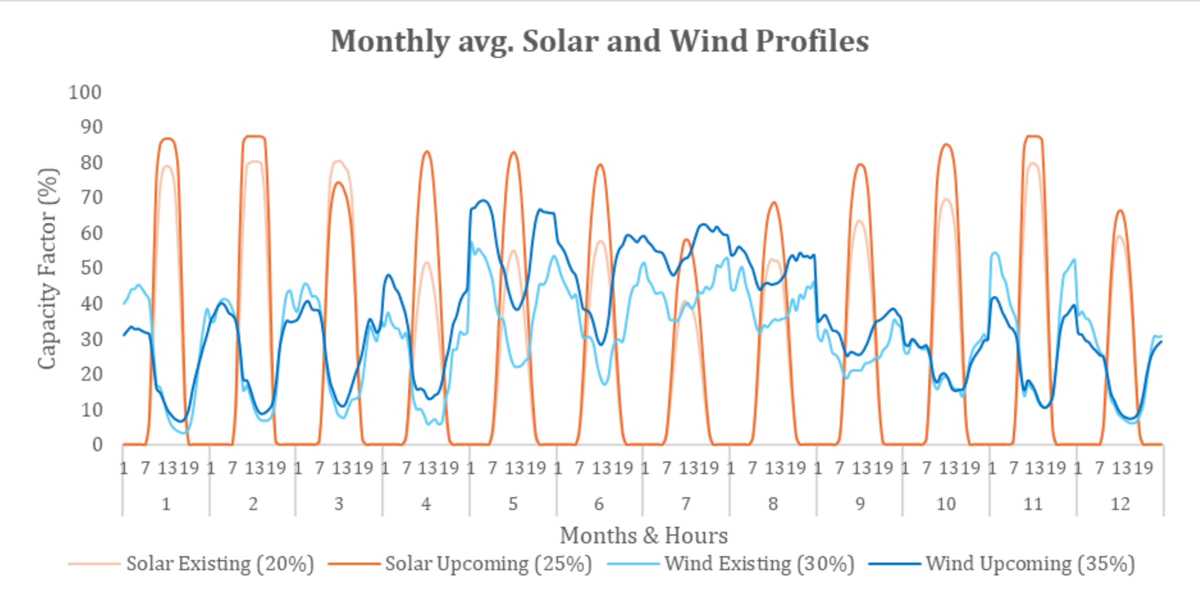

Figure 10: Monthly average Solar and Wind Profiles of Maharashtra

6.2. Stochastic Setup

Stochastic modeling is essential for addressing uncertainties in modern power grids, such as RE variability, fluctuating demand, fuel price volatility, and unplanned outages. Unlike deterministic models, it uses probability distributions and Monte Carlo simulations to represent real-world fluctuations, enabling more robust reliability assessments. By generating multiple scenarios with varying inputs like wind speed, solar irradiance, and load profiles, stochastic models estimate key reliability metrics such as LOLP and EENS. This approach supports resilient power system planning by identifying generation, storage, and transmission strategies that remain reliable under diverse conditions. Advanced tools like PLEXOS incorporate stochastic modeling to optimize decisions and ensure long-term grid stability.

RE generation is inherently variable due to its dependence on weather conditions, and electricity demand fluctuates significantly on yearly, monthly, and hourly scales due to various factors. Accounting for these variations in grid studies is critical to ensuring grid stability and minimizing stress on both the grid and other generators. To address this, a stochastic approach is adopted using historical data, where available, or alternative datasets for demand and RE generation, including solar, wind, and hydro resources.

The analysis focused on quantifying the variability in hourly data, evaluating it on a monthly basis to compute the coefficient of variation (CV) for use as an input to the model. The following systematic steps were undertaken:

1. Variance: The variance for each month was calculated to quantify the dispersion of hourly data points. Variance provides a measure of how much the data deviates from the mean, reflecting the spread within the dataset.

2. Standard Deviation: The standard deviation, as the square root of the variance, provides an interpretable measure of the spread of data in the same units as the original dataset.
3. Determination of the Coefficient of Variation: The coefficient of variation was computed for each month as the ratio of the standard deviation to the average. This metric, expressed as a percentage, indicates the relative variability of the data compared to its mean, allowing for a standardized comparison across months.

This approach provides a robust framework for assessing variability in load and RE generation data, offering valuable insights into their consistency and predictability over different months.

To illustrate, five stochastic samples of load and RE generation variability were generated:

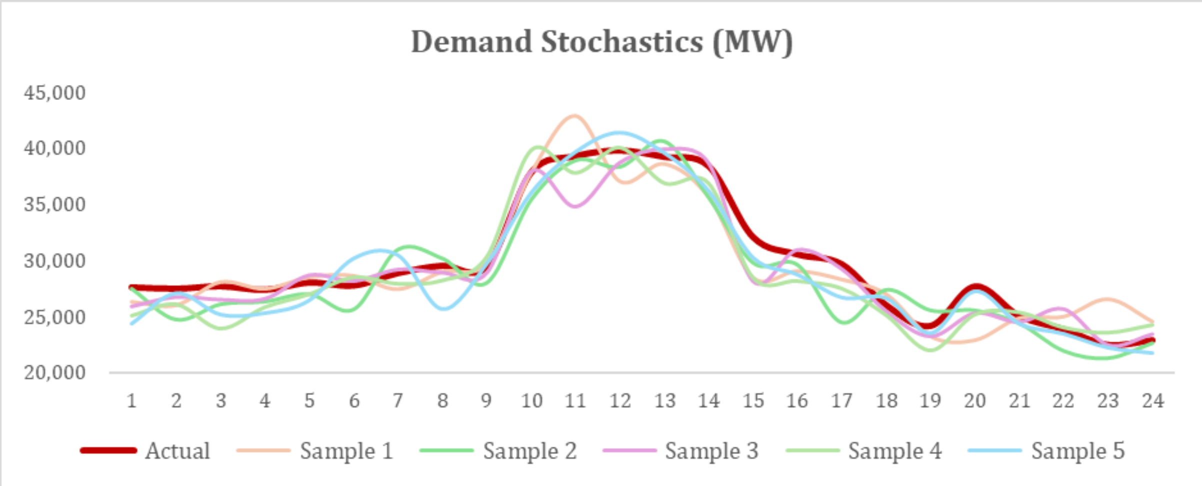

Figure 11: Demand Stochastics (MW)

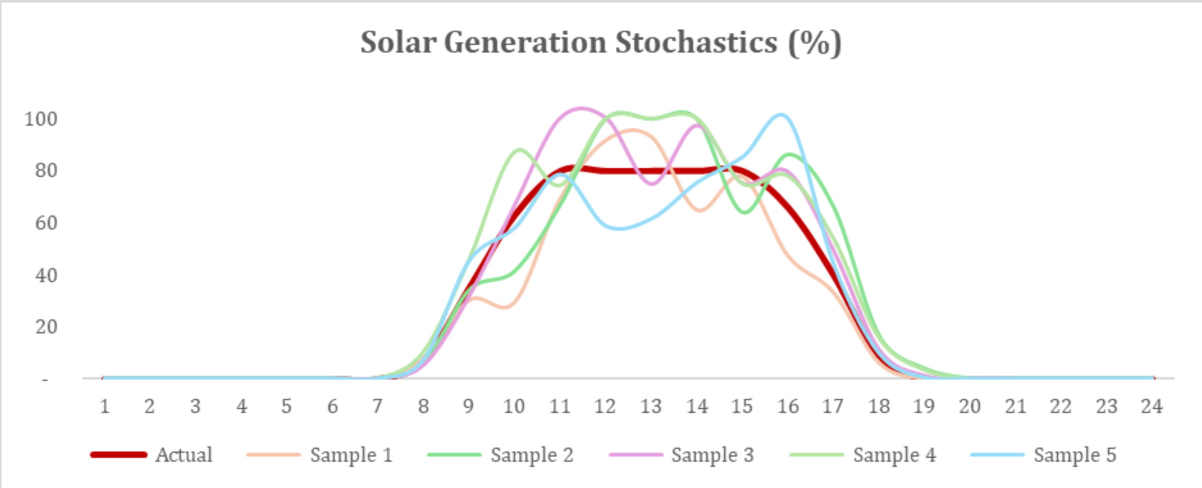

Figure 12: Solar Generation Stochastics (%)

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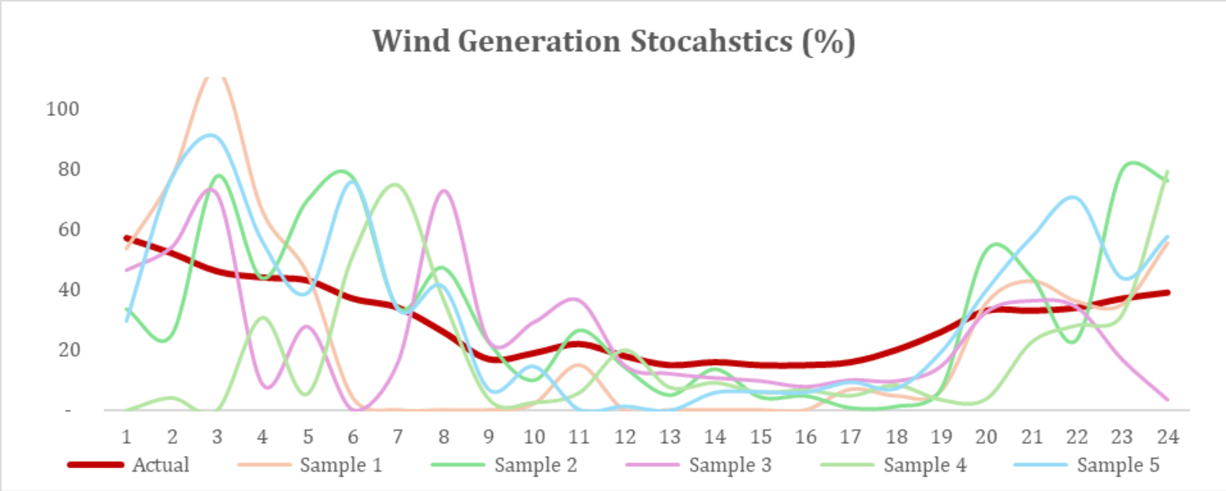

Figure 13: Wind Generation Stochastics (%)

6.3. Resource-wise Input Assumptions

The power generation model outlined above provides a comprehensive overview of the existing and planned capacities across various energy sources within the Maharashtra region. Each type of generator, whether coal, nuclear, hydro, solar, wind, biomass, or pumped storage hydro, is meticulously characterized based on operational parameters[1], including allocated capacities, heat rates, PLFs, start costs, VO&M, FO&M, forced and planned outages, minimum up/down time, and maximum ramp up/down etc. Notably, the model incorporates upcoming capacity additions for renewable sources, such as solar and wind, in alignment with regulatory obligations. Furthermore, the inclusion of storage technologies underscores a proactive approach towards addressing intermittency challenges associated with renewables, thereby enhancing the overall resilience and reliability of the power system. The Table 2 shows the Resource-wise Model Input Assumptions as below:

Table 2: Resource-wise Model Input Assumptions

Resource Type	Existing Capacity (MW)	Upcoming Contracted Capacity (Allocated) (MW)	Cost Escalation / Reduction Assumptions
Coal	23,129	NA	1% increase
Gas	1,246	NA	3% increase
Nuclear	740	NA	1% increase
Hydro	3,020	190 MW in FY25 130 MW in FY26 183 MW in FY27	Constant
Solar	3,610	16,305 MW in FY27	Constant
Wind	5,226	1,950 MW in FY27	Constant
Hybrid	100	615 MW in FY27	Constant
Biomass & Others	2,813	933 MW in FY25	3% increase
Pumped Storage Hydro (PSH)	630	5,000 MW in FY27	3% increase

In the PLEXOS model, some candidate capacity of solar, wind and Battery energy storage plants was considered for different years to meet the required reliability level i.e., UE less than 0.05%, LoLP less than 0.2%.

To ensure a reliable power supply, it is essential to meet reliability criteria. Hence the study considers solar and wind candidate requirements.

- **Solar Candidate:** The solar candidate capacity represents additional solar power capacity that can be installed to ensure the system meets reliability standards.
  - **VOM:** 2.5 Rs/kWh for FY25, reducing at 2% YoY till FY30, then reducing at 1% and reaching 2.17 Rs/kWh by FY34.
  - **CUF:** 25%
- **Wind Candidate:** The wind candidate capacity includes additional wind power plants that can be developed to enhance system reliability.
  - **VOM:** Starting at ₹2.89/kWh for FY25, then reduces by 2% YoY until FY30, remaining constant thereafter through FY34.
  - **CUF:** 30%
- **BESS 2-hr:** 2-hour battery energy storage system will mitigate contingency risks and facilitate the efficient storage of excess renewable energy.
  - **VOM:** 3.56 Rs lakhs/MW/month for FY25, reducing at 5% YoY till FY30, then at 2% and reaching 2.49 Rs lakhs/MW/month by FY34
- **BESS 4-hr:** 4-hour battery energy storage system will mitigate contingency risks and facilitate the efficient storage of excess renewable energy.
  - **VOM:** 5.71 Rs lakhs/MW/month for FY25, reducing at 5% YoY till FY30, then at 2% and reaching 4.07 Rs lakhs/MW/month by FY34

6.4. Renewable Purchase Obligation (RPO)

Maharashtra has mandated the RPO till 2030 and the same percentage has been retained till FY34 and same is shown in Table 3.

Table 3: Renewable Purchase Obligation[14]

FY	Other RPO	New Wind RPO	New DRE RPO	New Hydro RPO
2024-25	27.35%	0.67%	1.50%	0.38%
2025-26	28.24%	1.45%	2.10%	1.22%
2026-27	29.94%	1.97%	2.70%	1.34%
2027-28	31.64%	2.45%	3.30%	1.42%
2028-29	33.10%	2.95%	3.90%	1.42%
2029-30	34.02%	3.48%	4.50%	1.33%
2030-31	34.02%	3.48%	4.50%	1.33%
2031-32	34.02%	3.48%	4.50%	1.33%
2032-33	34.02%	3.48%	4.50%	1.33%
2033-34	34.02%	3.48%	4.50%	1.33%

As per the above RPO mandates, and considering existing and upcoming contracted capacities, additional capacities required to meet these RPO mandates were calculated, it is as per Table 4:

Table 4: RPO Plants

14 RPO Targets | MoP

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FY	SOLAR (MW)	WIND (MW)	DRE (MW)	TOTAL (MW)
2024-25	0	0	0	0
2025-26	0	0	0	0
2026-27	0	0	0	0
2027-28	4,000	0	0	4,000
2028-29	4,000	0	750	4,750
2029-30	3,000	400	1,050	4,450
2030-31	1,000	50	200	1,250
2031-32	1,000	50	300	1,350
2032-33	1,500	150	200	1,850
2033-34	2,000	150	300	2,450
TOTAL	**16,500**	**800**	**2,800**	**20,100**

6.5. Monthly Peak Demand and Daily Load Profile

The base year for this study is taken as FY24. In this fiscal year, the highest peak demand was recorded in April, peaking at 28,389 MW. The graph below shows Maharashtra's monthly peak demand for FY24:

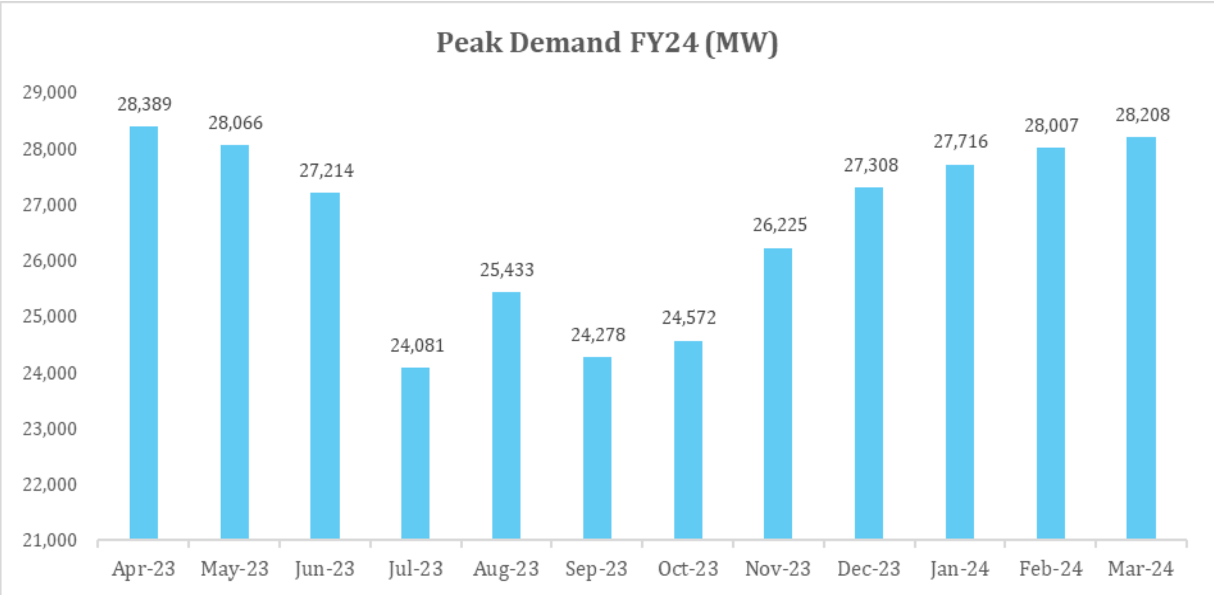

Figure 14: Maharashtra's Monthly Peak Demand for FY24

In this study, to accurately represent the impact of the Mukhyamantri Saur Krishi Yojana (MSKVY) solar project on the existing load profile, an agricultural load shift was implemented starting from the fiscal year 2027. This adjustment was predicated on the projected commissioning of MSKVY solar capacities by that time. Specifically, the peak load distribution was modified to reflect the anticipated transfer of agricultural demand to periods of peak solar generation. This resulted in a concentration of peak load during daylight hours coinciding with maximum solar irradiance, and a corresponding decrease in demand during non-solar hours. Furthermore, to account for the overall increase in energy demand attributed to the MSKVY solar project, the total peak demand was augmented by 45% of the total installed MSKVY solar capacity. This adjustment aimed to capture the expanded energy consumption associated with the increased agricultural activity enabled by the solar infrastructure.

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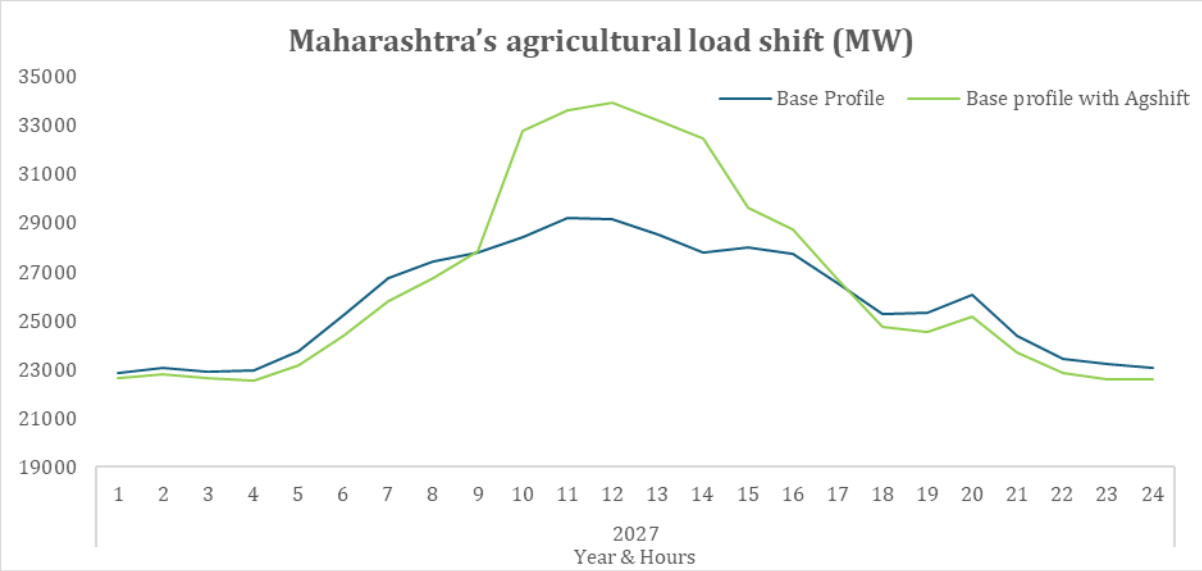

Figure 15: Maharashtra's agricultural load shift (MW)

Considering the hourly load profile for FY24, hourly load profile for future years is projected through Plexos without change in the load shape. The monthly average hourly profile shown in the graph below:

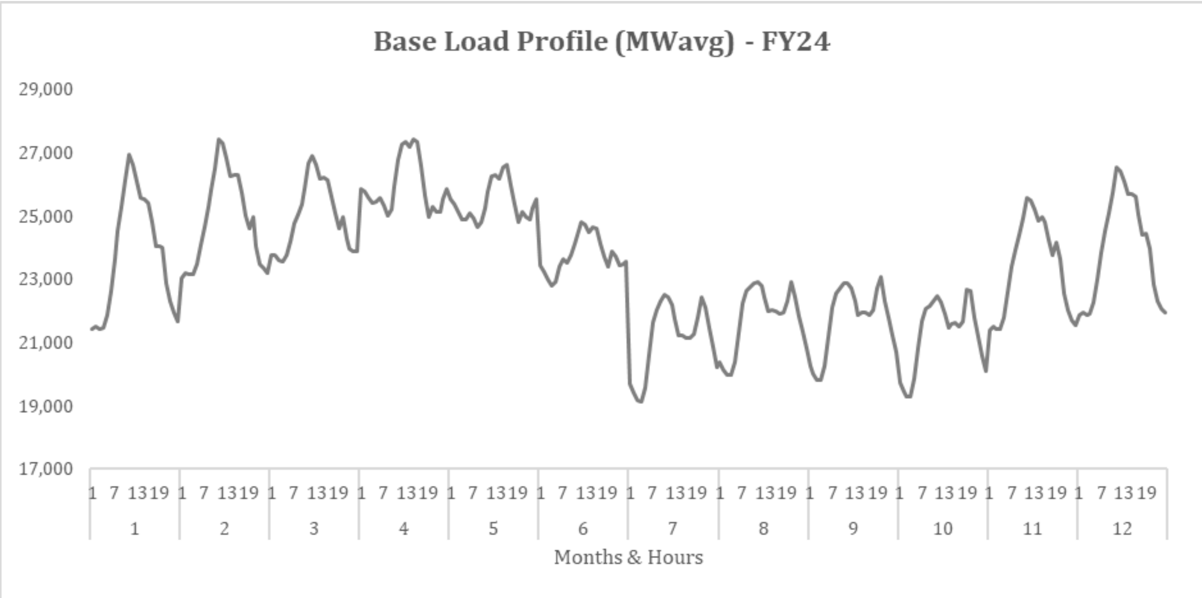

Figure 16: Monthly average Hourly Load Profile for FY24

6.6. Demand Projection Considered

FY24 was considered as base year and annual peak and energy projections from the 20th EPS were utilized from FY25 to FY34. The demand profile was adjusted to account for an agricultural shift. This involved shifting peak demand to solar hours and reducing it during non-solar hours. While the peaks were modified, the overall energy requirement remained unchanged. The energy projection shows a CAGR of 4.12%, with peak demand growing at 5.3%.

Table 5: Scenario Matrix of Maharashtra

FY	20th EPS Projections		20th EPS Projections with Agricultural shift	
	Energy Projections (MUs)	Peak Projections (MW)	Energy Projections (MUs)	Peak Projections (MW)
FY25	2,00,087	32,999	2,00,087	32,999
FY26	2,09,593	34,567	2,09,593	34,567
FY27	2,19,726	36,376	2,19,726	40,502
FY28	2,29,362	38,105	2,29,362	42,231
FY29	2,39,207	39,891	2,39,207	44,017
FY30	2,51,578	42,042	2,51,578	46,168
FY31	2,58,529	43,373	2,58,529	47,499
FY32	2,64,793	44,622	2,64,793	48,748
FY33	2,75,609	46,593	2,75,609	50,719
FY34	2,86,866	48,651	2,86,866	52,777

By considering the 20th EPS projections which are available up to FY32, the projections have been extended and computed up to FY34.

The energy (in MUs) and peak demand (in MWs) projections required to model for this study are taken from the above table and shown in Figure 17 below:

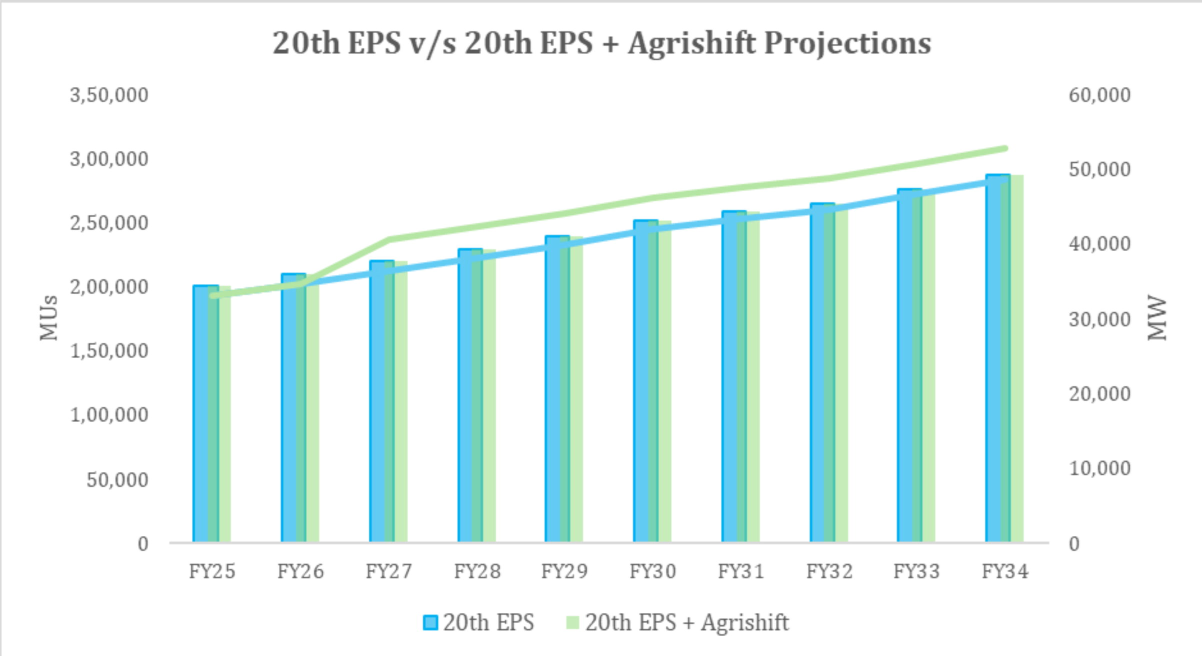

Figure 17: Maharashtra's YoY Peak and Energy projections: 20th EPS and 20th EPS + Agrishift

Having detailed the input assumptions, the key findings subsequently derived from the energy modeling. The following chapter summarizes the output parameters, such as unserved and dump energy, reliability metrics, year-over-year (YoY) resource-wise installed capacity and generation, battery energy storage capacity, resource-wise average hourly generation, and APPC. These findings provide critical insights into the performance and reliability of the power system.

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7. Study Findings

This chapter presents the findings derived from the study based on the input discussed in previous chapters. The key insights extracted from the analysis for 20th EPS with agricultural shift projections are summarized in the following sub-sections:

1. YoY Resource-wise Installed Capacity
2. YoY Resource-wise Generation
3. Average hourly generation
4. Unserved and Dump Energy
5. Reliability metrics
6. Average Power Purchase Cost

7.1. YoY Resource-wise Installed Capacity

The graph below illustrates the year-on-year resource-wise installed, contracted, and additional capacity mix for Maharashtra, with the corresponding data provided in tabular form in the annexure.

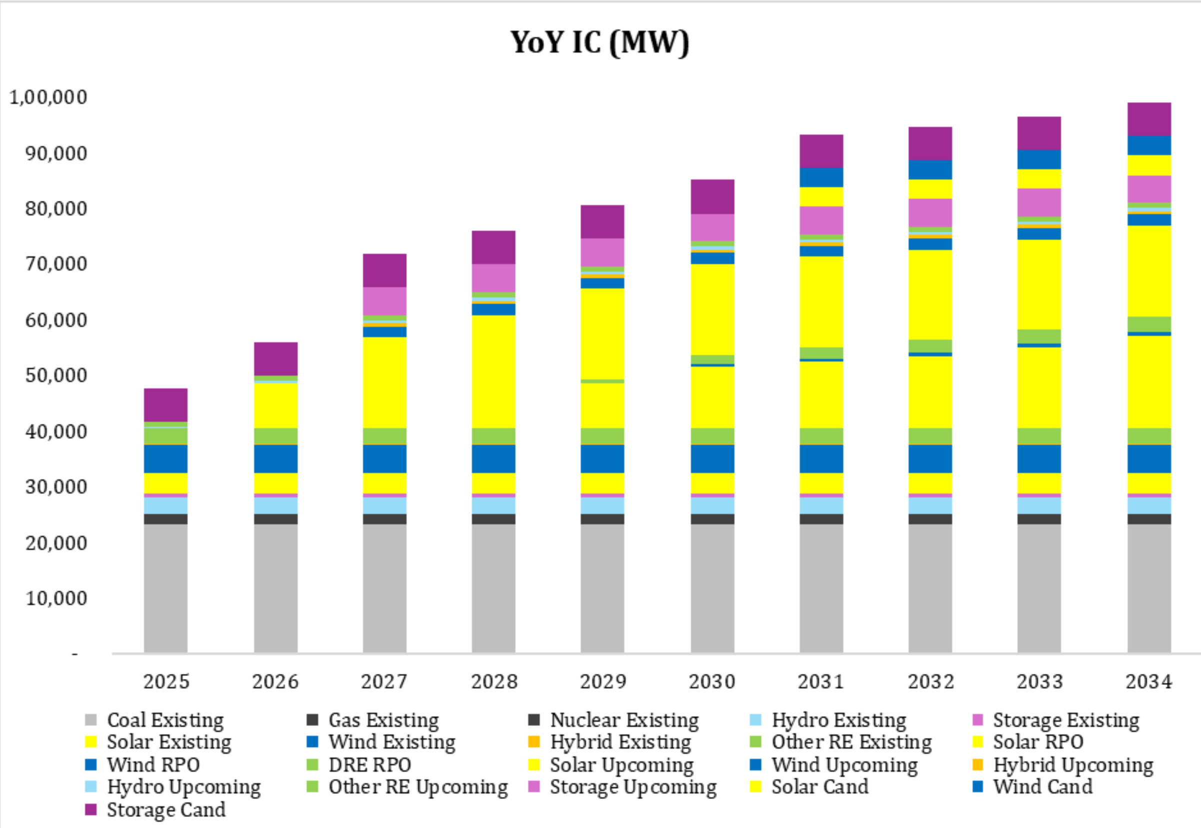

Figure 18: YoY Installed Capacity and Additional Capacity Required

- From the above graph it can be observed that solar capacities are more than double of coal capacity.
- No upcoming conventional plants were considered as per the data we received from state.
- RE and storage upcoming capacities are significantly added in FY27.

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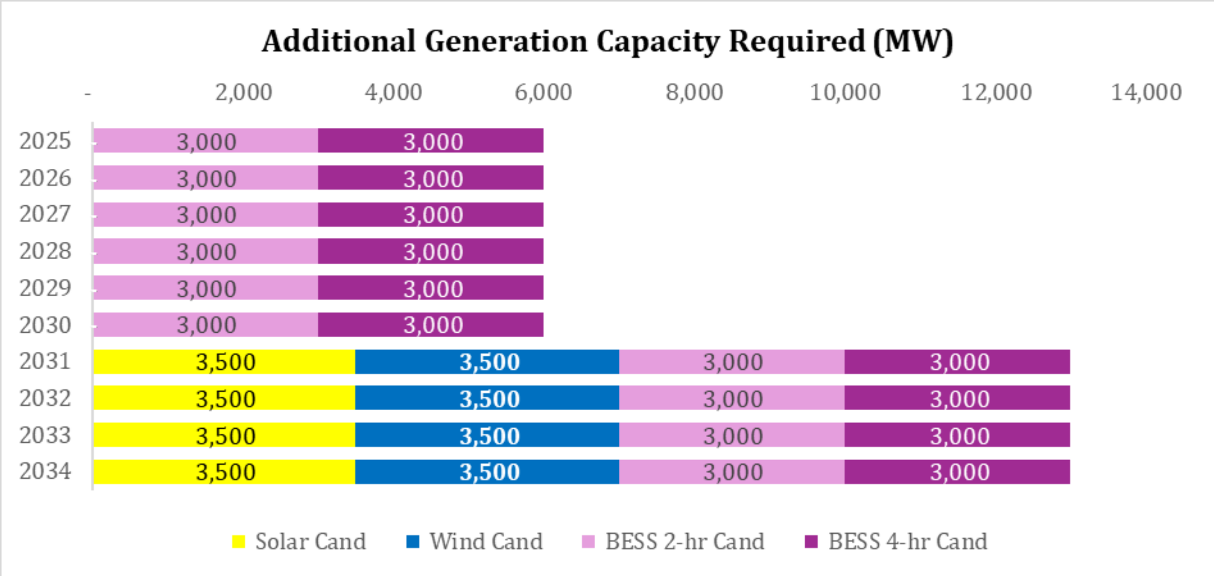

Figure 19: Additional Capacity Required (MW)

Due to agricultural load shift, the high RE generation is aiding the load pattern, thus requiring less additional plants. But requirement of storage is crucial to utilize the excess generation from RE.

7.2. YoY Resource-wise Generation

Below is graph of resource-wise generation and table for capacity factor resource wise YoY:

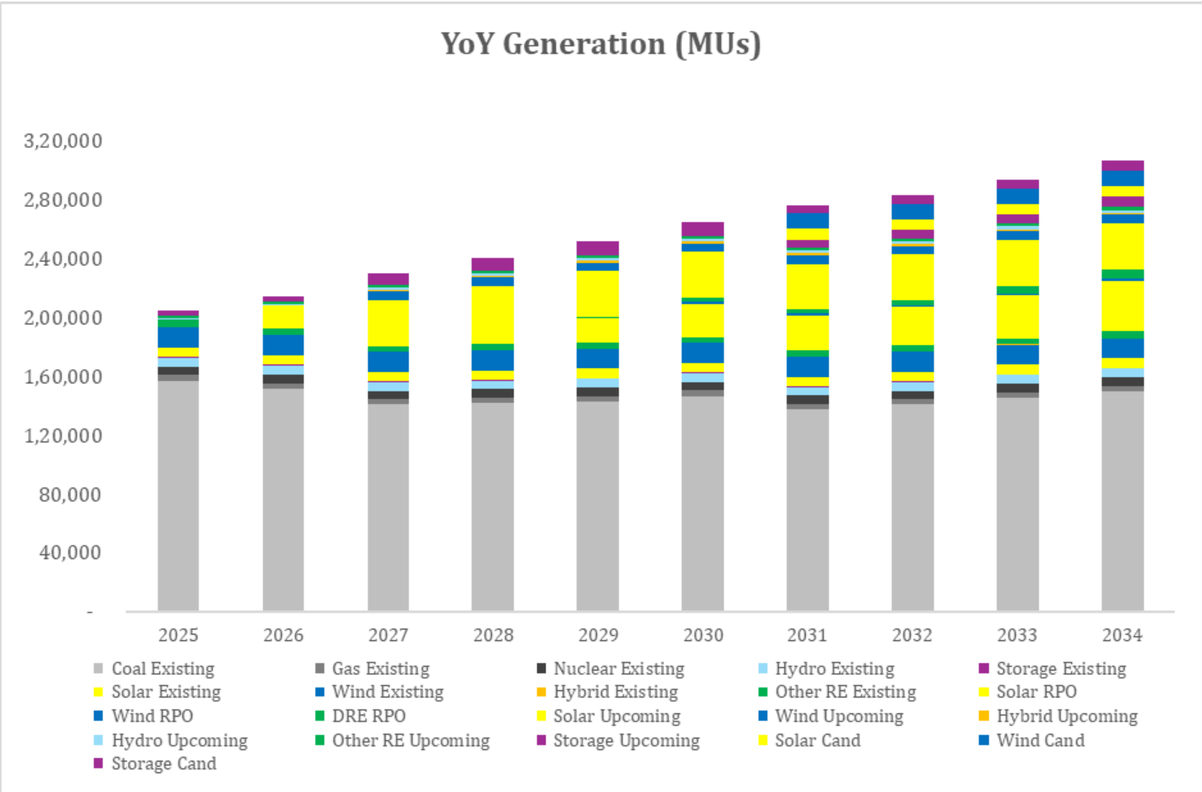

Figure 20: YoY Generation (MUs)

- It can be observed that even though the installed capacity of RE is higher than coal, contribution of coal generation continues to be significant thereafter reducing significantly from FY27 onwards.
- Storage generation is also helping meet the peaks significantly.

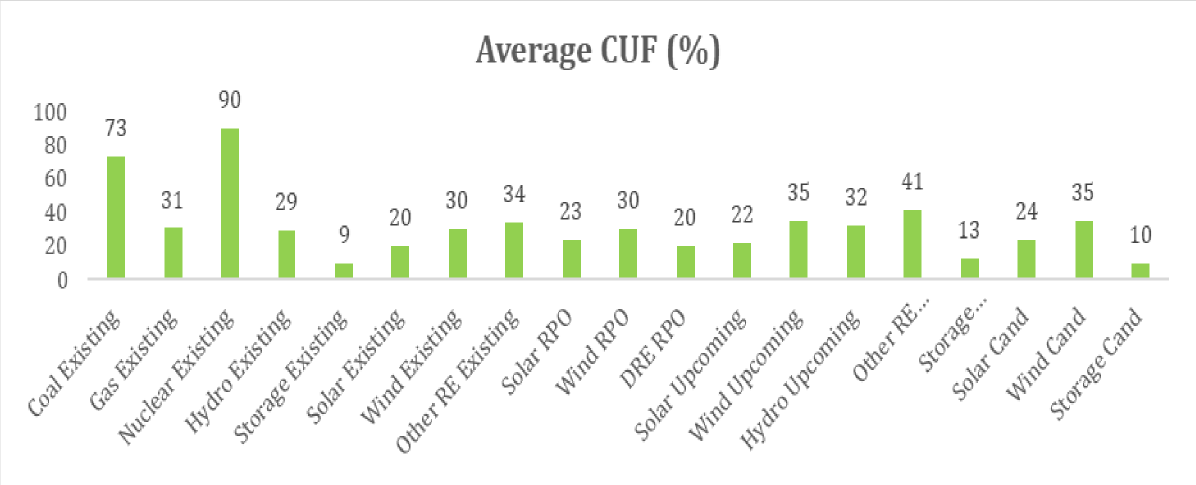

Figure 21: Average CUF (%)

- It can be observed that coal plants CUF has reduced to 73%, but Nuclear is running at 90%.
- The additional capacity of solar and wind that was added is also running near to its maximum CUF.
- There is an opportunity to trade this extra capacity of solar can be traded with other states.

7.3. Average Hourly Generation

The following graph shows average hourly generation for terminal year of FY34:

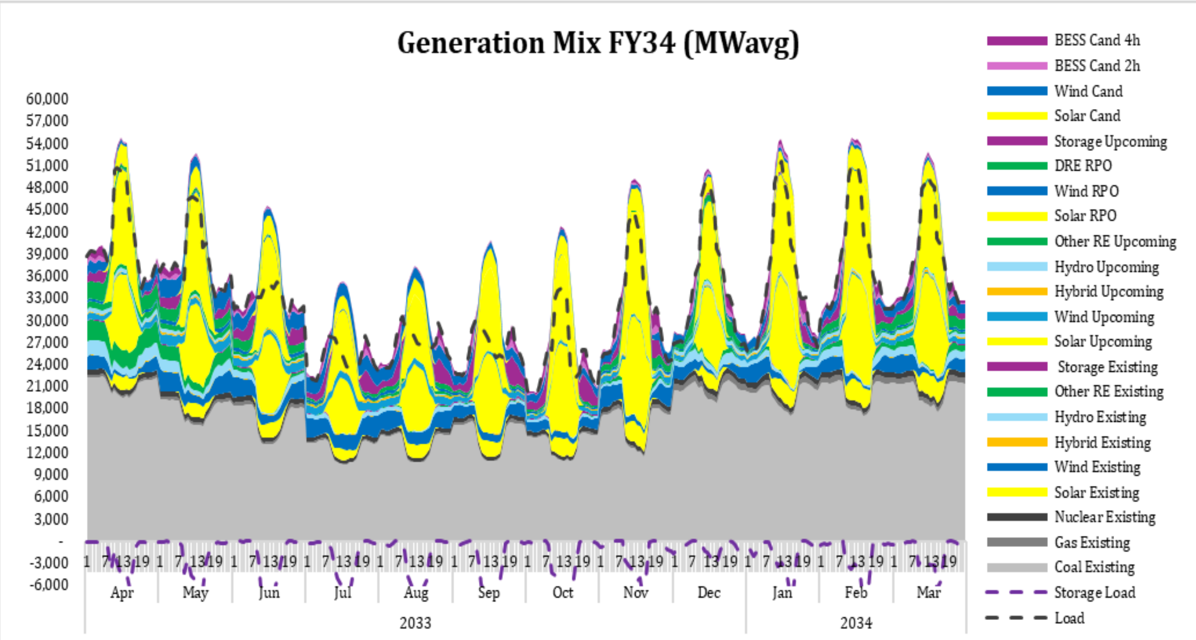

Figure 22: Generation Mix FY34 (MWavg)

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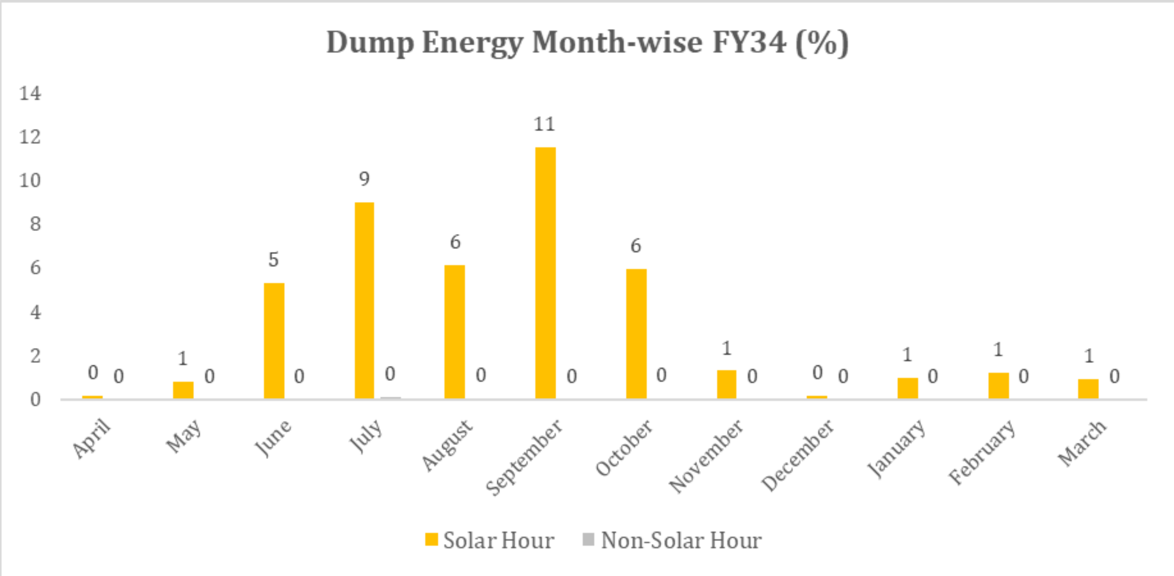

Figure 23: DE Month-wise FY34 (%)

- It is observed that in the months of June to October the dump energy is high for solar hours, as the load is on the lower side.
- In non-solar hours there is not much excess energy.

7.4. Unserved and Dump Energy

The following table shows YoY unserved and dump energy resulting from the buildout and dispatch:

Table 6: Unserved Energy and Dump Energy

FY	Unserved Energy Factor (%)		Dump Energy (%)		Dump Energy (MUs)	
	Existing + Planned	Existing + Planned + Candidate	Existing + Planned	Existing + Planned + Candidate	Existing + Planned	Existing + Planned + Candidate
25	0.69	0.05	0.31	0.02	784	50
26	0.24	0.01	0.46	0.08	1,227	225
27	0	0	0.54	0.3	1,751	996
28	0.01	0	0.59	0.24	2,007	822
29	0	0	0.77	0.28	2,661	993
30	0.01	0	1.07	0.46	3,807	1,676
31	0.05	0	1.08	1.05	4,022	3,903
32	0.24	0	1.03	1.02	3,959	3,721
33	0.68	0	1.01	0.91	3,693	3,590
34	1.64	0.04	1.12	0.96	4,140	3,826

- Maharashtra has sufficient upcoming resources to meet the projected demand, resulting in minimal surplus energy and very low unserved energy, though it remains slightly above 0.05%.
- However, to be RA compliant, additional capacity is required.

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7.5. Reliability Metrics

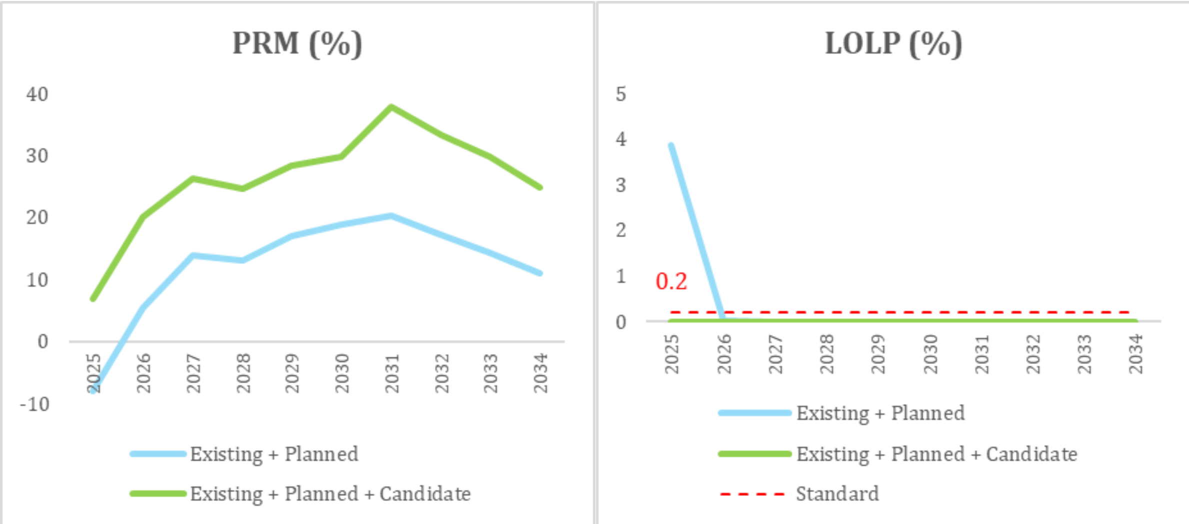

Figure 24: PRM & LoLP: with and without required capacity

- Figure 24 shows reliability metrics without and with consideration of candidate capacity (over and above existing installed and upcoming contracted capacity).
- In FY25 the total energy generated is less than the energy required, thus the PRM is negative and LoLP is very high.

The following table shows YoY reliability metrics of capacity margin and LoLP:

Table 7: Reliability Metrics

FY	Planning Reserve Margin (MW)	Planning Reserve Margin (%)	LoLP (%)
25	4,431	11.59	0
26	7,748	18.72	0
27	17,008	35.31	0
28	17,871	35.9	0
29	18,032	33.64	0
30	21,502	39.35	0
31	20,516	36.6	0
32	19,740	33.93	0
33	17,451	28.68	0
34	15,404	23.88	0

7.6. Average Power Purchase Cost

The following table shows YoY APPC resulting from the buildout and dispatch:

Table 8: APPC (Rs/kWh)

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FY	**Coal Existing**	**Gas Existing**	**Nuclear Existing**	**Hydro Existing**	**Storage Existing**	**Solar Existing**	**Wind Existing**	**Hybrid Existing**	**Other RE Existing**	**Solar RPO**	**Wind RPO**	**DRE RPO**	**Solar Upcoming**	**Wind Upcoming**	**Hybrid Upcoming**	**Hydro Upcoming**	**Other RE Upcoming**	**Storage Upcoming**	**Solar Cand**	**Wind Cand**	**Storage Cand**	**System Cost**
25	5.43	6.32	3.61	3.05	5.63	3.44	5.03	5.03	6.31	0.00	0.00	0.00	0.00	0.00	0.00	2.27	6.98	0.00	0.00	0.00	10.05	**5.26**
26	5.44	6.02	3.65	3.07	5.88	3.44	5.03	5.03	6.49	0.00	0.00	0.00	2.50	0.00	0.00	2.25	6.99	0.00	0.00	0.00	9.70	**5.04**
27	5.50	6.05	3.68	3.10	6.01	3.44	5.03	5.03	6.69	0.00	0.00	0.00	2.50	3.00	3.50	2.24	6.99	5.41	0.00	0.00	8.67	**4.80**
28	5.56	5.98	3.71	3.12	6.25	3.44	5.03	5.03	6.89	2.50	0.00	0.00	2.50	3.00	3.50	2.24	6.99	5.46	0.00	0.00	6.23	**4.55**
29	5.61	6.14	3.75	3.14	6.32	3.44	5.03	5.03	7.08	2.50	0.00	6.40	2.50	3.00	3.50	2.24	6.99	5.46	0.00	0.00	5.26	**4.63**
30	5.65	6.71	3.78	3.17	6.45	3.44	5.03	5.03	7.30	2.50	3.00	6.40	2.50	3.00	3.50	2.24	6.99	5.37	0.00	0.00	4.82	**4.57**
31	5.73	7.49	3.82	3.20	6.61	3.44	5.03	5.03	7.53	2.50	3.00	6.40	2.50	3.00	3.50	2.24	6.99	5.08	2.24	2.75	4.37	**4.40**
32	5.78	7.03	3.85	3.22	6.76	3.44	5.03	5.03	7.76	2.50	3.00	6.40	2.50	3.00	3.50	2.24	6.99	5.05	2.21	2.75	4.31	**4.40**
33	5.82	7.64	3.89	3.24	6.99	3.44	5.03	5.03	7.99	2.50	3.00	6.40	2.50	3.00	3.50	2.24	6.99	5.03	2.19	2.75	4.06	**4.44**
34	5.87	7.45	3.92	3.27	7.08	3.44	5.03	5.03	8.22	2.50	3.00	6.40	2.50	3.00	3.50	2.24	6.98	4.94	2.17	2.75	3.69	**4.43**

- In FY25, due to low dump energy, additional storage is not utilized, leading to high per unit costs, which reduces thereafter. This leads to overall APPC reduction from 5.3 Rs/kWh to 4.4 Rs/kWh.
- Storage costs fluctuate yearly based on UE and DE.

8. Key Insights from CEA's RA Study

The CEA has published a Resource Adequacy (RA) report for the state of Maharashtra, which provides an assessment of the state's electricity demand and the required generation capacity to ensure a reliable power supply. This section presents a high-level analysis of the study, highlighting key findings, and insights.

Unserved Energy (MUs) for different years from CEA's and Idam's RA studies are depicted as follows:

Table 9: Unserved Energy (MUs)

Year	CEA		Idam	
	ENS (MU)	ENS (%)	ENS (MU)	ENS (%)
2024-25	977	0.6	1,387	0.69
2025-26	1,719	1	510	0.24
2026-27	2,351	1.3	9	0
2027-28	2,778	1.4	29	0.01
2028-29	3,342	1.7	6	0
2029-30	1,823	0.9	23	0.01
2030-31	3,363	1.6	145	0.05
2031-32	4,500	2	665	0.24
2032-33	6,847	3	1,968	0.68
2033-34	10,397	4.3	4,917	1.64

The comparison of UE for different years from CEA's and Idam's RA studies highlights key differences in energy shortfall estimation:

Key insights:

- An important note is that CEA's RA study has been carried out for MSEDCL while this study has been carried out for the entire state of Maharashtra.
- CEA estimates a higher total ENS of 10,397 MUs by FY34, whereas this study projects 4,917 MUs by FY34
- 2032-33 and 2033-34 are critical years where both projections indicate substantial energy shortages, necessitating urgent planning for capacity expansion or demand-side management.

The Capacity Mix Projections (MW) from CEA and Idam are shown as follows:

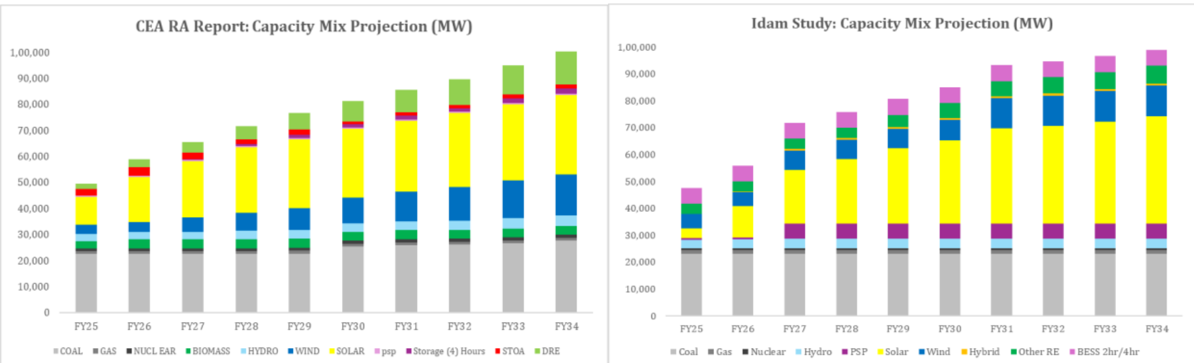

Figure 25: CEA & Idam - Capacity Mix Projections (MW)

The Planned capacity, additional, market and candidate capacities requirement from CEA and Idam are shown as follows:

Table 10: CEA- Planned capacity, additional and market capacity requirement

CEA															
FY	Thermal		Nuclear	Hydro		Solar		Wind		Biomass	Storage(4 Hours)	Yearly STOA	DRE	Total	
	Planned	Additional	Planned	Planned	Additional	Planned	Additional	Planned	Additional	Planned	Additional	Additional	Additional	Planned	Additional
FY25	1,660	0	223	183	0	4,943	0	500	0	76	0	2,482	2,052	7,585	4,534
FY26	0	0	0	0	0	6,410	0	500	0	690	0	3,310	949	7,600	4,259
FY27	0	0	0	109	0	4,000	500	0	1,500	0	378	2,359	1,049	4,109	5,786
FY28	0	0	0	313	0	3,000	500	0	1,500	0	475	1,687	1,121	3,313	5,283
FY29	228	0	0	104	0	717	500	0	1,500	0	327	2,057	1,208	1,049	5,592
FY30	3,564	42	0	0	0	0	0	0	1,500	0	0	1,117	1,358	3,564	4,017
FY31	0	619	0	0	0	0	1,000	0	1,500	0	140	1,250	1,081	0	5,590
FY32	0	124	0	288	0	0	1,000	0	1,500	0	91	1,218	1,103	288	5,036
FY33	0	542	0	323	0	0	1,000	0	1,500	0	344	1,487	1,332	323	6,205
FY34	0	1,002	0	0	0	0	1,000	0	1,500	0	339	1,457	1,440	0	6,738
Total	**5,452**	**2,329**	**223**	**1,320**	**0**	**19,070**	**5,500**	**1,000**	**12,000**	**766**	**2,094**		**12,693**	**27,831**	**53,040**

Table 11: Idam - Planned capacity, additional and candidate capacity requirement

Idam												
FY	Hydro	Solar		Wind		Hybrid	Other RE		PSP	BESS 2hr/4hr	Total	
	Planned	Planned	Additional	Planned	Additional	Planned	Planned	Additional	Planned	Additional	Planned	Additional
FY25	190	0	0	0	0	0	933	0	0	6,000	1,123	6,000
FY26	130	8,153	0	0	0	0	0	0	0	0	8,283	0
FY27	183	8,153	0	1,950	0	615	0	0	5,000	0	15,901	0
FY28	54	0	4,000	0	0	0	0	0	0	0	54	4,000
FY29	0	0	4,000	0	0	0	0	750	0	0	0	4,750
FY30	0	0	3,000	0	400	0	0	1,050	0	0	0	4,450
FY31	0	0	4,500	0	3,550	0	0	200	0	0	0	8,250
FY32	0	0	1,000	0	50	0	0	300	0	0	0	1,350
FY33	0	0	1,500	0	150	0	0	200	0	0	0	1,850
FY34	0	0	2,000	0	150	0	0	300	0	0	0	2,450
Total	**557**	**16,305**	**20,000**	**1,950**	**4,300**	**615**	**933**	**2,800**	**5,000**	**6,000**	**25,360**	**33,100**

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The capacity mix projections for MSEDCL from CEA and whole state Maharashtra from Idam show significant differences in the planned thermal, renewable energy, hydro, and storage capacity additions over the forecast period. CEA has also considered coal capacity to meet reliability metrices, whereas Idam has only considered solar, wind, and BESS to meet the metrices

Key Comparisons:

Thermal Capacity:

- CEA forecasts a significant increase in coal capacity, reaching 27,562 MW by FY34.
- In this study, the increase in coal capacity as candidate buildout has not been considered.

Biomass**:**

- CEA anticipates biomass capacity to grow to 3,439 MW by FY26.
- Idam's projection includes 933 MW of planned capacity and an additional 2,800 MW to meet RPO.

Hydro and Wind:

- CEA projects hydro capacity to reach 1,320 MW by FY33, while Idam forecasts 557 MW by FY28 and 3,577 MW by the same year.
- CEA's wind capacity projections (12,000 MW) are significantly higher than Idam's (4,300 MW).

Solar Capacity:

- CEA forecasts 30,285 MW of solar capacity by FY34.
- Idam projects a considerably larger 39,915 MW by FY34.
- CEA forecast a higher contracted solar capacity and a lower additional solar requirement than Idam.

Battery Storage & PSP:

- CEA considers battery storage of 4 hours as an additional requirement from FY27 onward (gradually increasing to 2,094 MW by FY34), whereas Idam estimates a much higher battery capacity of both 2 hours and 4 hours in starting year itself (6000 MW in FY25), thereafter no addition.
- Idam has assumed existing and upcoming contracted capacity of PSP totalling to 5,630MW.

The capacity additions from CEA and Idam present two distinct approaches to RA planning, with variations in coal, renewable energy, and storage deployment.

9. Conclusion

This study undertook a comprehensive Resource Adequacy (RA) assessment for the state of Maharashtra, with the objective of exploring and evaluating the multifaceted aspects of RA and its associated metrics. The overarching goal was to ensure a reliable and cost-effective power supply while adhering to established RA guidelines.

Key Findings:

- **FY25 Capacity Adequacy:** The analysis indicates that in the fiscal year 2025, the existing contracted capacity would not be sufficient to meet the defined reliability metrics. This presents Maharashtra with strategic options: either to procure additional power from the market or to invest in the development of new generation facilities.
- **Cost Reduction with RE:** The increasing integration of RE sources, particularly solar and wind, has shown to contribute to a reduction in overall system costs over time.
- **Reliability Metric Compliance:** The study successfully demonstrated compliance with key reliability metrics, including Loss of Load Probability (LoLP) and Normalized Energy Not Served (NENS), validating the robustness of the modeling approach.

Key Recommendations:

- **Accelerated Generation Capacity Expansion:** Given the rapid growth in demand, Maharashtra should expedite the development of new generation facilities to prevent potential shortfalls.
- **Leveraging Solar Energy:** The state's aggressive pursuit of the MSKVY solar project will significantly contribute to meeting demand by shifting load to periods of excess solar energy generation.
- **Cost-Effective Solar Integration:** The economic viability of solar energy will provide substantial benefits to the state in the coming years.
- **Investment in Storage Capacity:** Adequate storage capacity is crucial for Maharashtra to effectively utilize excess solar energy and ensure supply during peak demand periods.
- **Capacity Expansion Planning:** Regular assessment of capacity addition requirements is needed to avoid under- or over-investment in power generation assets.

By adopting these strategies, Maharashtra can ensure a sustainable, cost-effective, and reliable power supply, supporting its long-term economic and energy transition goals.

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10. Appendix

10.1. List of Existing Plants

List and details of existing plants considered in the model:

Table 12: Existing Coal Plants

Type	Plant Name	Installed Capacities (MW)	Allocated Capacities (MW)
State Plants and State Central Plants	Paras-3 to 4	500	500
	RATAN INDIA UNIT-01 TO 05	1,350	1,350
	Parli-6 to 7	500	500
	Parli-8	250	250
	Chandrapur-3 to 4	420	420
	Chandrapur-5 to 7	1,500	1,500
	Chandrapur-8 to 9	1,000	1,000
	IPP - Dhariwal Infrastructure Ltd. Power Plant	300	185
	Khaperkheda-1 to 4	840	840
	Khaperkheda-5	500	500
	Koradi-6 to 7	420	420
	Koradi-8 to 10	1,980	1,980
	NTPC MOUDA STAGE-1	1,000	397
	NTPC MOUDA STAGE-2	1,320	549
	ADANI TIRODA (UNIT- 2,3)	1,320	1,320
	EMCO	200	200
	ADANI- TIRODA (UNIT- 1,4,5)	1,980	1,980
	IPP - Sai Wardha Power Plant	540	100
	TROMBAY UNIT-5	500	500
	TROMBAY UNIT-8	250	250
	Bhusawal -3	210	210
	Bhusawal -4 to 5	1,000	1,000
	JSW (2023)	300	300
	Nashik-3 to 5	630	630
	NTPC Solapur	1,320	665
	Adani Dahanu Thermal Power Station	500	500
	JSW U1-4, JAIGAD	1,200	1,200
Other Central Plants	CGPL MUNDRA UMPP	4,000	760
	NTPC Gadarwara	1,600	110
	NTPC Kahalgaon stage-II	1,500	140
	NTPC Khargone	1,320	99

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Type	Plant Name	Installed Capacities (MW)	Allocated Capacities (MW)
	NTPC Korba stage 1-3	2,600	778
	NTPC Lara	1,600	291
	NTPC Sipat stage 1-2	2,980	868
	NTPC Vidhyanchal stage 1-5	4,760	1,152
	Total	**42,190**	**23,444**

Table 13: Existing Gas Plants

Type	Plant Name	Installed Capacities (MW)	Allocated Capacities (MW)
State Plants and State Central Plants	TPC-G UNIT 7	180	180
	GTPS Uran WHR - AO	120	120
	GTPS Uran WHR - BO	120	120
	Uran GT-5	108	108
	Uran GT-6	108	108
	Uran GT-7	108	108
	Uran GT-8	108	108
Other Central Plants	NTPC Jhanor-Gandhar Gas	657	195
	NTPC Kawas GPP	656	199
	Total	**2,165**	**1,246**

Table 14: Existing Nuclear Plants

Type	Plant Name	Installed Capacities (MW)	Allocated Capacities (MW)
State Central Plants	Tarapur APS 1&2	320	160
	Tarapur APS 3&4	1,080	432
Other Central Plants	Kakrapar APS 1&2	440	148
	Total	**1,840**	**740**

Table 15: Existing Hydro Plants

Type	Plant Name	Installed Capacities (MW)	Allocated Capacities (MW)
State Plants	Koyna 2 x 18 MW units	36	36
	Koyna, Stg-I 4 x 70 MW units	280	280
	Koyna, Stg-II 4 x 80 MW units	320	320
	Koyna, Stg-III 4 x 80 MW units	320	320
	Koyna, Stg-IV 4 x 250 MW units	1,000	1,000
	Tillari Unit	60	60
	Vaitarna Unit	60	60
	IPP - Dodson II	34	34
	TPC-G Bhivpuri	75	75
	TPC-G Khopoli	72	72

Type	Plant Name	Installed Capacities (MW)	Allocated Capacities (MW)
	TPC-G Bhira	380	380
Other Central Plants	Sardar Sarovar Project	1,450	392
	Pench	160	54
	Total	**4,247**	**3,083**

Table 16: Existing Pumped Hydro Storage Plants

Plant Name	Installed Capacities (MW)	Allocated Capacities (MW)
Ghatghar - Pumped storage	250	250

10.2. YoY Installed Capacity

Data of YoY Installed Capacity results:

Table 17: YoY Installed Capacity (GW)

FY	Coal Existing	Gas Existing	Nuclear Existing	Hydro Existing	Storage Existing	Solar Existing	Wind Existing	Hybrid Existing	Other RE Existing	Solar RPO	Wind RPO	DRE RPO	Solar Upcoming	Wind Upcoming	Hybrid Upcoming	Hydro Upcoming	Other RE Upcoming	Storage Upcoming	Solar Cand	Wind Cand	Storage Cand
25	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	0	0	0	0	0	0	0.2	0.9	0	0	0	6
26	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	0	0	0	8.2	0	0	0.3	0.9	0	0	0	6
27	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	0	0	0	16.3	2	0.6	0.5	0.9	5	0	0	6
28	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	4	0	0	16.3	2	0.6	0.6	0.9	5	0	0	6
29	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	8	0	0.8	16.3	2	0.6	0.6	0.9	5	0	0	6
30	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	11	0.4	1.8	16.3	2	0.6	0.6	0.9	5	0	0	6
31	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	12	0.5	2	16.3	2	0.6	0.6	0.9	5	3.5	3.5	6
32	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	13	0.5	2.3	16.3	2	0.6	0.6	0.9	5	3.5	3.5	6
33	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	14.5	0.7	2.5	16.3	2	0.6	0.6	0.9	5	3.5	3.5	6
34	23.1	1.2	0.7	3	0.6	3.6	5.2	0.1	2.8	16.5	0.8	2.8	16.3	2	0.6	0.6	0.9	5	3.5	3.5	6

10.3. YoY Generation

Data of YoY Generation results for both scenarios:

Table 18: YoY Generation (BUs)

FY	Coal Existing	Gas Existing	Nuclear Existing	Hydro Existing	Storage Existing	Solar Existing	Wind Existing	Hybrid Existing	Other RE Existing	Solar RPO	Wind RPO	DRE RPO	Solar Upcoming	Wind Upcoming	Hybrid Upcoming	Hydro Upcoming	Other RE Upcoming	Storage Upcoming	Solar Cand	Wind Cand	Storage Cand
25	157	4	6	6	1	6	14	0	5	0	0	0	0	0	0	1	2	0	0	0	3
26	152	4	6	6	1	6	14	0	5	0	0	0	16	0	0	1	2	0	0	0	3
27	141	4	6	6	1	6	14	0	4	0	0	0	31	6	1	2	2	4	0	0	3

FY	Coal Existing	Gas Existing	Nuclear Existing	Hydro Existing	Storage Existing	Solar Existing	Wind Existing	Hybrid Existing	Other RE Existing	Solar RPO	Wind RPO	DRE RPO	Solar Upcoming	Wind Upcoming	Hybrid Upcoming	Hydro Upcoming	Other RE Upcoming	Storage Upcoming	Solar Cand	Wind Cand	Storage Cand
28	142	3	6	6	0	6	14	0	4	8	0	0	31	6	1	2	2	4	0	0	5
29	143	3	6	6	1	6	14	0	4	16	0	1	31	6	1	2	2	4	0	0	5
30	147	4	6	6	1	6	14	0	4	23	1	3	31	6	1	2	2	4	0	0	5
31	137	3	6	6	1	6	14	0	4	24	1	3	31	6	1	2	2	6	7	11	6
32	141	4	6	6	1	6	14	0	4	26	1	3	31	6	1	2	2	6	7	11	6
33	145	4	6	6	0	6	14	0	4	29	2	5	31	6	1	2	2	6	7	11	6
34	150	4	6	6	1	6	14	0	4	34	2	6	31	6	1	2	2	7	7	11	6

10.4. Additional Capacity Required

Table 19: Additional Capacity Required (GW)

FY	20th EPS + Agrishift		
	Solar Cand	Wind Cand	Storage Cand
25	0	0	6
26	0	0	6
27	0	0	6
28	0	0	6
29	0	0	6
30	0	0	6
31	3.5	3.5	6
32	3.5	3.5	6
33	3.5	3.5	6
34	3.5	3.5	6