A

Seminar Report

On

IMPACT ANALYSIS OF SHORT TERM POWER PROCUREMENT PLANNING FOR RENEWABLE ENERGY RICH DISCOMs

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By

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CERTIFICATE

This is to certify that the seminar entitled **"Impact Analysis of Short Term Power Procurement Planning for Renewable Energy Rich Discoms"** submitted by Mr. Bala Ganesh K (2020PCV5316) at **Malaviya National Institute of Technology Jaipur** towards partial fulfilment of the requirements for the award of the degree of **Master of Technology** in Renewable Energy at **Centre for Energy and Environment** is a bonafide record of the work carried out by him under my supervision.

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DECLARATION

I hereby declare that the seminar report titled **"Impact Analysis of Short Term Power Procurement Planning for Renewable Energy Rich Discoms"** being submitted by me in partial fulfilment for the award of the degree of **"Master of Technology"** in Renewable Energy at, Centre for Energy and Environment, Malaviya National Institute of Technology Jaipur is my own work, carried out under the supervision of Dr. Parul Mathuria.

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ABSTRACT

Distribution Companies (Discoms) aim to meet the ever-fluctuating demand with the available diversified generation resources through power procurement planning, which is a strategic process of forecasting the demand and arranging necessary supply resources at specified time. The Indian Grid is in its transition phase with the evolution of Power Markets, Distributed Energy Resources (DERs), Energy Storage (ES), flexible and smart technology elements, focusing on transforming into a more responsive system. So, there is a need to seamlessly integrate all these active transient components and manage the demand side and generation side flexibility requirement while still obtaining the desired safety and reliability standards for grid operation. Ultimately, the goal is to supply demand at optimal cost in the desired specifications for which Discoms have to procure power optimally. Technical constraints like intermittent generation from Renewable Energy Sources (RES), ramping limits of coal power plants, fuel availability for gas generators, Surge Impedance Loading (SIL) limit of transmission lines and fluctuating load demand, narrow down the power procurement options of Discoms. Policy directives like Renewable Purchase Obligation (RPO), Cap on deviations from scheduled power quantum through Deviation Settlement Mechanism (DSM), INDC targets with respect to generation mix in long term scenario, impact the decisions and choices of power procurement. Planning the power procurement for short term is even more challenging because all the contracts signed for long term procurement, Commercial Operation Date (COD) of upcoming power plants and dynamic variations in the demand to be met impact the portfolio of short-term procurement. Discoms have financial challenges in the form of stranded fixed cost payment for unused quantum, cash liquidity for system operation with unrealized income due to ineffective metering etc. all of which reflect the gap between Average Cost of Supply and Average Revenue Realized (ACS-ARR). The power market is a viable solution for all these issues or constraints with power procurement, since it serves as an infinite bus where bilateral power transactions can be done, in a comparatively narrow time interval. The point of concern with market procurement is the uncertainty in both cost of power and landed cost for a location which depend on the time of procurement (peak or off-peak etc.). The other factor is DSM, which penalises any deviations in power supply and power procurement beyond specified limits. As per Draft DSM Regulations 2021 the limits are 2%selling quantum for seller in both over and under injection case and 12% of demand for buyer in case of over drawl. Thus, the short-term power procurement of Discoms can be

optimized with a strategic planning and allocation of the renewable generation quantum available, power purchase from other sources through contracts or Power Purchase Agreements (PPAs), scheduling of its own conventional generators, with the necessary cost optimization achieved through market procurement, thus matching the demand at any instant of time. This is done by ensuring all technical, policy and financial constraints are addressed without compromising on deviation limits specified.

SIGNIFICANCE

In the Indian scenario, DISCOMs procure power in most of the cases to cater to consumer demand. The source from where it procures and the consumer demand both have high degree of variability. Due to climate change concerns, switch to Renewable Energy Sources (RES) are mandated globally which is also driven by the exhausting fossil fuel resources. The capacity utilization of operating conventional power plants and future capacity addition of power system infrastructure are also adding up to the constraints in power management. The socio-economic conditions, local and national policy decisions also impact the power procurement by DISCOMs. The significant increase in RES quantum brings along with increased requirement of back up reserves to compensate its unpredictable availability. For this purpose, the Discoms go for available market options like Day Ahead Market (DAM), Real Time Market (RTM) etc. but which in turn causes a new problem in the form of uncertain price of electricity. This forces the DISCOMs to go for power procurement planning in short term to ensure optimal power management in the overall scenario. So, this study aims to study the impact of such market uncertainties in the power procurement planning of state DISCOMs in India, by taking prevailing conditions and constraints in the power system in a high RE scenario.

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ABBREVIATIONS	EXPANSIONS
DISCOMs / Discoms	Distribution Companies
DERs	Distributed Energy Resources
RES	Renewable Energy Sources
RPO	Renewable Purchase Obligation
SIL	Surge Impedance Loading
DSM	Deviation Settlement Mechanism
UI	Unscheduled Interchange
COD	Commercial Operation Date
ACS	Average Cost of Supply
ARR	Aggregate Revenue Requirement
PPAs	Power Purchase Agreements
DAM	Day Ahead Market
RTM	Real Time Market
G-DAM	Green – Day Ahead Market
TAM	Term Ahead Market
IEX	Indian Energy Exchange
PXIL	Power Exchange of India Limited
OA	Open Access
HT, LT	High Tension, Low Tension
RoI	Return on Investment
ISGS	Inter State Generating Stations
NTPC	National Thermal Power Corporation
NHPC	National Hydro Power Corporation
NPCIL	Nuclear Power Corporation of India Limited
DAE	Department of Atomic Energy
RTC	Round The Clock
PLF	Plant Load Factor
NLDC	National Load Despatch Centre
RLDC	Regional Load Despatch Centre

SLDC	State Load Despatch Centre
CTU	Central Transmission Utility
STU	State Transmission Utility
POSOCO	Power System Operation Corporation Limited
CERC	Central Electricity Regulatory Commission
GIS	Gas Insulated Substation
UDAY	Ujjwal Discom Assurance Yojana
IPDS	Integrated Power Development Scheme
RAPDRP	Restructured Accelerated Power Development and Reform Programme
PFC	Power Finance Corporation
DT	Distribution Transformer
ERP	Enterprise Resource Planning
HVDC	High Voltage Direct Current
EA	Electricity Act
EHV	Extra High Voltage
AT&C	Aggregate Technical & Commercial
EDLC	Electric Double Layer Capacitor
WEG	Wind Energy Generators
RTSPV	Roof Top Solar Photo Voltaic
DG, DS	Distributed Generation, Distributed Storage
TNO	Transmission Network Owner
CPP	Captive Power Producer
IPP	Independent Power Producer
PPP	Power Procurement Planning
FIT	Feed In Tariff
SCED	Security Constrained Economic Dispatch
SEBI	Security Exchange Bureau of India
MERIT	Merit Order Dispatch of Electricity for Rejuvenation of Income and Transparency
RRAS	Reserve Regulation Ancillary Services
FRAS	Fast Response Ancillary Services

NSGM	National Smart Grid Mission
ISGTF	India Smart Grid Task Force
ISGF	India Smart Grid Forum
TO	Tariff Order
NIWE	National Institute of Wind Energy
NISE	National Institute of Solar Energy
SECI	Solar Energy Corporation of India Limited
REC	Renewable Energy Certificates
HPO	Hydro Purchase Obligation
HEMS	Home Energy Management System
EVs	Electric Vehicles
EMS	Energy Management Systems
DR	Demand Response
MCP	Market Clearing Price
ACP	Area Clearing Price
DAC	Day Ahead Contingency
G-TAM	Green Term Ahead Market
GAMS	General Algebraic Modelling System

CHAPTER - 1

INTRODUCTION

Energy, defined as the ability to do work, is the basic requirement to make all the machines around us work and give the desired output. Energy can be classified broadly based on 3 important factors as given in **Fig.1.1**. Primary energy includes the raw form of energy available directly from source, say coal, petroleum, oil, natural gas etc. while the Secondary energy is obtained by processing and treating the primary energy. Based on their availability and ability to reform after consumption, energy is classified as Renewable energy (solar, wind, tidal etc.) which is inexhaustible in nature and Non-Renewable energy (fossil fuels) which is exhaustible, as they are available only in fixed quantum and take millions of years to reform. Based on their market value in terms of monetary benefits, they are classified as Commercial energy (saleable in markets) and Non-Commercial energy. Electricity or electrical energy is one of the most important secondary energy sources used today. It can be generated both from renewable and non-renewable sources of primary energy. Electrical energy is one of the most commercialized forms of energy available today and there are specific markets which transact electricity between various entities **[1]**.

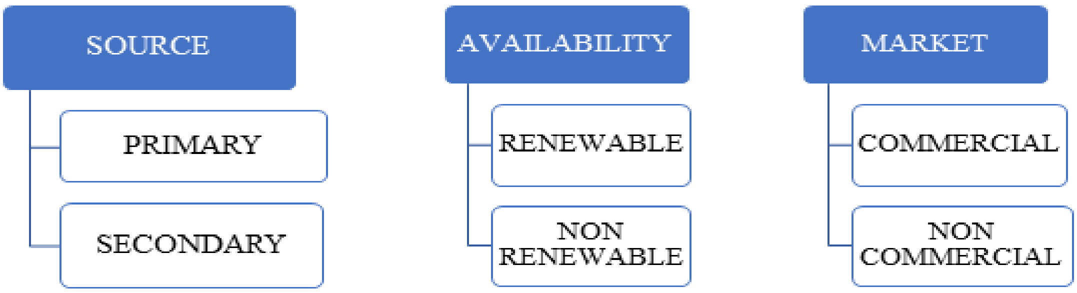


Fig. 1.1 Classifications of Energy

The rate of doing work by consuming a specific amount of energy over time is defined as power. Electric Power has been the inadvertent component in development and growth of India, apart from breaking its technological, economic and social barriers. The various advancements and breakthroughs in the electricity sector have facilitated a parallel technological advancement in all other fields of engineering, medicine, science etc. in the country. The major sectors in India that consume electric power are listed in **Fig. 1.2**, which includes industry, commercial establishments, agriculture, domestic (residential), transportation and construction **[1], [8], [11]**.

Fig. 1.2 Major Sectors in Electric Power Consumption

The electric power/energy or electricity to cater all these consumers, is generated from various sources of energy as mentioned in **Fig. 1.3,** like thermal (coal, gas, oil etc.), nuclear (fissile materials like uranium, plutonium etc.), hydro and other renewable sources like solar, wind energy etc. Now, the generated electricity has to be supplied to the consumers in the required specification and this work is done by agencies called Distribution Companies (Discoms), while in some cases if the consumer is large enough, say with a power demand of more than 1MW, the consumer can directly purchase and use the electricity from generators by Open Access (OA) either through Power Purchase Agreements (PPAs) or from the power market **[9], [10]**.

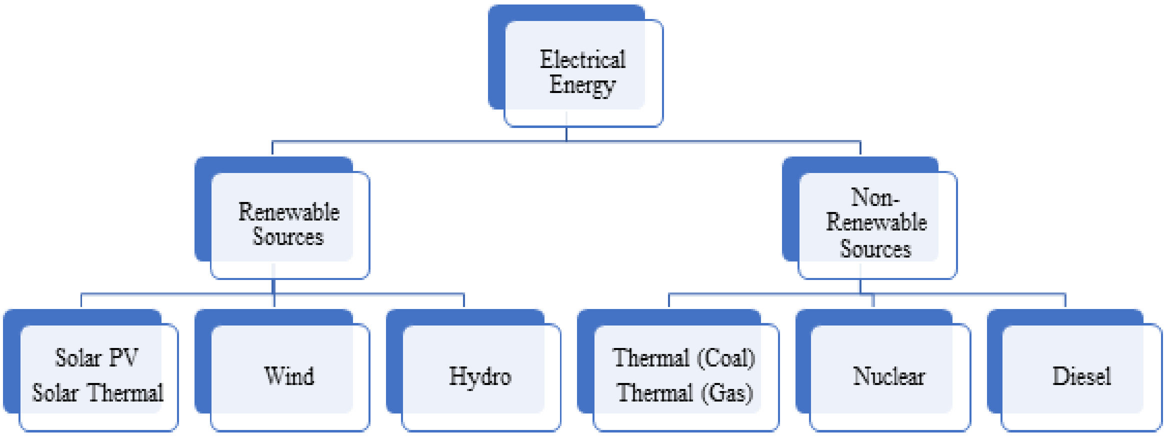


Fig. 1.3 Sources of Electricity Generation

In today's scenario, there is a specific market existing for the purpose of electricity transactions, facilitating the purchase of power by consumers or Discoms and sale of power by the generators. This power market is handled by two entities in India namely, Indian Energy Exchange (IEX) and Power Exchange of India Limited (PXIL). These two exchanges were established in 2008 along with the Open Access regulations facilitating for Day Ahead market and Over The Counter (OTC) transactions and guidelines for the operation of these exchanges came in 2010 with the Power Market Regulations. Electricity consumers can go for OA power procurement if they satisfy the eligibility criteria, else they would depend on the Discoms. So, the Discoms have to take into account such specific consumers too before deciding the quantum of procurement **[3]**, **[21]**. The specification of electric power utilized by these consumers is not the same, but differ in quantity, quality and their time of use in a day as given in the **Table 1.1 [9, 10]**

Table 1.1 Specifications of Electric Power for various Consumers

Category	Sanctioned	Maximum	Voltage Level	Time Of Use
Domestic, Agriculture	3 kW-5 kW	50 kVA	LT (230V,440V)	Morning, evening &
Commercial	10 kW	500 kVA	LT (230V,440V)	Day
Small-scale Industry	Up to 20 kW	1000 kVA	LT (440V)	Day
Medium-scale	Up to 100 kW	1000-5000	HT	Day
Large-scale Industry,	>100 kW	>5000 kVA	HT (>33 kV)	24 hours

This classification in the above table, specifies the customer profile as per the mandates of Discom for a particular state of Tamil Nadu and this might be different from country to country based on their particular grid structure and operation, even from state to state within a given country. As indicated in Table 1.1, the industries might need a High-Tension (HT) supply at about 6.6KV or more and they consume electricity throughout the day, while domestic (residential) users need a Low-Tension (LT) supply at 440V or 230V, mainly during morning, evening and night hours, whereas commercial establishments like shopping centres, corporate offices etc. have their consumption during the day time. Their demand is not constant, but keeps varying instantaneously, sometimes causing significant peaking or dipping problems **[2], [4]**.

With these varied requirements and fluctuations, there is a need to properly plan the power requirement that is to be met and usage of electricity by such a variety of consumers, both in the long term and short-term scenario to ensure reliable and cost-effective operation of the whole system. Apart from these variations on the demand side, the generation is also not constant due to many factors like fuel availability for conventional power plants, intermittency in the solar radiation, wind etc. which makes these generations unreliable and unexpected or unprecedented fault occurrences in the generators. The transmission corridor which evacuates the generated electricity to point of consumption, is a deciding factor in some cases when there is network congestion due to unexpected surge in load demand or any faults in the transmission lines etc. **[2], [4]**

The Power Procurement Planning aims to optimally balance the demand with available generation from multiple resources and markets. Optimal here implies both financial and technical considerations that will be taken into account while matching generation with demand. Financial considerations aim to enable the power plants to achieve desired Return on Investment (RoI), reduce the gap between ACS-ARR of the DISCOMS and ensure cost effective power availability for the end user. Technical considerations include operating the grid safely at optimal voltage at desired points and close to national frequency at all times. It also encloses the flexibility constraints due to the various fluctuations injected into the grid **[2]**. In this report the impact analysis of short-term power procurement planning for renewable energy rich Discoms in India are studied in detailed and a model is developed to determine the optimal power procurement portfolio respecting all the constraints in the existing system. The implications of the short-term procurement portfolio thus obtained on all the stakeholders involved from the power agencies of generation, transmission, distribution to the end consumers is discussed.

CHAPTER 2
POWER AGENCIES - INDIA

2.1 Generation

As stated earlier, India is being an energy deficit country at present even though the installed capacity of generation is way beyond the peak load demand **[20]**. The highest peak load demand was recorded on 7th July 2021 at 200.57 GW **[9]** while the total installed capacity is almost twice this quantity. The summary of sector wise installed generation capacity is given in the following table,

Table 2.1 Installed Generation Capacity (Sector Wise) - India [9]

Sector	MW	% of Total
Central	97,637	25.2
State	1,03,921	26.8
Private	1,86,576	48.1

The central sector includes large Inter State Generating Stations (ISGS) fuelled by either thermal, hydro or nuclear energy **[20]**. The thermal energy generation includes stations using coal or gas as their source of energy and they are operated by National Thermal Power Corporation (NTPC) Limited. Similarly, hydro energy generation indicates stations that use potential energy of stored water by converting it into kinetic energy during flow and are operated by National Hydro Power Corporation (NHPC) Limited. Nuclear energy generation harnesses energy released during fission of uranium and its isotopes in a controlled chain reaction. Power Stations that use this type of technology are owned and operated by Nuclear Power Corporation of India (NPCIL) Limited under the Department of Atomic Energy (DAE), Govt. of India **[9]**.

Apart from these ISGS, there are State Generating Stations (SGS) owned and operated by state governments which are mostly thermal and hydro energy based. From the above Table 2.1 we can see that both these sectors together contribute to approximately 50% of the installed generation capacity and the third important sector which is the private generators add on to the remaining 50% capacity **[9]**. This is an important point to be noted as this is one prime reason for the above stated point of energy deficiency in spite of twice the generation capacity. A major chunk of these private generators, unlike the other two, do not operate Round the Clock

(RTC) throughout the year due to various operational, technical and financial constraints like fuel availability, lack of expertise in plant operation and high cost of generation **[20]**.

Two important aspects of generation are the Plant Load Factor (PLF) and Ramping Rates of the conventional generators, which indicate the capacity utilization and rate at which they can increase or decrease their power output. Due to the large-scale integration of DERs and bulk RES, there is more and more intermittent injection of electricity into the grid which in turn forces more pressure on the ramping capabilities of the conventional generators. The PLF of thermal plants has been decreasing since the last decade and the ramping requirement during peak hours in India is increasing with more and more renewable penetration. So due to these intermittencies in the installed RES quantum, uncertain operation of private generators and failing to stick to proper maintenance schedules of power system components result in the required generation quantum not available at specified time slots, thus making overall system energy deficit **[9], [20]**.

2.2 Transmission

Transmission sector takes the responsibility of evacuating power from point of generation say a thermal power plant or a remote hydro power unit to the point of consumption. They are mostly Overhead lines with single or double circuit and in some areas like major metropolitan cities they are used as Underground cables. POWERGRID Corporation of India Limited establishes transmission lines across the country and maintains it. The line capacity varies from 220KV to 765KV in AC and in HVDC it goes up to 1200KV. There were 5 regional grids in India, which were merged into one single grid in 2013, with the aim of one nation one grid one frequency. For the operation of the transmission networks 5 Regional Load Dispatch Centres (RLDCs) in the 5 regions of the country were functioning under the National Load Dispatch Centre (NLDC). In 2010 the Power System Operation Corporation Limited (POSOCO) was setup to manage all these RLDCs and NLDC. From 2013, after the establishment of 765 KV Raichur – Solapur transmission line, the southern grid was connected synchronously to the other grids, thus one nation one grid one frequency concept came into existence with all regional grids interconnected and operated through Inter State Transmission System (ISTS). At present in India, POWERGRID owns and maintains majority of the transmission lines and it is the Central Transmission Utility (CTU). Apart from this in each state there are transmission lines owned and maintained by State Transmission Utility (STU) **[9]**, **[20]**.

Today, the total length of transmission network in the country extends up to 4,50,552 circuit km with majority 220 KV and 400 KV lines. 765 KV lines are upcoming in many places along with 1200 KV HVDC lines. The transformation capacity amounts to 10,71,506 MVA with substations all over the country spread out ensuring last mile connectivity. Gas Insulated Substations (GIS) are being established replacing the older substations to ensure efficient hassle-free operations. The total inter regional transmission capacity is currently at 112 GW which is expected to grow up to 120 GW by the end of 2022.

The separation of carriage and content came in 2014 with the amendment in Electricity Act 2003. The state Discoms have multiple roles of laying out and maintaining the transmission network in the state functioning as the State Transmission Utility (STU) apart from supplying the consumers with required power mandating to all obligations and respecting the system constraints. With some states failing to appreciate the amendments in the Electricity Bill 2014, a revised draft amendment was again proposed by the Ministry of Power in 2018 segregating the electricity distribution (supply business) from ownership of the networks (wire business). According to this, a new structure was proposed with an intermediary company dealing the PPAs directly with the generators followed by multiple transmission licensees. These licensees merely transact the power based on signed contracts while the maintenance of the networks would be taken care by the CTU and STU. Now again in each state there would be multiple distribution licensees involved in the supply of electricity through the networks owned and maintained by STU and other private network providers. The structure before and the separation of content and carriage in transmission and distribution sector is given in **Fig. 2.1**. With the involvement of more transmission and distribution licensees, competition is more prevalent resulting in efficient and optimal cost operation of the entire network **[11], [13]**.

Traditionally, as mentioned above there were only large Inter State Generating Stations (ISGS) so the lines were interconnecting them and it was a 24*7 load on them. But now with the integration of RES there are more challenges to be faced. There are large solar parks coming up in various parts of the country along with existing and newly added wind farms. The existing wind farms are also being upgraded with high power wind turbines which will require increase in the existing evacuation capacity. With the National Offshore Wind Energy Policy introduced in 2015 a target of 30 GW is set for Offshore wind generation. With such a huge quantum of generation from wind turbines located in sea corresponding transmission lines have to be setup appropriately to evacuate this power.

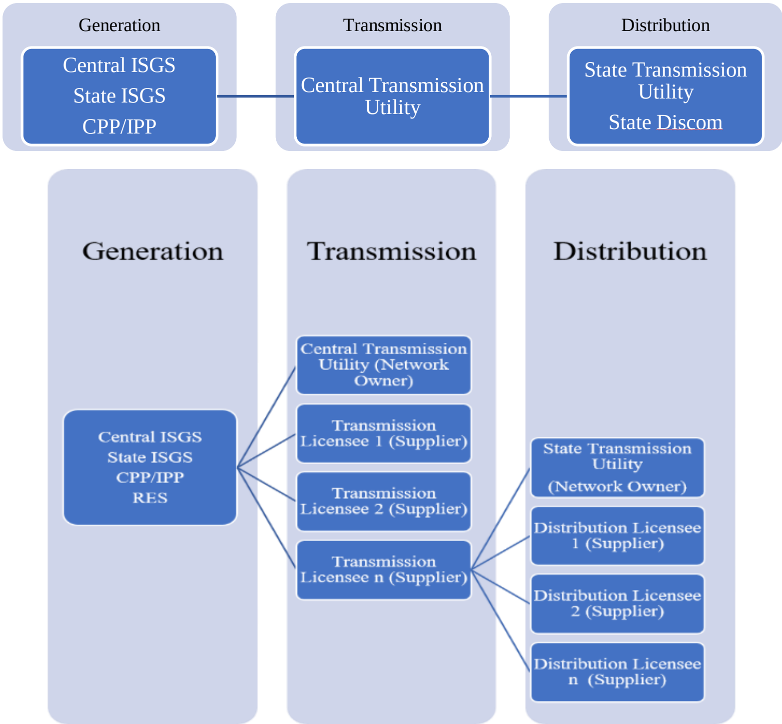


Figure 2.1 Separation of Carriage and Content in Transmission and Distribution

To strengthen the inter and intra state transmission networks in renewable energy rich states like Tamil Nadu, Karnataka, Gujarat, Rajasthan etc. Green Energy Corridors project was launched in the 12th plan period. This aimed at evacuation of approximately 33,000 MW of RES generated power avoiding curtailment due to insufficient tie line capacity. In regards with the latest targets for solar energy generation large solar parks are planned for a capacity of 20,000 MW and specifically to evacuate power generated from these areas, dedicated transmission networks under Green Energy Corridors – Phase II are being established **[9]**, **[20]**.

2.3 Distribution

Today, almost every citizen of India has access to grid electricity, power deficiency has decreased sharply, and the installed renewable energy capacity has reached a fourth of the total capacity. These are achieved in the background of a strong distribution network connectivity across the country operated and managed by state owned Discoms while in some major cities by private DISCOMs. Distribution includes maintenance of the distribution network and retail supply of electricity to the consumers, conventionally by purchasing power from generation companies through PPAs and supplying it to their consumers. Off late the Discoms are in poor financial situation except for very few and this has been affecting their ability to buy power for supplying the consumers, and the ability to invest in improving the distribution infrastructure, impacting the quality of electricity that consumers receive **[4], [21]**.

To strengthen the distribution sector infrastructure and revive the financial conditions of the Discoms many specific schemes and programs were introduced by the central government. Ujjwal Discom Assurance Yojna (UDAY), Restructured Accelerated Power Development and Reform Programme (RAPDRP) and Integrated Power Development Scheme (IPDS) are few of the important schemes introduced to improve the overall standard of distribution sector. UDAY was launched in 2015 for financially reviving the Discoms of India which were in crores of debt. The main reasons for the poor financial state of the Discoms are listed in the **Fig. 2.2**. According to the scheme the state governments will take up 75% of the debts of the state Discoms and pay them by issuing bonds while Discoms would take care of the remaining 25% and issue bonds for that part **[4], [13]**.

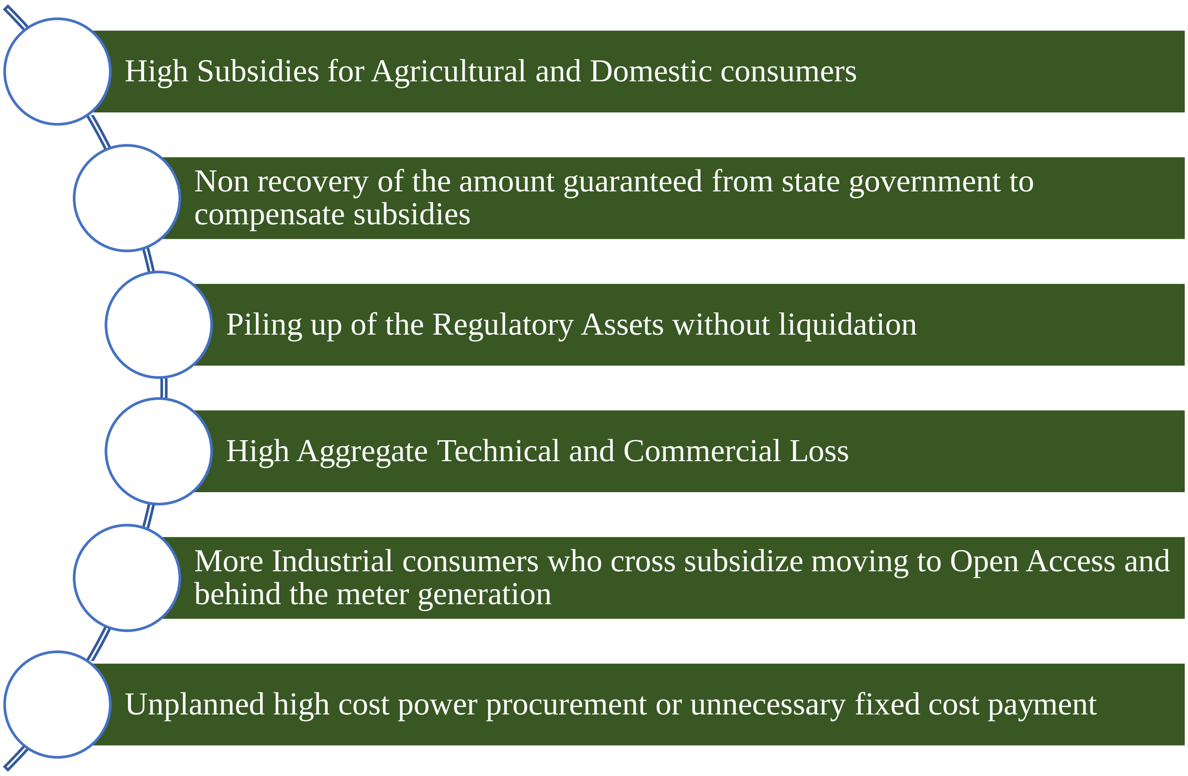


Figure 2.2 Factors contributing to poor financial state of Discoms

The RAPDRP was an upgraded version of the APDRP introduced in 2002, and it was introduced in the 11th five-year plan with reformed terms and conditions under the direct monitoring of the central government. The programme mainly focussed on targeted loss reduction in the distribution segment of the power sector. Apart from that it aimed at setting up advanced automated infrastructure for data collection and enabling Information Technology (IT) services in energy billing and accounting. This programme focussed on urban towns and cities with population more than 30,000 with projects under them being taken up in two parts.

In Part A, infrastructure development projects for IT enablement, consumer services and baseline data collection were carried out under 100% loan from government of India. In Part B, with 25% loan support from the government distribution network strengthening projects were undertaken including renovation, upgradation and modernization of existing substations and transformers mostly in 11KV level while in some cases the sub transmission level of 33KV also considered **[6], [9]**.

The IPDS was introduced in 2014, including the RAPDRP with Power Finance Corporation (PFC) as the nodal agency as in the case of RAPDRP. IPDS aimed at strengthening sub-transmission and distribution networks by metering the Distribution Transformers (DT), feeders and consumers in the urban areas. Schemes for Enterprise Resource Planning (ERP), underground cabling in major cities as per state demand, smart metering solutions for states that perform well under UDAY and installation of solar panels in government buildings were some other highlights under IPDS. All Discoms were given 60% of funding as grant with an additional 15% of funds as per milestones achieved **[6], [9]**.

Electricity Act (EA) 2003 introduced many new policies specific to the distribution sector such as open access, multi-year tariff frameworks, distribution franchisees, de-licensing generation, establishment of renewable purchase obligations, and the creation of independent regulatory bodies **[4]**. All these policy measures restructured the power sector in India wholistically with aim of increasing the short-term transactions rather than the current scenario where almost 90-95% is through long term contracts. But at the same time introduced new challenges to the Discoms in terms of dealing with uncertain and dynamic components of the power system. So, these challenges that the Discoms already face are adding up to the new constraints imposed on them due to the huge quantum of RES integration and the market uncertainties. To deal with these emerging challenges short term power procurement is important and proper planning for the same is required.

With these power agencies and their operation in the existing Indian scenario as discussed in the following chapter, we should devise suitable methods and policies for successful integration of the huge renewable energy quantum into the system, while ensuring no adverse impacts are caused to the system as a whole and any of the stakeholders involved.

CHAPTER 3

POWER PROCUREMENT - INDIAN SCENARIO

Historically, the Indian Grid has been energy deficit and so the power procurement was defined by the available generation from large power plants based on thermal, nuclear and hydro energy. Next important factor was the evacuation of the generated power from these large power plants located in remote areas to the major consumption zones in cities or towns through the transmission network. Up to the last decade the evacuation was done majorly through 220KV lines with very few 400KV lines. But now with the advent of (Extra High Voltage) EHV and Ultra EHV lines, the transmission network has grown vast and wide spread ranging from 220 KV to 1200 KV with more High Voltage DC (HVDC) lines coming into the grid in the recent past **[9]**, **[20]**. A basic overview of the Indian Power Sector with the management of power and the various participating entities are given in the Fig. 3.1 below,

Fig. 3.1 Basic Overview of Indian Power Sector with power management

The consumers have multiple options available to get their required electric power supply. They can avail supply from Distribution Companies (DISCOMS) or go for their own captive generation. Alternatively, if they have a power requirement of more than 1 MW then they can also go for Open Access (OA) from the electricity market through Power Exchanges. The points of consideration in any mode of power procurement would be the cost, quality & reliability of power **[3]**, **[7]**.

The DISCOMs can be state government owned, as in majority of the cases or a private company. They have the responsibility of supplying power to the end users with desired specifications at minimal cost. In this process, they have certain constraints to be met like ensuring power for all, 24x7, meeting the RPOs which cater to the environmental impacts of power generation, maintaining power quality till the last point connectivity, minimizing Aggregate Technical and Commercial (AT&C) losses and cost optimization. To ensure these constraints are met, apart from having an uninterrupted generation, robust transmission network there must be the intervention of one more important aspect called Distributed Energy Resources (DERs) **[12]**.

The term DER encompasses Distributed Generation (DG) and Distributed Storage (DS). DG involves electricity generation from sources like Roof-Top Solar Photo Voltaic (RTSPV) panels, Small and Micro Wind Energy Generators (WEG), Diesel Generators etc. DS includes the storage of electrical energy in various forms like, Electrostatic Energy in super capacitors (Electric Double Layer Capacitor (EDLC), Hybrid capacitors, Pseudo capacitors etc.), Magnetic Energy in Superconducting Magnetic Energy Storage (SMES) coils, Electrochemical Energy in batteries (Lithium-ion, Lead-acid, Sodium-sulphur, Flow batteries etc.), Mechanical Energy in flywheels and Thermal Energy Storage (TES) systems **[5]**.

These additional systems ask for a sophisticated and efficiently interconnected distribution network than the traditional one which is more of a radial network, distributing power down the power system hierarchy. The distribution infrastructure should also be suitably enhanced to accommodate the huge quantum of DG and DS into the system without causing any adverse impacts to the existing grid.

To ensure seamless integration of DERs and optimal procurement without causing any adverse impacts to the system, there should be a healthy intra-state and inter-state transmission network with sufficient power evacuation capacity. Based on cost incurred for establishing the transmission network, RoI expected and some factors the charges are set for transmission of power through the network lines and allocation of the network for a particular DISCOM or OA consumer is prioritized based on type and duration of power procurement contracts. In India POWERGRID Corporation of India Limited (PGCIL) is the Transmission Network Owner (TNO) and Power System Operation Corporation Limited (POSOCO) is the Transmission System Operator (TSO). This bifurcation of content and carriage came as a result of various deregulation actions taken in line with the Electricity Act 2003, its subsequent amendments and National Tariff Policies and their amendments. This aimed to ensure efficient, smooth and safe operation of the power system with limited but accountable responsibilities for each entity **[4]**, **[5]**, **[12]**.

In the generation side India has more than sufficient installed capacity of generating stations to generate the required power. The generation mix is a combination of various types of energy sources from coal, nuclear, gas etc. to renewable sources like hydro, wind, solar etc. The main challenge of the generation sector in India is not meeting the base demand but the peak demand which occurs in a few instances of the day. At first the generating companies were only government owned either central or state. After deregulation of the power sector, Electricity Act 2003 etc. many private companies entered into the generation of electric power. They were either Captive Power Producers (CPP) generating and consuming their own power or Independent Power Producers (IPP) generating and selling power to consumers. The generators can sell their electricity in two ways. One is through the Power Exchanges in the market which have various options like Day Ahead Market (DAM), Term Ahead Market (TAM), Real Time Market (RTM). The other way is by indulging into Power Purchase Agreements (PPA), contracts etc. with DISCOMS and large Open Access consumers directly **[3]**, **[21]**.

Procurement is generally obtaining goods or services for any business purpose on a larger scale. In case of power procurement, it aims to meet the instantaneous demand (electrical load) with the available supply (electricity generation) at all times. As we know, a proper planning is needed for optimally procuring power and this phenomenon is termed as Power Procurement Planning (PPP). PPP is a strategic process of forecasting the demand and arranging necessary supply resources at specified time ensuring technical, financial, legal and policy constraints are met. The broad steps involved in PPP are given in the **Fig. 3.2** below,

Fig. 3.2 Steps involved in Power Procurement Planning

The first step is demand forecasting which is a process of estimating the future demand based on historical data and analytical techniques. Based on the approach, data and extrapolating techniques used it is classified into various forecasting methods. The next step is identifying the source or the suppliers of the required power. The DISCOMS in this regard can either generate their power through conventional power plants like thermal, hydro, nuclear or renewable installations. The other option for them is that they can purchase from external sources and markets to match their consumer load demand. While carrying out the above process, technical constraints will be taken into account like the ramping and minimum operating limits of their own generators, RPOs, fuel availability, renewable intermittency and demand side fluctuations. In all levels of the power procurement cycle, cost optimization to ensure financial benefits to all parties involved will be an important aspect **[8]**, **[11]**, **[18]**.

Based on these considerations, DISCOMS can choose their own suppliers from whom they wish to procure, listing out terms and conditions thus establishing power procurement contracts with them for specified time periods. This contract includes the quantum of power transacted and cost of the same by evaluating it at the predetermined rate. Depending on the time period of such contracts or agreements signed between the generating and procuring agency the procurement can be classified as given in **Fig. 3.3**.

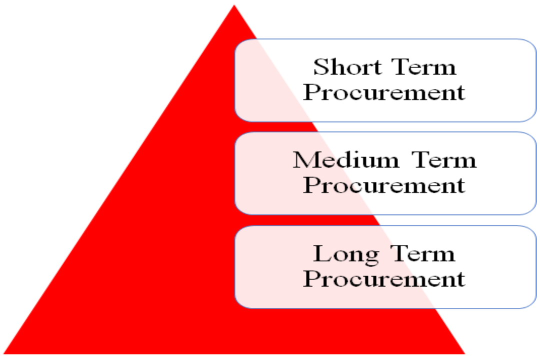


Fig. 3.3 Procurement Types

A summary of the power procurement scenario in India is given in **Fig. 3.4.** It gives the timeline of power procurement from long term till short term along with the various generation types, transmission allocation priorities and specific distribution agencies involved. The long-term power procurement is the most common, simple method of procuring power with minimal risk but while paying huge amount of fixed costs which has to be paid irrespective of quantum of electricity consumed. Now, every Discom would have signed such long-term contracts with Inter State Generating Stations (ISGS) owned and operated by National Thermal Power Corporation (NTPC), National Hydro Power Corporation (NHPC), Nuclear Power Corporation of India Limited (NPCIL) etc. existing for a period of at least 12 – 25 years. The reason for such contract signing is that the fixed and variable cost of electricity supplied by these ISGS would be the lowest possible in the market considering long term and would be a reliable source of supply too. These contracts once signed have corresponding transmission corridors allocated for evacuating the specified quantum for the designated time period. Transmission network charges will be levied based on the MW of power contracted to be evacuated given in Rs./MW. Only state owned Discoms sign such long-term contracts as they would have long term reliable customers on the other hand to supply and it would be an ever increasing demand apart from the financial backup that they have from the state governments. In many cases they operate with minimal profit by giving more importance to social and economic welfare of the customers **[7], [9], [11]**.

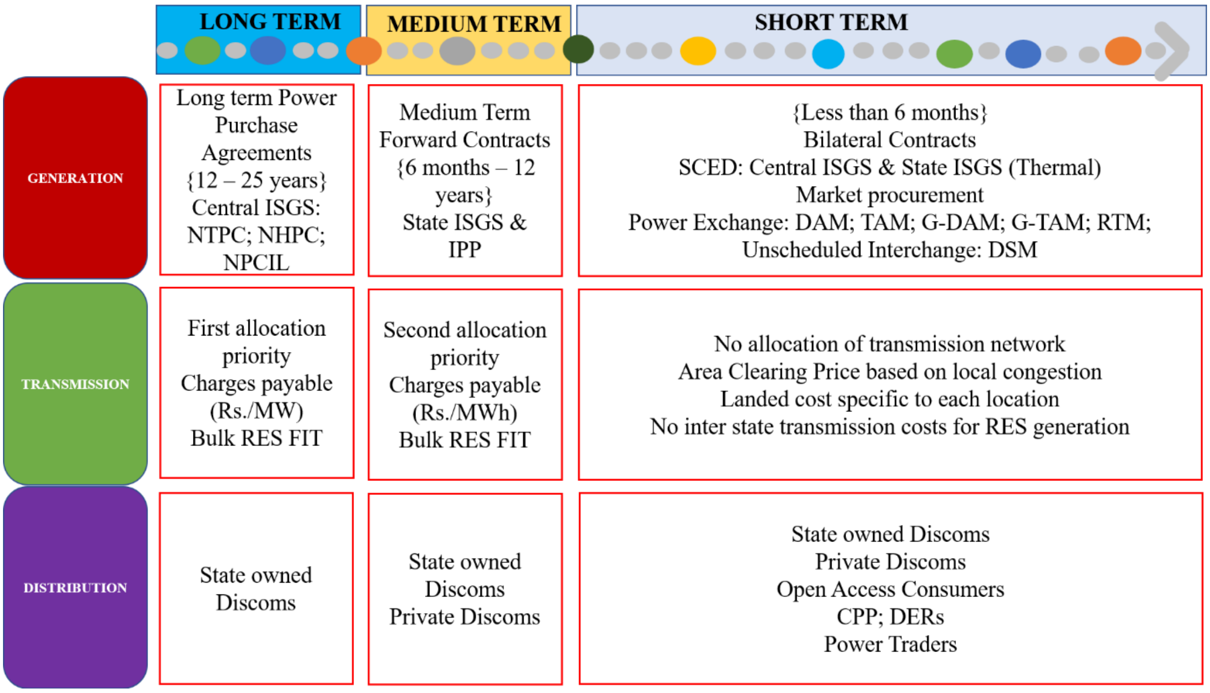


Fig. 3.4 Summary of Power Procurement Scenario – India

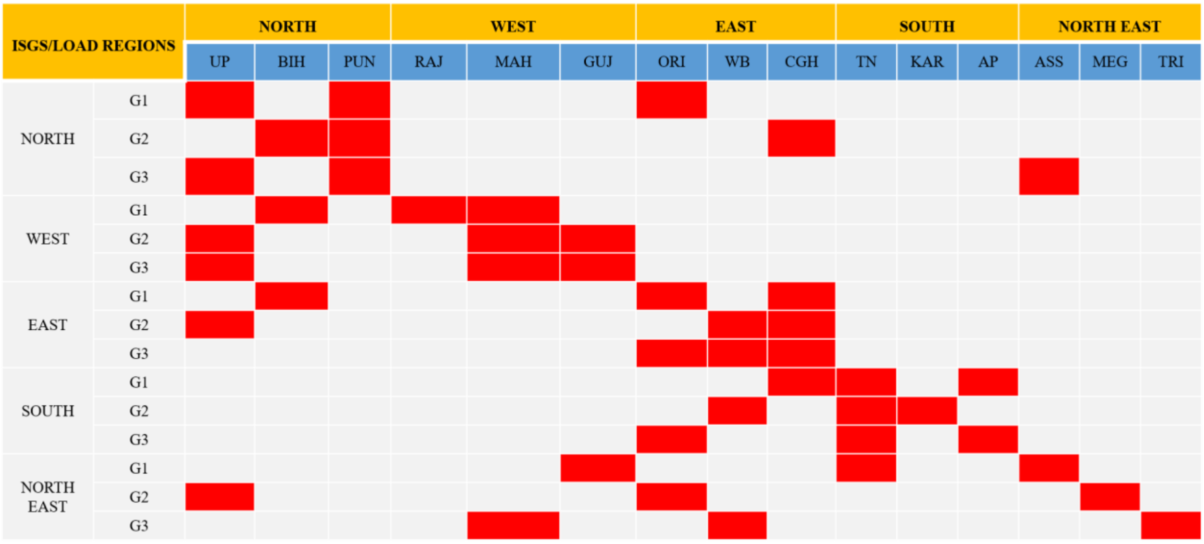
With the integration of RES coming into picture, large number of solar parks which are basically solar photovoltaic panels interconnected for bulk power generation and wind farms which consists of numerous wind turbines constructed in a specific orientation within the given area. The generation from such solar parks and wind farms are integrated to the transmission network after appropriate power conversions and this quantum is comparable to conventional power plants generating electricity. To recover the costs of establishing such large RES power generation plants and to promote the usage of such intermittently available but free and clean electricity, long term contracts are signed by Discoms with these generating companies at a particular rate known as the Feed In Tariff (FIT). Such FITs even though encourages more and more venturing into RES generation business, such long-term contracts are a point of concern for the Discoms as the cost of such RES generation will decrease drastically with the introduction of newer technologies and a greater number of such generators.

In the medium-term scenario, contracts would be signed between the various parties involved for a comparatively shorter time than the long-term scenario, say for a time period between 6 months to 12 years. Forward or derivative contracts are the most popular form of transactions in this scenario, but due to the regulatory dispute between two statutory bodies viz., Central Electricity Regulatory Commission (CERC) and Security Exchange Bureau of India (SEBI) these contracts were not used for electricity transactions in the market. Derivative contracts are those that derive their values from underlying asset, index or an interest rate and are signed between two or more parties. A forward contract is an example of derivative type contract which is usually signed between two parties to transact a commodity at a specified price in a future date. In October 2021, this dispute was settled by a verdict from Supreme Court of India by allocating all the physical delivery forward contracts under CERC and financial derivatives under the jurisdiction of SEBI. Till date, there are no financial derivative contracts available in the market and only physical delivery-based contracts are traded in power exchanges. Such contracts also require allocation of transmission network for evacuation and are given second priority in network allocation after the long-term contracts are allocated. Apart from the bulk RES generators that sign specific quantum at FIT, the rest of the conventional generation based contracts have to pay a transmission charge in Rs./MWh depending on the usage of the line. In these scenarios, some private Discoms also participate and procure power through such contracts along with the state owned Discoms, as they take up the responsibility of distributing power inside the balancing area of state Discoms, say like major cities of New Delhi, Mumbai etc. for which they have to procure their own power **[7]**.

In short term scenario, the other two procurements discussed above in medium- and long-term cases, impact the portfolio mix. This is because the contracts signed for long term or medium-term cases has to be respected before adopting any short-term procurement options because the fixed cost quantum has to be paid anyway irrespective of the quantum consumed. One more important constraint will be from generators point of view like, if many of the consumers violate the signed contract quantum then it will be difficult to maintain the plant load factor of the conventional power plants. In India, the short-term procurement quantum is increasing with the introduction of market mechanisms and increasing share of RES quantum in the generation mix. There are bilateral contracts signed directly between generators and Discoms apart from those signed between Discoms based on energy exchange during different months due to geographical variations and weather patterns faced by each of them. A major chunk of the short-term transactions occurs through the power exchanges only via the various market mechanisms offered in them. Day Ahead Market is the most common mechanism followed by Term Ahead Market which in turn has 4 types of contracts in it, able to sign contracts for power delivery in a time duration from 3 hours up to 11 days ahead from any instant of time. For power delivery after an hour, a new market mechanism was introduced in 2020 called Real Time Market. To promote RES generation and to help the Discoms satisfy the RPO mandates separate markets for RES generation were introduced in the form of Green Term Ahead Market in 2020 and Green Day Ahead Market in 2021. With the quantum of DERs increasing and introduction of more flexible loads and sophisticated control systems enabling demand response programs etc. there are talks of a separate Ancillary Services Market being introduced in recent future **[3], [13]**.

In 2018, the POSOCO introduced the pilot project for Security Constrained Economic Despatch (SCED) aiming to fully utilize the unscheduled power available at low variable cost from ISGS generators. The despatch in this mechanism would be based on MERIT order ensuring the transmission constraints are taken into account. There is a mandate for all the ISGS, as of now the thermal ISGS only, to participate in this common pool of despatch nationally managed by the NLDC. This mandatory participation has led to the establishment of a Reserve Regulation Ancillary Services (RRAS) mechanism that can assist in the safe operation of national grid. The SCED pilot project was aimed at optimizing the despatch of approximately 150 ISGS generators for the 15-minute time block period. In India, there are ISGS located at various locations across the country, like near the coal reserves, port cities etc. and so they have to be despatched to the load centres that maybe located in some other region of the country far away from their location. Due to various reasons like prevailing weather conditions the load demand differs in each state from what was predicted during scheduling each generator despatch. So, there will be changes in the drawl of states and this additional surplus would be usually bought through short term markets or through DSM which is costlier than the undispatched quantum that is available in ISGS generators. Thus, the major objectives of the pilot SCED project were optimizing the scheduling and dispatch of generators respecting the system wide operational constraints and improving the flexibility of meeting the demand variability starting from low-cost generators available. An example summary of the location of ISGS generators and allocations to specific load regions can be given as follows in **Table 3.1. [9]**

Table 3.1 An example summary of location of ISGS generators and allocations of load



One more important method under which procurement in short term is done is the Unscheduled Interchange (UI) mechanism, which is the deviation in actual drawl from the scheduled one. The previous UI mechanism allowed for specified over and under drawl by consumers and injection by generators. But the main drawback with that was the stakeholders were taking advantage of the rebates being given in the UI mechanism and going for wider deviations irrespective of the system frequency with only focus on financial benefits. So, a Deviation Settlement Mechanism (DSM) with rate based on system frequency at any instant of time was introduced in 2014. A cap was set for the maximum allowable over and under drawl through DSM at 12% of the demand for any consumer with rebate for under drawl when system frequency is less than rated value. This mechanism is being updated to tighten the frequency range in which the grid is operating, with the latest target range being 49.90 to 50.05 Hz. The DSM slab rates based on system frequency are given in the **Table 3.2** below **[6]**.

Table 3.2 DSM Rate for different frequency values of the grid

Frequency (Hz)	DSM Rate (Rs./kWh)	Frequency (Hz)	DSM Rate (Rs./kWh)
49.3	8.24	49.88	4.28
49.7	8.03	49.89	4.07
49.71	7.82	49.9	3.86
49.72	7.62	49.91	3.66
49.73	7.41	49.92	3.45

49.74	7.2	49.93	3.24
49.75	6.99	49.94	3.03
49.76	6.78	49.95	2.82
49.77	6.57	49.96	2.61
49.78	6.36	49.97	2.41
49.79	6.16	49.98	2.2
49.8	5.95	49.99	1.99
49.81	5.74	50	1.78
49.82	5.53	50.01	1.42
49.83	5.32	50.02	1.06
49.84	5.11	50.03	0.712
49.85	4.91	50.04	0.356
49.86	4.7	50.05	0
49.87	4.49	50.06	0

It can be seen from the above table that the DSM rate increases as the frequency decreases more from the rated value of 50 Hz. This discourages the consumers from drawing more power than scheduled through DSM when system frequency is less than 50 Hz thereby supporting stable system operation at rated frequency.

In the short-term power transactions through such mechanisms discussed above the main point to be noted is that there is no transmission line allocation done. After line allocation for long term and medium-term contracts are done the remaining line capacity is used for short term transactions. In the market clearing mechanisms and in SCED the system operational constraints, congestions in particular areas etc. during evacuation are taken into account and they are reflected in the form of area clearing prices and landed cost at the specific location. The interstate transmission costs are waived off for RES generation until 2022 as per CERC order in order to promote the generation through RES like solar and wind and to maximize the profit attained by such generators so that more individual developers would be motivated to get involved in RES generation business. This will help in achieving the target of meeting 50% demand through RES generation by 2030 **[3], [13]**.

Now with the introduction and gaining popularity of short term power transactions, apart from the Discoms owned by state and private, customers directly prefer open access to power from markets or from generators. With market mechanisms being easier to handle and allowing third party access, agencies that deal with electricity as a business also are now participating in trade. Such power traders buy electricity through any of the market mechanisms available and supply them to Discoms or any consumer with a profit margin. Apart from these, consumers are now becoming prosumers i.e., they install DERs in their own area and consume electricity for their own use and sell the rest in the market or to the Discoms. Some industries do this on a larger scale to suffice their total load demand and are called Captive Power Producers (CPP) and while they commercially sell the power to other consumers through any mechanism available, they are called Independent Power Producers (IPP). All these are newer market options and methodologies that come into existence along with the development in the short-term power transactions. They are backed by different kind of regulatory and policy initiatives specific to each country and so are in different stages of evolution globally. But we can clearly see that short term power procurement will be the future of power management in any level of power system hierarchy.

From the above discussion we can understand that whatever transitions that happen in the power system due to the RES integration, the corresponding changes in policy directives etc. the companies that are involved in transmission, distribution and generation business are the ones directly impacted. So it is important to know how these companies function in the existing grid and what changes they would have to undergo due to the evolving changes in the system.

CHAPTER 4

TRANSMISSION AND DISTRIBUTION COMPANIES IN SHORT TERM PLANNING

Generally, the focus in power procurement portfolio goes into the scheduling of available generators economically and what type of fuel is used for generation, the quantum of RES integration etc. But the other side which is often failed to gather attention is the transmission and distribution sectors and the companies involved in the same. In India, considering any state, the state owned Discom would be the nodal agency to manage the power procurement to meet the state demand. This may be a single company as in the case of Tamil Nadu or multiple companies handling specific locations of the state say 3 as in Rajasthan. There is a separate STU which deals with the transmission network establishment, its operation in coordination with the state load despatch centre and the maintenance of the same. Such transmission and distribution companies deal with many factors that add up to their total expenditure in operating to meet the demand posed by their consumers while also tackling the various challenges in procuring the required power or generating them on their own.

Apart from the challenges posed by huge RES quantum if generation that is integrated into the existing system, the Discoms and the transmission companies have to ensure the smooth transition from the traditional phase of grid to the evolving smart grid features. In India, the smart grid transition started way back in 2010 with the establishment of India Smart Grid Task Force (ISGTF) and India Smart Grid Forum (ISGF). They worked on the installation of smart meters instead of the traditional ones and implementation of pilot smart grid projects across the country. With the establishment of National Smart Grid Mission (NSGM) in 2015, the transition into smart grid was more streamlined and took pace. The Discoms in the state had to take the responsibility of facilitating all the necessary infrastructure and operational changes demanded by the smart grid transition. Many Discoms did not have the necessary financial and technical expertise to involve in this transition **[4], [5]**.

4.1 Financial Implications

A Tariff Order (TO) of a Discom, is a complete reflection of its performance over a period of time. This TO usually consists of two important parts, truing up of the previous years expenditure and income of the Discoms along with the Aggregate Revenue Requirement (ARR) for the upcoming years based on the predicted demand to be met by specific procurement from the available options. There are separate TO being calculated for the

Discoms including their own generation, TO for transmission company, TO for RES generation in the state and finally TO for the operation of State Load Despatch Centre (SLDC) and other miscellaneous charges. The organizations that are involved in the TO determination are the State Regulatory Commission along with the CERC, a State Advisory Committee (SAC), the Discoms and the transmission companies along with the public and other stakeholders involved. The guiding principles for TO determination include the Electricity Act 2003 and its amendments, National Tariff Policy which is being periodically updated from 2006, State Regulatory Commission Regulations along with the central regulations on power procurement from new and renewable sources, open access etc. Apart from this there would be state specific considerations like unbundling of the Discoms, the current financial status of it etc.

The annual balance sheet of the Discoms would be known from the TO, and this includes the true up of the previous years' accounts. This balances the approved ARR and the Revenue income with the total expenditure to arrive at the Revenue Gap and the Regulatory Assets (RA). With this available information the ARR for upcoming years are determined taking into account the existing revenue gap and RA along with the total proposed expenditure and energy sales in those years. The major factors that contribute to the ARR are given in **Fig. 4.1**. Once the ARR is calculated then the specific TO for various categories of consumers and sub utilities under the main Discom **[16], [17]**.

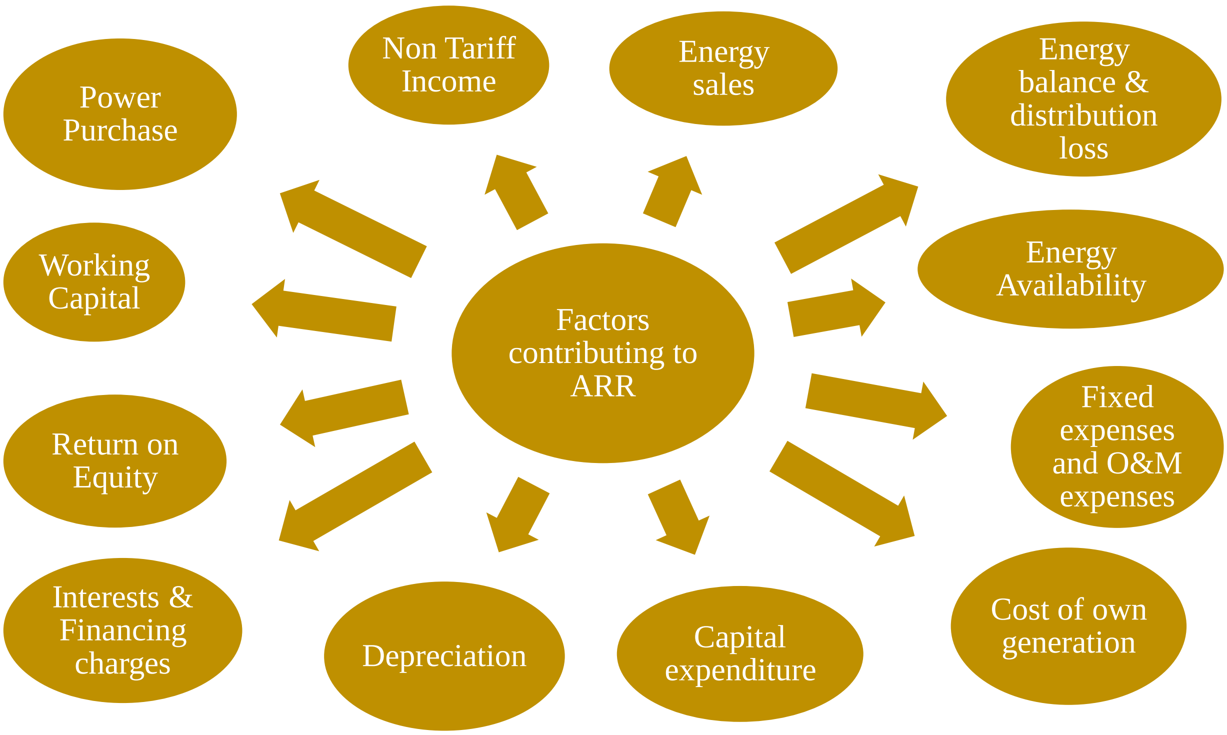


Figure 4.1 Factors contributing to Aggregate Revenue Requirement of Discoms

Whatever expenditure is incurred to the Discom in regards to power procurement to meet the demand is reflected in the ARR. Now the income to the Discom should balance this ARR with its total income and for that purpose the tariff for the various consumers and sub utilities and determined accordingly so that entire ARR is met or atleast the difference in Revenue earned and ARR is minimal. The tariff for various categories of consumers is calculated by a sequential process as depicted in **Fig. 4.2**. This might be slightly different for each Discoms due to involvement of the various stakeholders and the decisions made by state regulatory commissions.

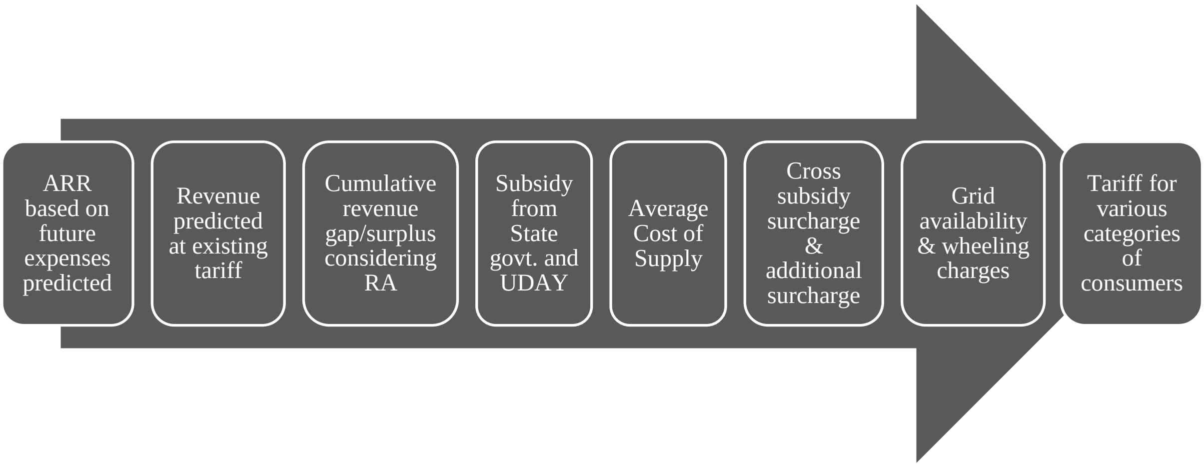


Figure 4.2 Tariff determination process adopted by Discoms

For the usage of transmission lines there are specific charges to be paid by the Discoms and the open access consumers except for the RES quantum transacted as the charges for them are waived off as per CERC regulations until 2022. As of now the Discom itself or in some cases a separate company handles the transmission business in the states. The important factors that contribute to the transmission charge determination are given in **Fig. 4.3 [16], [17]**.

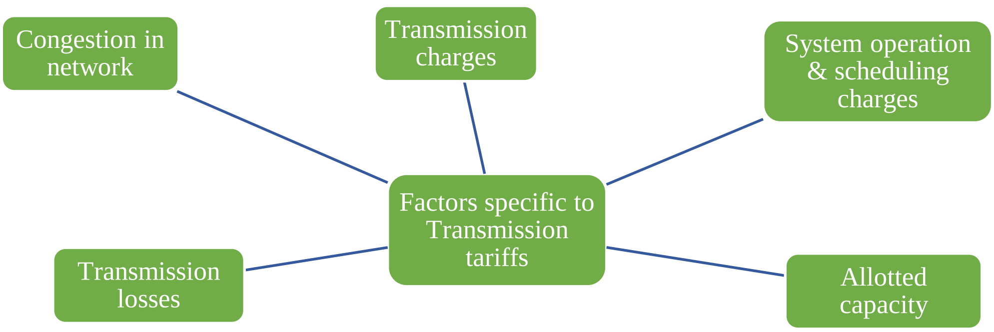


Figure 4.3 Factors constituting transmission tariff

Apart from these for the procurement of RES generation quantum from private or other state generators, there are usually three methods available. One is through preferential tariffs set by the state regulatory commission, the other is through competitive bidding process conducted by the Discom itself among the generators wishing to sell power and finally through power exchanges in the market.

4.2 Technical Implications

Apart from the financial constraints that the companies face, due to the huge quantum of RES integration into the grid there are many more technical challenges to be dealt with by the Discoms. Due to the increasing RES quantum the Discoms have to deal with temporal variability, output uncertainty and geographically specific availability in the power procurement portfolio. Their impact on the system operation can be classified under short term and long-term scenarios as given in **Fig.4.4**. From this we can infer that in the short term scenario to deal with the varying nature of RES generation flexibility support is mandatory. This flexibility is also important for the normal stable operation of the power system safeguarding it from disturbances and faults, ensuring power quality.

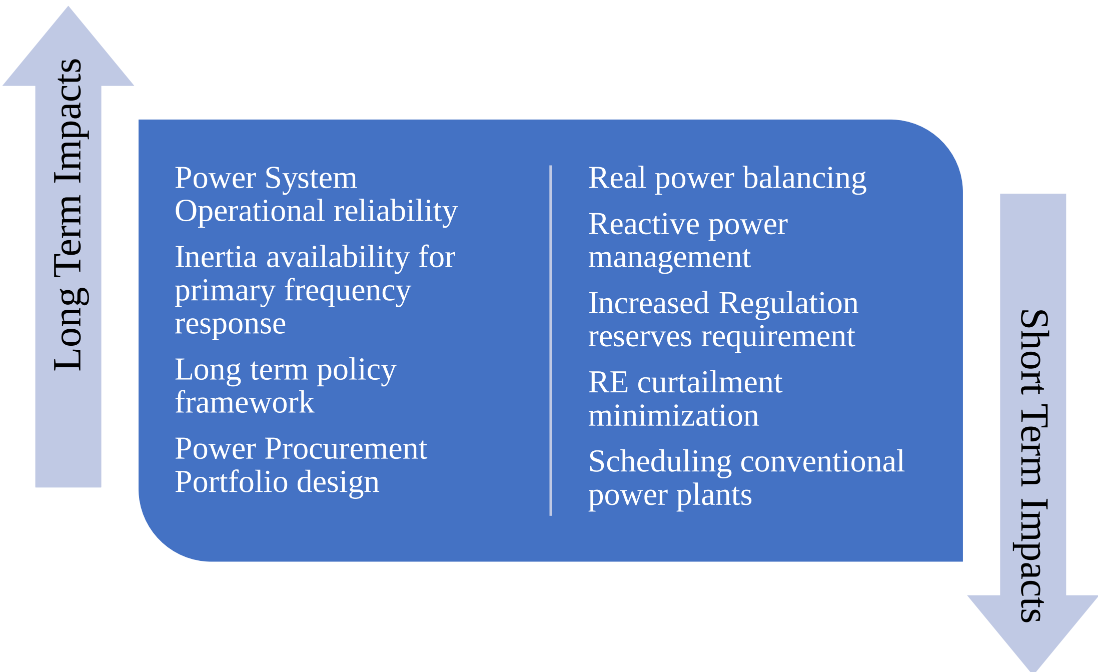


Figure 4.4 Technical Impacts of RE integration on procurement portfolio

Over the time due to the increasing quantum of RES in the overall energy mix, the reliability of power supply will be in check as the generation from RES are intermittent and weather dependent. The conventional power plants have huge synchronous generators which by its inbuilt features exerts significant inertia which indirectly offers primary frequency response in times of contingencies. Now, with the increasing solar and wind generation the number of conventional synchronous generators operating in the system are decreasing. This is due to the fact that thermal power plants are being shutdown as their life time gets exhausted and some even before their lifetime due to multiple factors, without any new plants having upcoming COD. This naturally decreases the primary frequency response from such generators during sudden contingencies like loss of transmission lines due to faults, generator failures etc. Now with power converters available with both and wind and solar generations, they can be reprogrammed and operated in such a way that they mimic the behaviour of synchronous generators and emulate their spinning action. Similarly, battery storage systems when available in bulk, can be used to provide fast frequency response and inertia in times of contingencies. Such a method of providing inertia using the available DERs is called synthetic or digital inertia. So, the Discoms should look for such new methodologies in near future to ensure that the RES integration can be well managed at any kind of contingency situation. The mandates and targets set for the renewable energy requires a strong policy framework supporting their integration into the existing system with the future procurement portfolio including a substantial quantum of RES generated power at all time blocks **[4], [5]**.

In the short-term scenario, the major point to be noted would be the load following which is the usual method of operation in the conventional power system. Now, with the solar and wind generation that are dynamically varying with time and weather conditions this is difficult to ensure and so the load also should be made able to follow the generation. For this purpose, there should be sophisticated demand response possible and also there should be sufficient back up in the load side through energy storage or other DERs. So, with the integration of RES such requirement for flexibility services for grid balancing and even for voltage instability mitigation and increasing manifold. With the wind and solar generation using power converters the quantum of reactive power handled is also increasing due to which optimal reactive power management in the transmission and distribution grids is important **[3]**.

Due to the one among the following factors or more than one, such as errors in renewable energy generation forecasting, sudden weather anomalies, operational constraints of conventional power plants, insufficient capacity of transmission lines to evacuate the generated power, at times there might be a necessity to curtail the available RES quantum. Such curtailment results in free of cost power from greener, cleaner sources being wasted and, in their place, costly power from any other conventional source like coal or gas being used.

Curtailing the available RES generation is not only financially but also technically not an optimal but inefficient way of operating the power system as it might lead to more pressure on the ramping limits of the conventional power plant generators. So, the Discoms or the system operators should always ensure that the conventional power plant scheduling are done in such a way that there is no curtailment of the energy available from RES.

As discussed above, due to the changes in the existing power grid both the transmission and distribution companies have to change their existing practices of system operation and go for new, more adaptable operational behaviours to include the transitions that are happening in the system. Apart from the integration of bulk RES into the system there are DERs like solar roof top photovoltaic panels, distributed energy storage, electric vehicles etc. that come into the picture at the far end of the distribution system. A Discom for short term power management has to predict the quantum of such resources that would be integrated in near future and the behaviour of already existing such resources.

CHAPTER 5

RENEWABLE ENERGY SOURCES INTEGRATION INTO THE GRID

In a geographically vast country like India, there is significant availability of Renewable Energy Sources (RES) that can be harnessed for electricity generation **[1], [2]**. The problem with these sources is their uncertainty and intermittency which makes their availability dynamically varying with time. The major RES that contribute for bulk of power generation are given in **Fig. 5.1**.

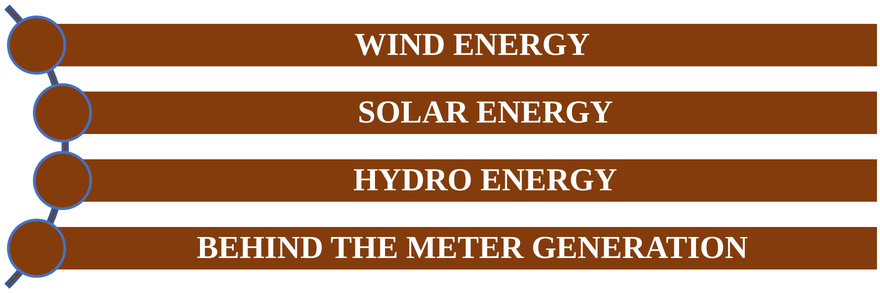


Fig. 5.1 Types of RES integrated to Grid

These RES are not only intermittent over time but also are geographically spread over the vast land and water bodies of the country. In some states of the country, they are available in huge quantum where the Discoms should additionally take care to procure backup reserves in case of sudden drop in their generation or ways to sell or store the excess generation in case of low demand with curtailing them. So, for such RE rich Discoms there is a need to properly plan the power requirement and means of meeting that in short-term scenario to ensure reliable and cost-effective operation of the whole system **[2]**, **[12]**.

5.1 Wind Energy

Wind energy is an intermittent source of energy coming from the moving air across the globe caused by the sun's uneven heating of the surface. So, it varies from each location and its potential must be known before deciding whether or not to install wind turbines in that particular location. To monitor the wind flow and estimate the potentials at various hub heights monitoring stations have been set up by National Institute of Wind Energy. India has a potential of 302 GW from wind energy at a hub height of 100m. As of today 40 GW of wind generation is installed in the country with future target of 60 GW by 2022. The potential for wind generation in various states of the country and their corresponding installed capacity of wind generation as of March 2021, is given in **Table 5.1**. From this we can see that only a minimal portion of the total existing potential from wind energy has been harnessed. The reason for this being the additional civil and mechanical support structures that are required to establish a wind generator along with the potential sites for establishment being in remote areas making construction and obtaining clearances difficult **[9], [22]**.

Table 5.1 Potential and Installed capacity of wind generation in windy states of India

S. No.	State	Potential (GW)		Installed Capacity (GW)
		100 m hub height	120 m hub height	
1.	Gujarat	84.43	142.56	8.6
2.	Rajasthan	18.77	127.75	4.3
3.	Maharashtra	45.39	98.21	5.0
4.	Tamil Nadu	33.79	68.75	9.6
5.	Madhya Pradesh	10.48	15.40	2.5
6.	Karnataka	55.85	124.15	4.9
7.	Andhra Pradesh	44.22	74.90	4.0

One more problem with the wind generators construction is the hub height at which the potential is there to harness maximum energy from wind. We can see from the above table that the construction has to be made at heights of atleast 100m or 120m which itself makes a significant difference between the two, in the available potential. In India these 7 states are the ones containing maximum potential for wind energy generation and the corresponding installed capacity is also given as of March 2021. We can see the coastal states of Tamil Nadu and Gujarat lead in the installed capacity of wind energy generation. Even with this much quantum of installed wind generation it is still merely 14.6% and 6% of the total potential that can be harnessed. So we can see that the target set for wind energy can be easily achieved, provided more focus is given to the policy framework for wind energy generation establishments in these states with high potential, making the clearances for construction and other regulatory and monetary support for the developers.

There is huge potential for offshore wind energy along the coastal areas of Gujarat and Tamil Nadu and there is a target to install 30 GW offshore capacity by 2030. The problems with such huge quantum of wind integration is that they are almost entirely private owned backed up by government support schemes like allowing for accelerated depreciation, waiving off excise duty and cutting of transmission charges until 2022. Even after such benefits the private generators mostly do not establish their own storage systems as per their need but rather rely on energy banking services from the grid. They also need start up power and might have problems with reactive power management also based on the type of generator used in the wind turbine. So, all these factors have to be accounted for when considering wind generation. To mandate the consumption of wind generation there are specific targets being set to Discoms and other individual open access consumers in the form of Renewable Purchase Obligations (RPOs). Currently as per latest regulations Non-Solar RPO target set by India is 10.5% to be achieved by 2022 **[9]**, **[24]**.

5.2 Solar Energy

Solar energy is abundantly available in India especially it is maximum in states of Rajasthan and Karnataka. Till today, around 48 GW of solar photovoltaic power generation has been installed including ground mounted and roof top generators. Apart from this there are numerous off grid installations, solar water pumps for agriculture, solar lanterns and solar water heaters being used. The future target for solar energy is 100 GW grid connected solar by 2022, with 60 GW from ground mounted and 40 GW from roof top installations. In India the Solar Energy Corporation of India (SECI) and National Institute of Solar Energy (NISE) look into the solar installations. The potential for solar generation in various states of the country and their corresponding installed capacity as of March 2021, is given in **Table 5.2**. From this we can see that only a minimal portion of the total existing potential from solar energy has been harnessed. The reason for this being the huge land area required for installations and their corresponding maintenance which would be challenging for small private developers. Also lack of clarity with regards to the net metering and gross metering concepts for commercial solar developers in many states due to the state specific policies and regulations on the same hinder new entrants.

Table 5.2 Potential and Installed capacity of solar generation in different states of India

S. No.	State	Potential (GWp)	Installed Capacity (GW)
1.	Gujarat	35.77	5.7
2.	Rajasthan	142.31	7.7
3.	Maharashtra	64.32	2.4
4.	Tamil Nadu	17.67	4.7
5.	Madhya Pradesh	61.66	2.6
6.	Karnataka	24.70	7.4
7.	Andhra Pradesh	38.44	4.4
8.	Jammu & Kashmir	111.05	0.042
9.	Himachal Pradesh	33.84	0.061

Similar to wind energy generation, we can see the total potential is far from harnessed in solar energy case too. So, the targets set for solar energy by 2022 and 2030 is easily achievable provided the private developers are supported through appropriate financial and policy means. They should be ensured with return on investment at the earliest possible so that more and more developers would come into the generation business. Also, the net metering and gross metering policies are being streamlined in all the states which would further bring clarity among the developers regarding the commercial tie-ups to me made with the Discoms or directly go for market mechanisms that are available. As per the latest amendment to the Electricity (Rights of Consumers) Rules 2020, the centre has allowed for net metering for roof top solar installations up to 500 kW or the sanctioned load, whichever is lower and gross metering for all capacities above 500 kW **[9], [22]**.

The major problem with solar generation in India is that the country has a morning and evening peak in load demand whereas the solar generation peak is in midday when demand is low. So, this forces either to install suitable energy storage systems or curtail the excess solar generation. Apart from this due to the huge quantum integrated into the grid it creates stress on the ramping limits of the conventional thermal generators and also reduces their plant load factor. So these factors must be addressed to ensure a smooth hassle free integration of the planned huge quantum of solar generation into the existing grid. Similar to wind energy case, for solar the RPO is set at 10.5% to be achieved by 2022. When Discoms cannot meet these RPOs directly by purchasing RE they can balance that by procuring Renewable Energy Certificates (REC) from the electricity market, where 1 REC equals to 1MWh of energy consumed from RES generation **[9]**, **[24]**.

5.3 Hydro Energy

Hydro energy is the potential energy of stored water in dams being converted into electrical energy by moving them over turbines. Based on the size of the turbine and generators they are classified as small and large hydro. Small hydro power projects are those that are less than 25 MW in size. Large hydro power plants require huge area of land to be cleared for dams and the power stations to be built resulting in displacing the people, their resettling and rehabilitation, clearing of the forest areas etc. Considering such reasons there were debates going on whether to classify them as RES or not. But government recently declared large hydro projects also as RES with which the entire installed capacity has now increased to 52,300 MW. Along with this there was a Hydro Purchase Obligation (HPO) separately introduced which now stands at

0.18%. The installed capacity of small and large hydro power generation state wise as of March 2021, are given in **Table 5.3**.

Table 5.3 Installed capacity of small and large hydro generation state wise in India

S. No.	State	Small Hydro (MW)	Large Hydro (MW)
1.	Gujarat	35.1	1990
2.	Himachal Pradesh	860.61	9809
3.	Maharashtra	375.57	3047
4.	Tamil Nadu	123.05	2178
5.	Madhya Pradesh	95.91	2235
6.	Karnataka	1230.73	3644
7.	Andhra Pradesh	162.11	1610
8.	Uttarakhand	214.32	3756
9.	Jammu and Kashmir	179.03	3360
10.	Telangana	90.87	2405

The marked difference can be seen in the installed capacity of small and large hydro power which is why there was a significant increase in the overall renewable energy generation capacity once the large hydro power plants were considered as renewables. The cost of generation from hydro power is very less compared to other conventional methods because the fuel here is free of cost. So only the fixed cost would be included in the tariff which is also very less comparatively as the life time of a hydro power station is between 50 - 80 years or even more. With the HPO set at 0.18%, which is expected to increase in the coming days, Discoms would find it comparatively easier to meet it than the solar and non-solar RPOs as hydro power generation is already predominant among the state Discoms. This would help in achieving the target set by India, of meeting 50% of the load demand with renewables by 2030 **[9]**, **[24]**.

The drawback with hydro generation is that it can be utilized only when there is water available in the dams with the exception of pumped hydro power plants. Pumped hydro plants have two reservoirs one up and one down the stream and they can pump water from downward reservoir to the upper reservoir during times of low demand. During peak demand they normally function as hydro generators taking water from upper reservoir. During times of low demand, they pump water from the lower reservoir to the upper reservoir thus contributing to the grid load. Normally the hydro power plants would be used as peak load plants only as they can be started quickly without any start up time. Similarly they do not have any minimum up time once they are turned on for generation and they can be shut down once the demand goes low suitable to be met by base load plants. Their biggest advantage is their high ramping capability which is 100% for pumped hydro, so they are regarded as Fast Response Ancillary services (FRAS) and are used to balance the system in times of contingencies **[9]**, **[24]**.

5.4 Behind the meter generation

This includes the off-grid generation in the form of roof top installations maybe along with some storage systems. The demand response programs which are increasing nowadays with the introduction of smart meters and Home Energy Management Systems (HEMS) also play a major part in behind the meter power management. They contribute to the load variability indirectly as the consumer draws power from the grid based on his available generation from solar and his demand that can be controlled. One more aspect to be noted is that, as already discussed there are two mechanisms to account the energy in a prosumer's premises. Net metering and gross metering. Based on the sanctioned load limit or 500 kW load, net metering is applicable which is kind of more beneficial to the consumers than the Discom. But for larger prosumers and bulk consumers gross metering is applicable which has two different accounts for consumption and injection, both at different tariff. When this happens in huge quantum due to the increasing roof top PVs and smart grid roll out programs resulting in more intelligent consumer behaviours, it creates challenges for the Discoms to properly predict the demand and plan their power procurement **[12]**.

From the above discussion, the major point of concern is that how these resources that are uncertain and intermittent in nature would be integrated without causing any adverse impacts to the existing system and its stakeholders. For this purpose there should be accurate forecasting done on the availability of these resources and on the existing power procurement methodologies and contractual practices that are being followed.

CHAPTER 6

POWER PROCUREMENT – FORECASTING & EXISTING CONTRACTS

6.1 Demand Forecasting

Demand forecasting is a mandatory requirement for efficient power procurement both in short term and long-term scenarios since electricity has different characteristics when compared to material products and it cannot be stored directly for later use. The demand pattern is more complex these days after the deregulation of the power system and introduction of new generation technologies like Distributed Energy Resources (DERs), smart grid, Electric Vehicles (EV), Energy Management Systems (EMS), Demand Response (DR) programs etc. along with the increase in population and improvement in living standards. The accuracy of this forecasting is very important for cost saving, safety and reliability of grid operation and future infrastructure development of the system. A summary of the different forecasting methods based on control time period are given in **Fig. 6.1 [7]**, **[8]**, **[11]**.

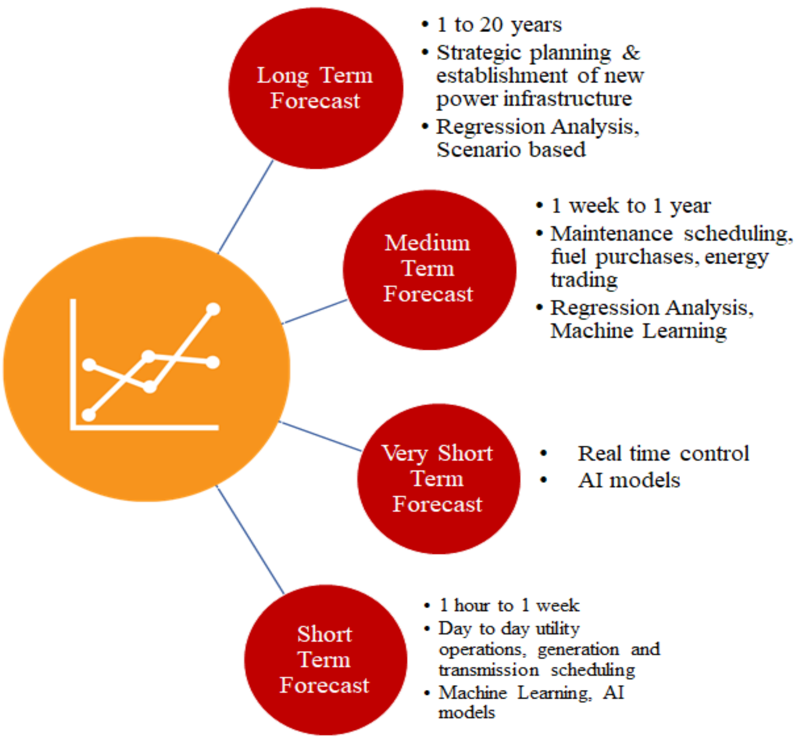


Fig. 6.1 Summary of forecasting methods based on control time period

These forecasts are carried out by using various techniques or models that differ based on parameters used and data available, thus giving a varied accuracy in the forecasting results. Based on the use of the forecasted data and cost considerations, the type of forecasting model can be decided. They are broadly classified into two types as shown in **Fig. 6.2 [7]**, **[8]**, **[11]**.

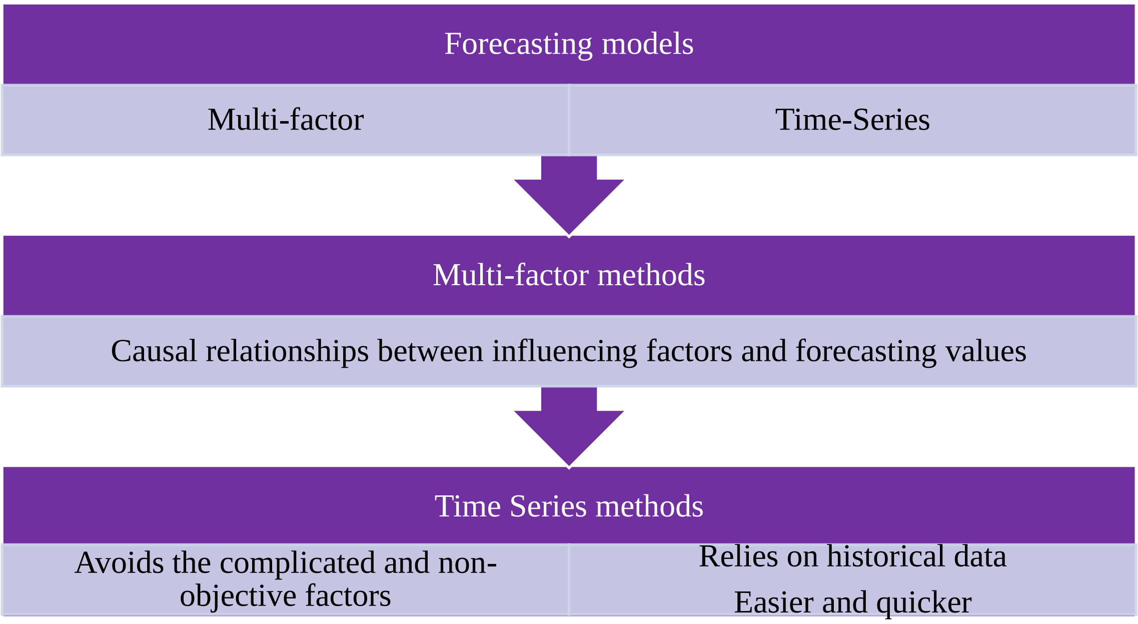


Fig. 6.2 Basic classification of demand forecasting models

Based on the duration of forecast, the models are classified into medium, long term forecasting methods and short-term forecasting methods. End use method and Econometric method are the ones that are usually used for medium and long term forecasts. End use method takes into account the uses of electricity in the residential, commercial, and industrial sector etc. where the demand is derived from customer's demand for light, cooling, heating, refrigeration, etc. Demand is treated as a function of the number of appliances in the market. Meanwhile in the econometric method, which is a more advanced one used recently, it combines economic theory and statistical techniques and estimates relationships between energy consumption (dependent variables) and factors influencing consumption (independent variables). A summary of the two methods along with the differences are given in **Table 6.1**. The 19th Electric Power Survey of India which gives the demand profile state wise and national level adopts the econometric method off late which is close to real scenario than the end use method which is more of predicting based on hypothesis.

Table 6.1 Long and Medium Term Forecasting methods [7], [11]

ECONOMETRIC APPROACH	END USE METHOD
Econometrics is the integration of economics, mathematics and statistics	Bottom-up approach & mostly under forecasts the demand
Obtains values of parameters that are coefficients of mathematical form of economic relationships	Requires analysis of utility function of consumers belonging to every segment
Statistical methods which help in explaining the economic phenomenon are adapted as econometric methods	Focus on final needs at a disaggregated level and aggregates demand by consumer categories

Used to find stochastic relationship in mathematical format	Demand calculated based on the use of various electric appliances
Relevant variables are used in model and rest are dumped as disturbances or random variables	Incorporates energy efficiency improvements & changes in energy-mix
Mathematical model is exact while statistical model contains a stochastic term	Future values of saturation are forecasted exogenously using economic & demographic variables
Model consists of (i) set of equations containing observed variables (ii) statement about errors in observed values of variables (iii) specification of probability distribution of disturbances.	Past surveys identify current position on curve and future saturations are extrapolated from there
Data types used in estimation: Time series, Cross section, Panel & dummy variable	Suitable for both energy and power demand forecast

These methods are not suitable for short term forecasting for which there are specific methods are used which are listed in **Fig. 6.3** below. Regression models are the most commonly used ones for short term forecasting and there are various regression methods available. Other methods like neural networks, fuzzy logic and statistical algorithms are advanced methods that are complex but give accurate results.

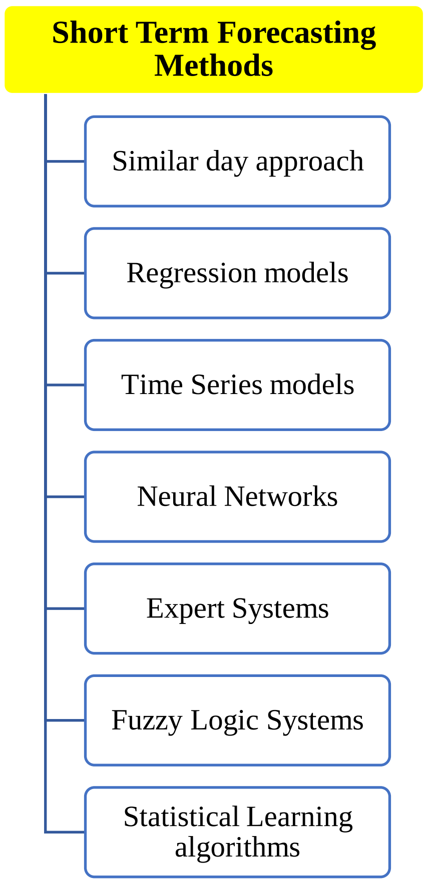


Figure 6.3 Short Term Forecasting methods

Once these demand forecasts are available, they have to be interpreted in a suitable form say as load profile or load duration curves so that they can be helpful in deciding the procurement portfolio. In short term forecasting some error factor can be considered and prior back up sources to procure from can be decided to avoid last minute contingencies resulting in load shedding or deviation from schedule **[13]**.

6.2 Renewable Energy Potential Forecasting

Similar to forecasting the demand pattern, estimating the available generation from RES is also equally important. This is because, only if the Discoms know the approximate generation that would be available from say solar and wind resources it can plan the procurement from rest of the available sources. This has two benefits like utilizing the low-cost power without curtailing it and also reducing the stress on ramping limits on conventional generators at the last moment. For forecasting the generation many factors such as temperature, humidity, air quality, hub height of installation for wind turbine, tilt angle at which the solar panel is installed etc. There are forecasting models available specifically for wind and solar energy. The basic data used by any forecasting model to develop wind or solar forecast are given in the **Fig. 6.4** below.

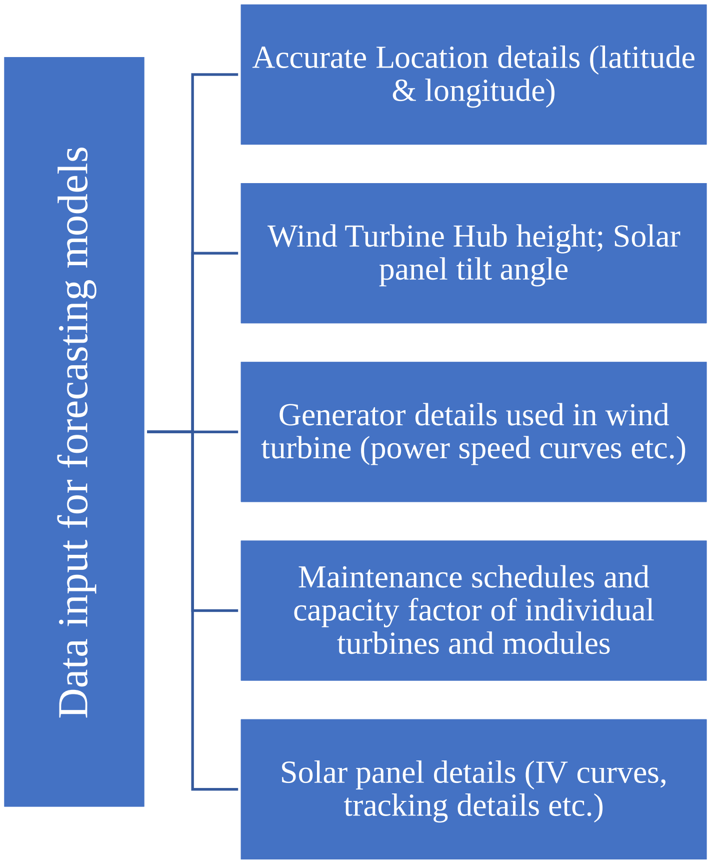


Figure 6.4 Data used by forecasting models for RE potential estimation

Once these forecasts are given, based on that with some factor of error the Discoms try to procure and keep backup reserves in those time blocks where the generation from RES is estimated to go down. Based on temporal variability estimated from the forecasts the operators can plan for the ramping requirement needed at specified time blocks and from which specific generator they can get the required ramping to supply the demand. The more accurate these forecasts are the more efficient the system operation can be. To increase the accuracy of the forecasts the number of data used as input to the models must be increased, i.e., more number of observations to ensure close to real conditions. Both the solar and wind generation vary diurnally and also seasonally so the generations from them have to be forecasted for these two scenarios **[12], [22]**.

6.3 Long Term PPAs

In India over 90% of the power procurement transactions occur through such long term agreements. The reason for this being, since electricity was generated under economy of scale concept in traditional power system only the large ISGS fuelled by either coal, hydro power or nuclear energy were solely generating power. So, the options available to Discoms was very limited that they signed power purchase agreements for long term duration of 12 – 25 years based on their demand forecast over that time period. With these agreements they had to pay fixed cost for the entire time period for which the agreement was signed and variable cost for power that is consumed from time to time. Even though there were risks of paying fixed costs for unconsumed power, the reliability of supply was ensured by these PPAs. Once the RES generation came into the power system, they were geographically diverse, unlike the conventional ISGS located only at specified locations. So, planning the transmission line requirements became somewhat complex and these generators were owned by private developers or small companies. So, there was a need to provide guarantee that whatever investments made by the developers, there should be returns for them at the earliest possible time and from a reliable source. So Discoms were mandated to sign long term contracts at predetermined FITs in accordance with the RPOs. The drawback of these long-term contracts with RES generators were that, initially the cost of such RES generation were quite high sue to the new technology and high cost of auxiliaries etc. But eventually the cost reduced manifold but these contracts signed for long term had to be respected by both the parties which resulted in financial losses for the Discoms. An example of the long term PPAs signed by a state Discom is given in **Table 6.2 [14], [16]**.

Table 6.2 Long Term PPAs signed by a state Discom (TANGEDCO – Tamil Nadu)

COMPANY	QUANTUM (MW)	TARIFF (Rs./kWh)	DATE OF PPA	FROM	TO
DB Power Limited	208	4.910	19.08.2013	01.02.2014	30.09.2028
Jindal Power Limited	400	4.936	23.08.2013	01.02.2014	30.09.2028
Ind Barath Energy Limited	500	4.952	08.08.2013	01.02.2014	30.09.2028
Bharat Aluminium Company Limited	100	5.063	23.08.2013	01.02.2014	30.09.2028
Dhariwal Infrastructure Limited	100	5.249	27.11.2013	01.06.2014	30.09.2028
PTC India Limited	100	5.366	18.12.2013	01.06.2014	30.09.2028
KSK Mahanadi Power Company Limited	500	5.486	27.11.2013	01.06.2014	30.09.2028
GMR Energy Trading Limited	150	5.681	27.11.2013	01.06.2014	30.09.2028
IL&FS Tamil Nadu Power Company Limited	540	6.134	12.12.2013	01.06.2014	30.09.2028
Coastal Energen Private Limited	558	6.182	19.12.2013	01.06.2014	30.09.2028
OPG Power Generation Private Limited	74	7.502	12.12.2013	01.01.2014	30.09.2028

From this table we can see that the PPAs are signed for a period of 14 years. The specified quantum as mentioned in the agreement would be supplied at the predetermined tariff. The drawback here is that in the control period the Discom would get cheaper power from various other sources or even it can start its own power stations from where it can generate power at a much lower cost than this PPAs signed. But still as per the signed agreement payment for the contracted quantum has to be paid. So, if the Discom is going for optimizing its power procurement portfolio in the control period of PPA, still this quantum has to be respected and only the remaining part of the demand available can be met from other means of procurement.

While considering the short-term power procurement, the first important factor is the existing power purchase agreements signed by the Discom. This is because whatever might be power procured from the corresponding source, the fixed cost for the entire contracted quantity has to be paid by the Discom. Also, the procured quantity cannot be continuously below a specified minimum limit too. So unplanned handling of such contracts may create huge financial risk. Similarly, the contracts signed with RE generators at a particular Feed In Tariff (FIT) should also be taken into account as they would have been signed for a long period of time to encourage RE generations. So, these kinds of long-term contracts have huge impact in overall cost optimization and procurement portfolio of Discoms in short term **[10]**.

Now, with all these points discussed above we can infer that there are some challenges for power procurement planning in short term scenario. These factors are summarized in the **Fig. 6.5** below.

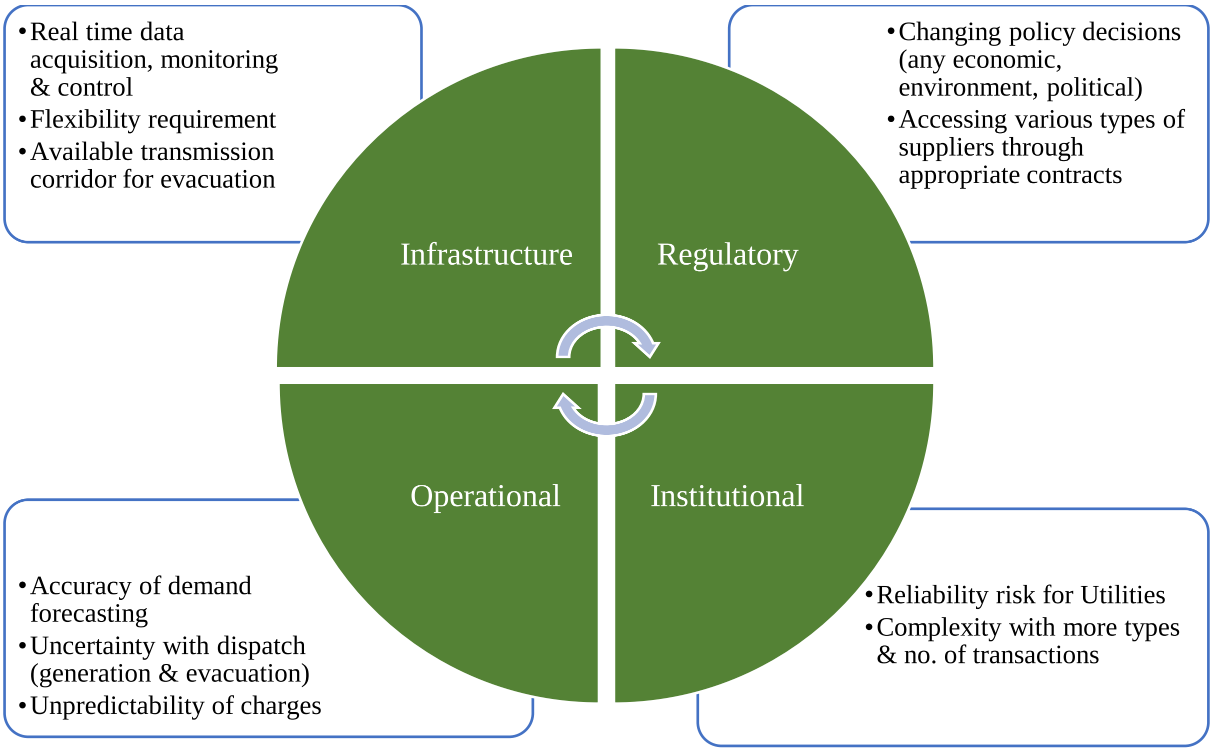


Figure 6.5 Challenges for Short Term Power Procurement

The state or private Discoms might have these challenges in varied proportions but they must account for all these risks and uncertainties to ensure meeting the prevailing demand through an optimal power procurement portfolio. Now, we have zoned into the actual scenario where there is an existing grid into which there is an integration of huge quantum of intermittent generation replacing the existing conventional generation. For having a hassle free and smooth transition between the existing and future systems and to ensure optimal and efficient operation of the proposed system under high quantum of intermittent generation, some new policy directives on the short term market mechanisms are being proposed. These new features and attributes of the electricity market that are coming up are aiming to facilitate procurement of power in the shortest possible interval so that the Discoms can efficiently handle the intermittencies in the system caused due to the integration of RES generation and deal with other contingencies caused during system operation. The future of power procurement would be through these market mechanisms that are evolving currently facilitating procurement of power in shortest possible intervals at optimal cost.

CHAPTER 7

MARKET MECHANISMS FOR POWER PROCUREMENT

Electricity market in India facilitates the purchase of power by consumers or DISCOMs and sale of power by the generators at very short intervals of time. This market is handled by two entities namely, Indian Energy Exchange (IEX) and Power Exchange of India Limited (PXIL) which are regulated by the Central Electricity Regulatory Commission (CERC) **[3]**. The various attributes of the Indian Electricity Market are given in the **Fig.7.1** below.

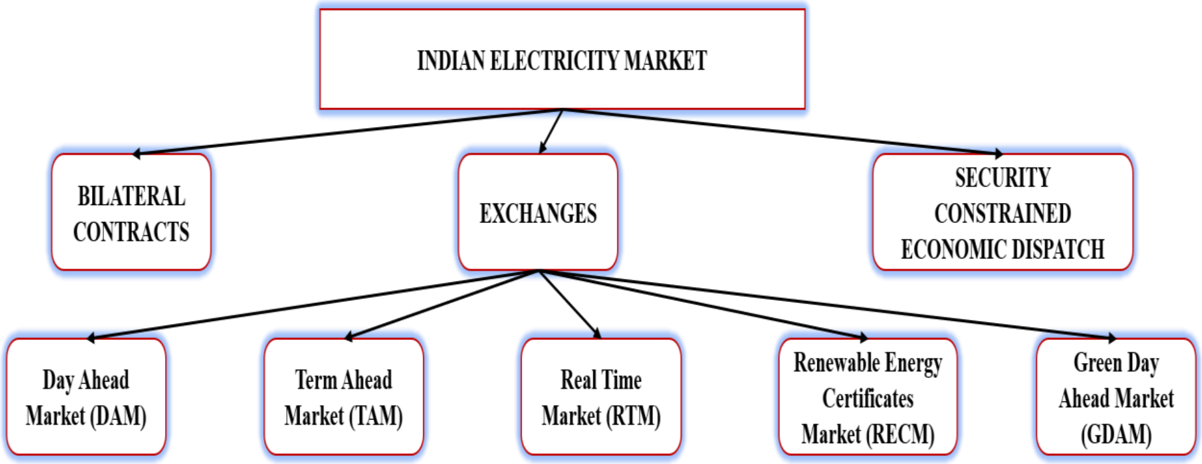


Fig. 7.1 Attributes of Indian Electricity Market Entities

These market mechanisms facilitated by the two exchanges promote competition among the participants, increase the transparency and liquidity and aim at achieving an optimal Market Clearing Price (MCP) for electricity at all time intervals. They also take into account the transmission congestion in each area of delivery and arrive at an Area Clearing Price (ACP) which together with the MCP gives the landed cost of electricity for the buyer in a specific area in a specific time block of a day. The Indian electricity market operates in 15-minute time blocks and the various attributes mentioned above provide procurement options in a time span from 11 days to 3 hours with some operating on monthly or weekly basis. Any consumer with demand or any generator with capacity more than 1MW can directly participate and trade in the market **[3]**, **[13]**.

7.1 Day Ahead Market

DAM trades contracts for the next day in 15-minute time intervals adding up to a total of 96-time blocks in a day. All of them would be double sided anonymous auction bidding processes. The market coordinates with system operator before clearing apart from facilitating congestion management through ACP and risk management by specific and additional margins for respective trading segment or contract **[3]**, **[21]**. The DAM operating timeline is given in **Fig. 7.2** below.

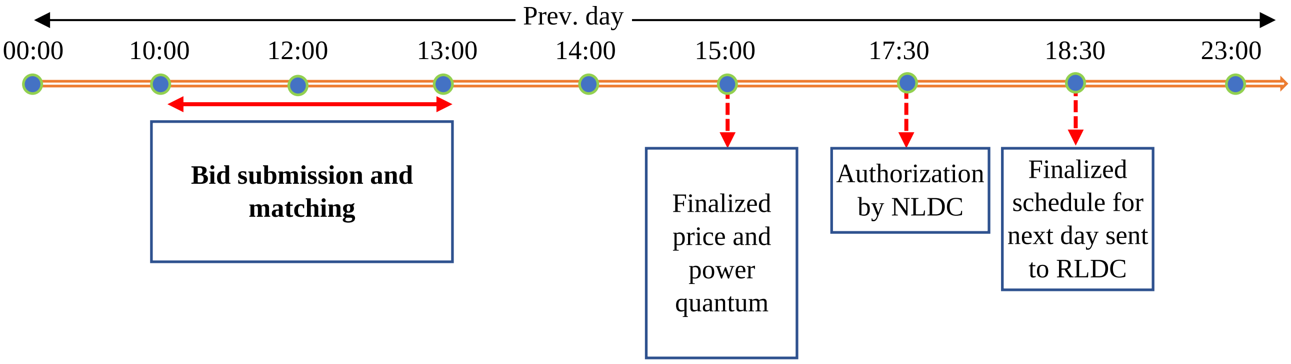


Fig. 7.2 Operating Timeline of DAM

Once the finalized schedule is sent to the RLDC then the market operation is complete and the contract would be validated the next day for power delivery. DAM is the most common and preferred market mechanism for short term power procurement. The cost in the DAM is based on the number of buy bids and sell bids submitted for any particular time block in the day **[21]**.

7.2 Term Ahead Market

TAM includes four different market options like Daily and Weekly contracts which were started way back in 2009 and Intra-day and Day Ahead Contingency (DAC) started in 2015. 20 hourly contracts are traded in Intra-day contracts with trading available from 00:30 to 20:30 hrs. for delivery on same day from 04:00 to 24:00 hrs. DAC are hourly contracts with trading available from 15:00 hrs. to 20:30 hrs. for delivery on next day**[3]**, **[21]**. The summary of TAM contracts are given in **Fig. 7.3.**

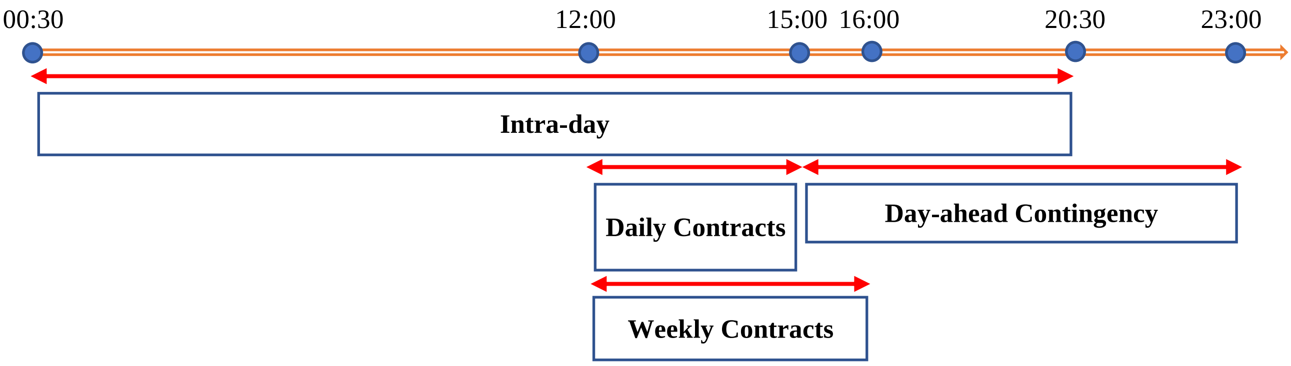


Figure 7.3 Summary of TAM contracts

These TAM contracts are comparatively less popular than the DAM. But out of these the Intra day and Day Ahead Contingency contracts are continuous trading contracts and so they were the best options for procuring power in a very short interval of time at the power exchanges **[21]**.

7.3 Renewable Energy Certificates

REC is the compensatory mechanism introduced to help Discoms that do not have sufficient RE options to procure from to fulfill their RPO targets. The Discoms that do not have sufficient RES generation of their own and also cannot have the option of procuring through any contracts from other available sources or markets can opt for these certificates as the last option. Every RE generator would be given 1 REC for every 1 MWh of electricity sold. This 1 REC is an intangible energy commodity representing 1 MWh of electricity from the corresponding RE source. Renewable generators receive these as environmental attributes to be traded for the equivalent amount of sold electricity **[3]**, **[21]**. 1 REC purchased by any consumer equals that 1MWh of demand is met from RES generation. By this way the consumer can satisfy the RPO mandates existing in any specific domain say solar non solar hydro etc. by purchasing the corresponding REC **[21]**.

7.4 Real Time Market

RTM is a latest version of market mechanism introduced in 2020 with MCP achieved by a double-sided closed auction bidding process. In this auction takes place every half an hour for power delivery in the subsequent hour, after 4-time blocks. Each bid session is of 15 minutes there are total 48 bid sessions in RTM **[3]**, **[21]**. The operation of RTM is summarized in **Fig. 7.4.**

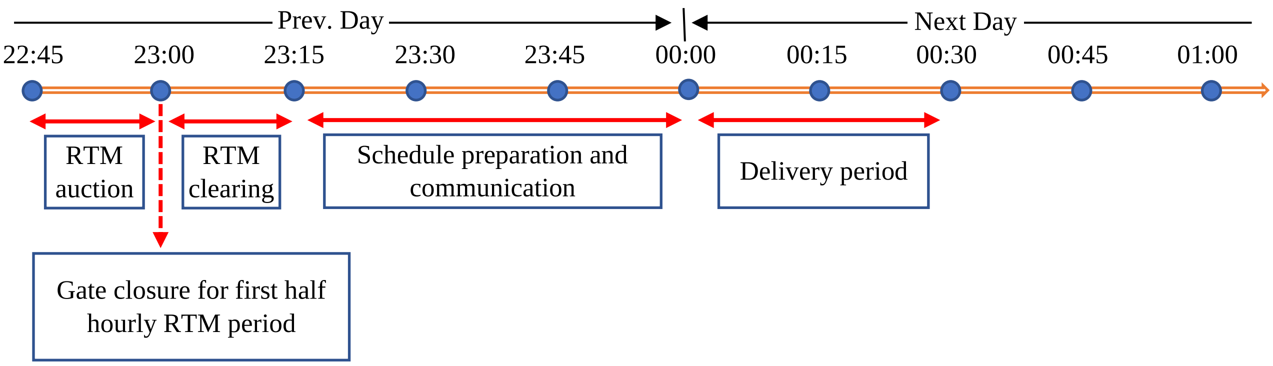


Figure 7.4 Operation of Real Time Market

This is the market from which electricity can be purchased in the least possible time interval. Excluding the power drawl through DSM, this market facilitates for the most instantaneous power procurement for any Discom to handle any last-minute contingencies. But generally, the price of electricity in this market is quite uncertain for obvious reasons depending on the demand for purchasing electricity in any particular time block. An Ancillary Service Market is being planned to be introduced in India, which if comes into operation will be the market with shortest possible power procurement option for Discoms.

7.5 Green Term-ahead Market (G-TAM)

G-TAM is a new market segment launched in year 2020. Similar to TAM, G-TAM also features four types of contracts Green-Intraday, Green-Day Ahead Contingency, Green-Daily and Green-Weekly and have similar trading mechanism and timelines. Unlike TAM hourly contracts, bidding in G-TAM takes places 15 min block wise. It provides 80 intraday contracts and 96 DAC contracts for solar and non-solar renewables separately. G-TAM mechanism would aim to incentivize renewable developers for RE capacity addition and facilitate its effective integration **[3]**, **[21]**.

7.6 Green Day Ahead Market (G-DAM)

G-DAM has separate bid categories for buyers and sellers in solar, non-solar and hydro categories with separate quantity limits for sellers in each category. Order Carry Forward (OCF) can be used to take the uncontracted bids to DAM market. Similar to DAM, GDAM is also double sided closed anonymous bidding auction in 15-minute time interval. There is a separate price formation for green and conventional power. Market clearing takes place sequentially with must run renewables first followed by the conventional quantum subject to transmission corridor availability **[3]**, **[21]**.

CHAPTER 8
IMPACT ANALYSIS MODEL

In this chapter the DISCOM in the state of Tamil Nadu having predominant wind generation and the DISCOM in the state of Rajasthan having predominant solar generation are considered with their various procurement options. To offset the effect of Covid 19 and its subsequent impacts on the power sector in India, the data from year 2019 are considered while the latest policy frameworks and regulations from 2021 are retained **[15], [16]**. This study is done on two scenarios of high and low RE penetration which eventually are in the months of July and November having peak and valley in wind generation of the region respectively for Tamil Nadu. For Rajasthan March month has maximum solar generation and average wind generation, so the months of March and November are taken for high and low RE scenario. The mathematical model is discussed followed by the inputs to the model and finally the results obtained **[14]**, **[17]**.

8.1 Tamil Nadu

8.1.1 Mathematical Model

A DISCOM with high wind generation capacity along with substantial solar PV generation is considered to be procuring power to meet its demand. It is considered to have 35 conventional generators which includes thermal generators and nuclear power plants. To offset the intermittency and optimize the cost of procurement it is assumed to participate in the short-term electricity market. Power drawl under DSM is also considered up to 12% of the maximum demand as per latest DSM regulations.

8.1.1.1 Procurement Cost Modelling

Total procurement cost is modelled as the sum of the costs of procurement from the various sources as given by,

$$\mathbf{C_{TOTAL} = C_C + C_H + C_{LS} + C_{DSM} + C_{PX} + C_{DAM} + C_{RTM} + C_{G\_DAM} + C_{S\_REC} + C_{NS\_REC}} \quad \textbf{(1)}$$

where C_C is the Conventional generation cost, C_{DAM} is the cost of procurement from DAM, C_H is the Hydro generation cost, C_{RTM} is the cost of procurement from RTM, C_{LS} is the penalty cost for Load Shedding, $C_{G\text{-}DAM}$ is the cost of procurement from G-DAM, C_{DSM} is the cost for power drawl through DSM, $C_{S\text{-}REC}$ is the cost of procuring Solar REC, C_{PX} is the TAM contracts procurement cost and $C_{NS\text{-}REC}$ is the cost of procuring Non-Solar REC. Each of the costs in (1) are in turn calculated separately as given below.

$$\mathbf{C_C} = \sum_{g=1}^{42} \sum_{t=1}^{96} \boldsymbol{\lambda_{TC} * P_t^C} \quad \textbf{(2)}$$

where t is the time, taken in blocks of 15 minutes, g is the set of conventional generators, λ_{VC} is the variable cost for conventional generation per MW and P_t^C is the power procured from conventional generation.

$$\mathbf{C_H = \sum_{h=1}^{4}\sum_{t=1}^{96} \lambda_{TCh} * P_t^H} \tag{3}$$

where h is the set of hydro generators, λ_{VCh} is the cost for hydro generation per MW and P_t^H is the power procured from hydro generation. The rest of the cost components C_{LS}, C_{DSM}, C_{PX}, C_{DAM}, C_{RTM}, C_{G_DAM}, C_{S_REC} and C_{NS_REC} are calculated as per the linear cost equation given by

$$\mathbf{C_x = \sum_{t=1}^{96} \lambda_x * P_t^x} \tag{4}$$

where λ_x is the cost per MW of corresponding quantum procured given by P_t^x from the respective source.

8.1.1.2 Power Balance

The overall cost optimization is done for the power procured to balance the existing demand which is given by,

$$\mathbf{P_t^C + P_t^H + P_t^{DSM} + P_t^{PX} + P_t^{DAM} + P_t^{RTM} + P_t^{G\_DAM} + P_t^{LS} + P_t^{WIND} + P_t^{SOLAR} = P_t^{DEMAND}} \tag{5}$$

where P_t^{DEMAND} is the power demand in MW, P_t^{SOLAR} and P_t^{WIND} are the solar and wind generation available in MW respectively. Equation **(12)** is subject to the following constraints,

$$\mathbf{P_t^C{}_{min} * u_t < P_t^C < P_t^C{}_{max} * u_t} \tag{6}$$

where $P_t^C{}_{min}$ & $P_t^C{}_{max}$ are minimum and maximum limits of conventional generators respectively and u_t is the binary variable indicating generator status.

$$\mathbf{P_t^H{}_{min} * uh_t < P_t^H < P_t^H{}_{max} * uh_t} \tag{7}$$

where $P_t^H{}_{min}$ & $P_t^H{}_{max}$ are the minimum and maximum limits of hydro generators respectively and uh_t is the binary variable indicating hydro generator status.

$$\mathbf{P_t^C * u_t - P_{t-1}^C * u_{t-1} < Rup * u_t} \tag{8}$$

$$\mathbf{P_{t-1}^C * u_{t-1} - P_t^C * u_t < Rdown * u_{t-1}} \tag{9}$$

$$\mathbf{u_t > u_{tt} - u_{tt-1} \text{ , when } [\, tt > t - UT \,]} \tag{10}$$

$$\mathbf{1 - u_t > u_{tt-1} - u_{tt} \text{ , when } [\, tt > t - DT \,]} \tag{11}$$

$$\mathbf{P_t^H * uh_t - P_{t-1}^H * uh_{t-1} < Rhup * uh_t} \tag{12}$$

$$\mathbf{P_{t-1}^H * uh_{t-1} - P_t^H * uh_t < Rhdown * uh_{t-1}} \tag{13}$$

where, Rup, Rdown and Rhup, Rhdown are the ramp up and ramp down limits of conventional and hydro generators respectively while UT and DT indicate the minimum up and down time respectively.

$$\mathbf{P_t^{DSM} < 0.12*[P_t^{\mathit{DEMAND}}]} \quad \mathbf{(14)}$$

$$\mathbf{[S\_RPO*\ P_t^{DEMAND}] < P_t^{G\_DAM} + \boldsymbol{P_t^{S\_REC}} + P_t^{SOLAR}} \quad \mathbf{(15)}$$

$$\mathbf{[NS\_RPO*\ P_t^{DEMAND}] < P_t^{G\_DAM} + \boldsymbol{P_t^{NS\_REC}} + P_t^{WIND}} \quad \mathbf{(16)}$$

where, S_RPO and NS_RPO are the obligations mandated for specific RE sectors.

8.1.1.3 Risk Modelling of uncertainities in price

The MCP of DAM and RTM depend on the available sell and buy bids in the market at that particular time block. So, they are dynamically varying since sell bids depend on the available generation from conventional sources and RES, while the buy bids depend on the prevailing demand. Also, the rate per MW under DSM keeps changing based on the system frequency. These uncertainties in MCP and DSM rate are modelled as variance of the cost **[10]** as follows,

$$\mathbf{Risk} = \sum_{t=1}^{96} \lambda_t^{DSMvar} (P_t^{DSM})^2 + \sum_{t=1}^{96} \lambda_t^{DAMvar} (P_t^{DAM})^2 + \sum_{t=1}^{96} \lambda_t^{RTMvar} (P_t^{RTM})^2 + 2\{\sum_{t=1}^{96} \lambda_t^{covar1}(P_t^{DSM} * P_t^{DAM}) + \sum_{t=1}^{96} \lambda_t^{covar2}(P_t^{DSM} * P_t^{RTM}) + \sum_{t=1}^{96} \lambda_t^{covar3}(P_t^{DAM} * P_t^{RTM})\} \quad \mathbf{(17)}$$

where, λ_t^{DSMvar} is the variance of DSM price based on changing real time grid frequency, λ_t^{DAMvar} is the variance of DAM clearing price, λ_t^{RTMvar} is the variance of RTM clearing price, λ_t^{covar1} is the co-variance between DAM clearing price and DSM rate, λ_t^{covar2} is the co-variance between RTM clearing price and DSM rate and λ_t^{covar3} is the co-variance between DAM clearing price and RTM clearing price.

8.1.1.4 Objective Function

The final cost is the objective function which is a sum of total procurement cost and the Risk multiplied by a factor α, known as the risk weighing factor which when increases indicates the decreasing willingness of the DISCOM to take risk with more procurement from short term market. The objective is to minimize the final cost given as follows,

$$\mathbf{Min\ \{ C_{FINAL} = C_{TOTAL} + [\alpha * Risk]\ \}} \quad \mathbf{(18)}$$

where C_{FINAL} is the total cost incurred to DISCOM at various levels of risk-taking scenario with MCP uncertainty, C_{TOTAL} is the total cost of procuring power at maximum risk of MCP uncertainty, Risk is the uncertainty in MCP of DAM, RTM and DSM rate, and α is the Risk weighing factor, which when increases indicates lesser willingness to take risk.

8.1.2 Input Data

The Generator details of conventional power plants consisting of the cost components, power limits, ramping rates, minimum up and down time are given as parameter inputs **[9, 10]** through Microsoft Excel. The wind, solar generation data and demand profile to be given as inputs are estimated from **[14]** and **[15]** respectively and they are depicted in **Fig. 8.1** for the month of November and **Fig. 8.2** for July.

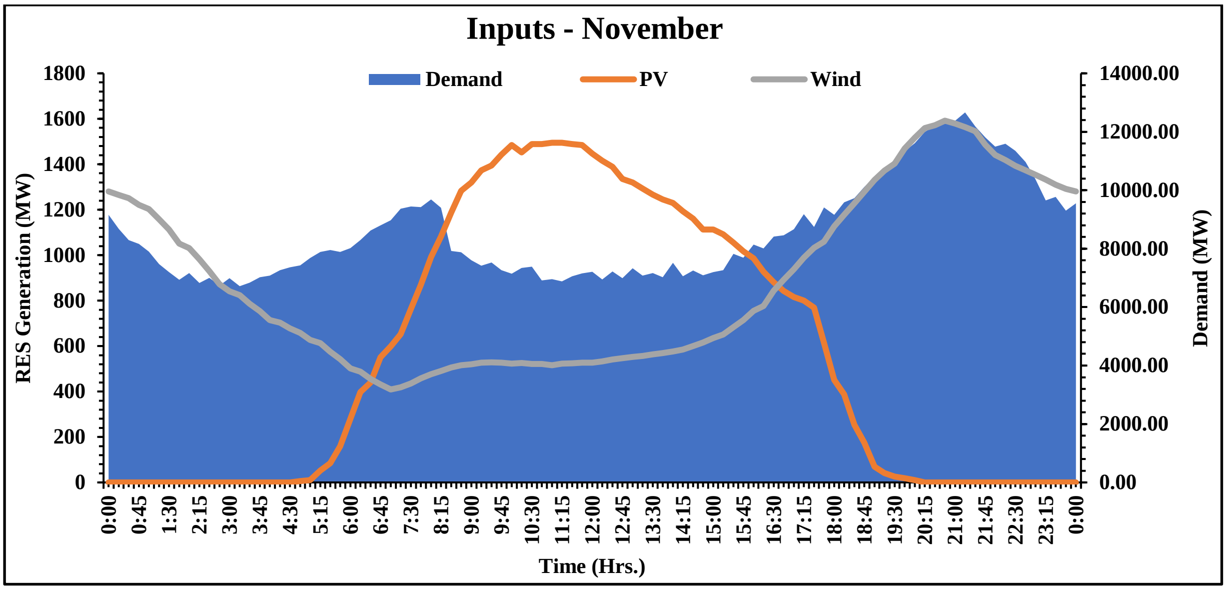


Figure 8.1 Input Data for Low RE scenario

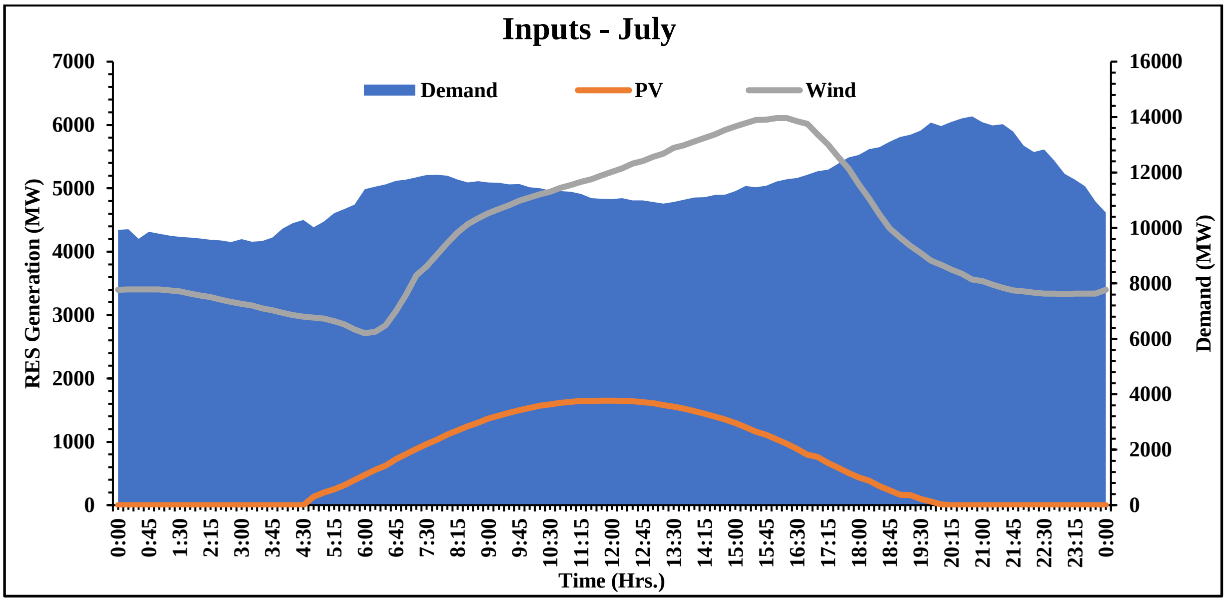


Figure 8.2 Input Data for High RE scenario

8.1.3 Uncertainty

The short-term procurement for the DISCOM is mainly from DAM and RTM, but with the introduction of G_DAM in October 2021, there began a more wider market option for meeting the variable demand while sticking to the RPO mandates. The quantum that is being scheduled under DSM due to the real time variations that could not be countered by these short-term procurements, has to be procured at the DSM rate based on the grid frequency at any instant. The problem with these procurement methods is the uncertainty in their prices over time which is calculated using the variance of cost approach and is illustrated in **Fig. 8.3** and **Fig. 8.4** below **[13, 15]**.

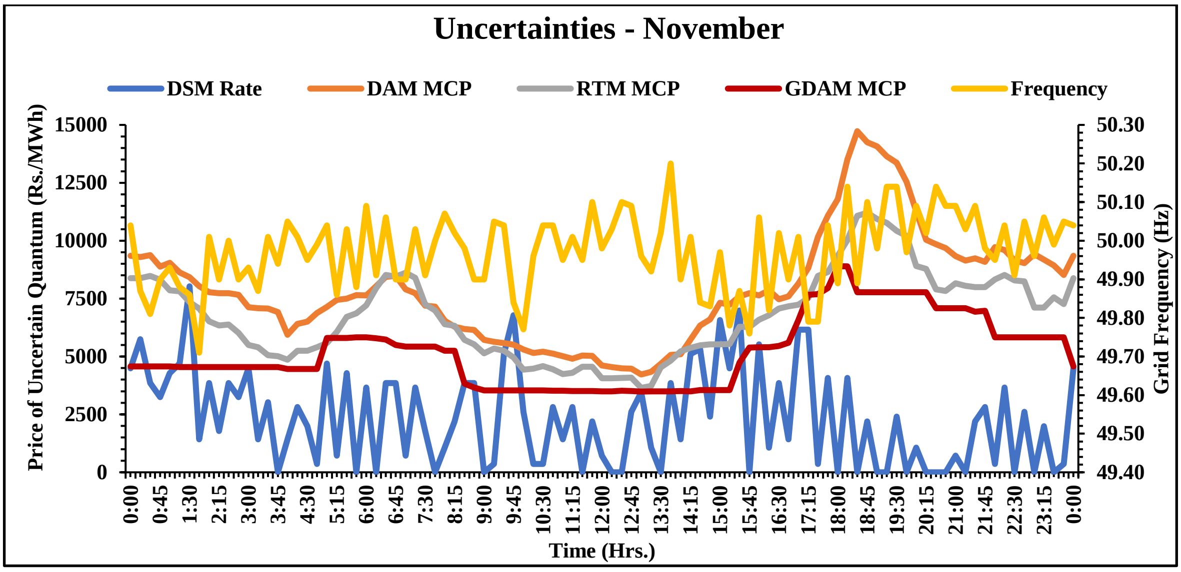


Figure 8.3 Uncertainties in MCP – Low RE scenario

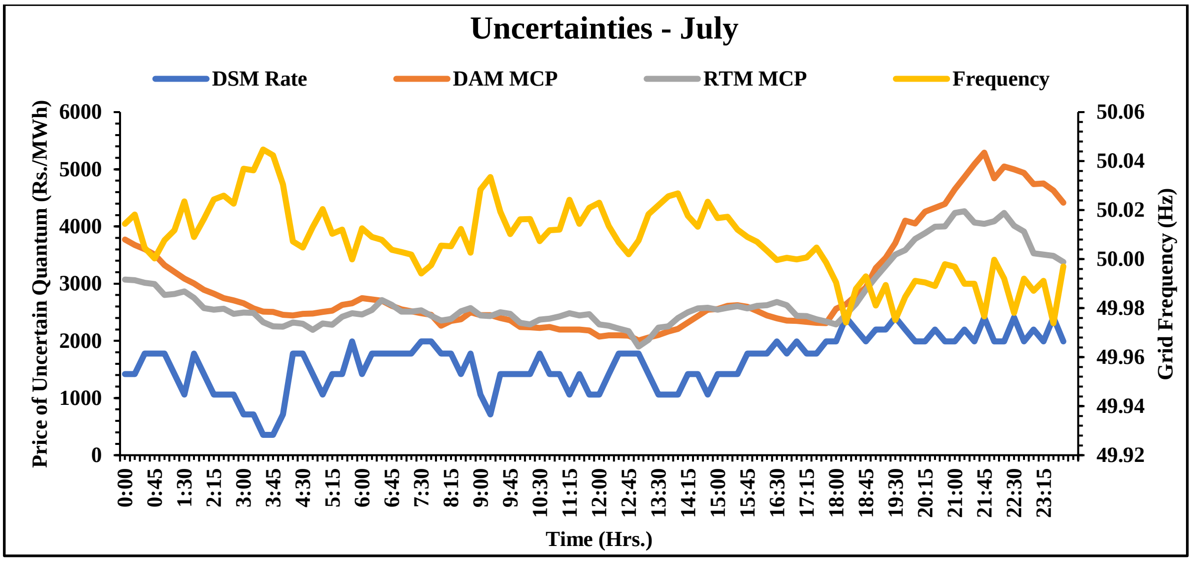


Figure 8.4 Uncertainties in MCP – High RE scenario

8.1.4 Simulation Details

The mathematical equations are modelled using the General Algebraic Modeling System (GAMS) software. This is a high-level modeling system available for mathematical optimization of linear, nonlinear and mixed integer type problems. This is a Mixed Integer Non Linear Programming (MINLP) type problem for which the SBB solver is used for the MIP optimization and the CONOPT for the NLP optimization. The inputs and outputs are given and obtained respectively using Microsoft Excel. All the simulations are carried out for 15-minute time interval.

8.1.5 Results and Discussion

The results are obtained separately for the two scenarios considered. The results for High RE scenario are discussed by comparing two cases of High and Low risk taken by the DISCOM with the procurement portfolio in **Fig. 8.5** and **Fig. 8.7** respectively indicating a maximum of 53% of total demand is supplied from RES whereas the risk analysis illustrated in **Fig. 8.6**. The peak demand in both the cases are met variably with more procurement from short term market observed in the latter where risk is high, amounting to a total procurement cost of 165.7 crores per day against 175.7 crores in the former where risk is low, subsequently short-term procurement is low. It is interesting to see that in high risk case the cost reduction is aided by lesser curtailment of wind than in the low risk scenario where more curtailment of free cost wind energy results in higher procurement cost. Annual procurement cost comparisons stand at 72,462.4 crores for high risk scenario against 76,118.3 crores for lower risk one.

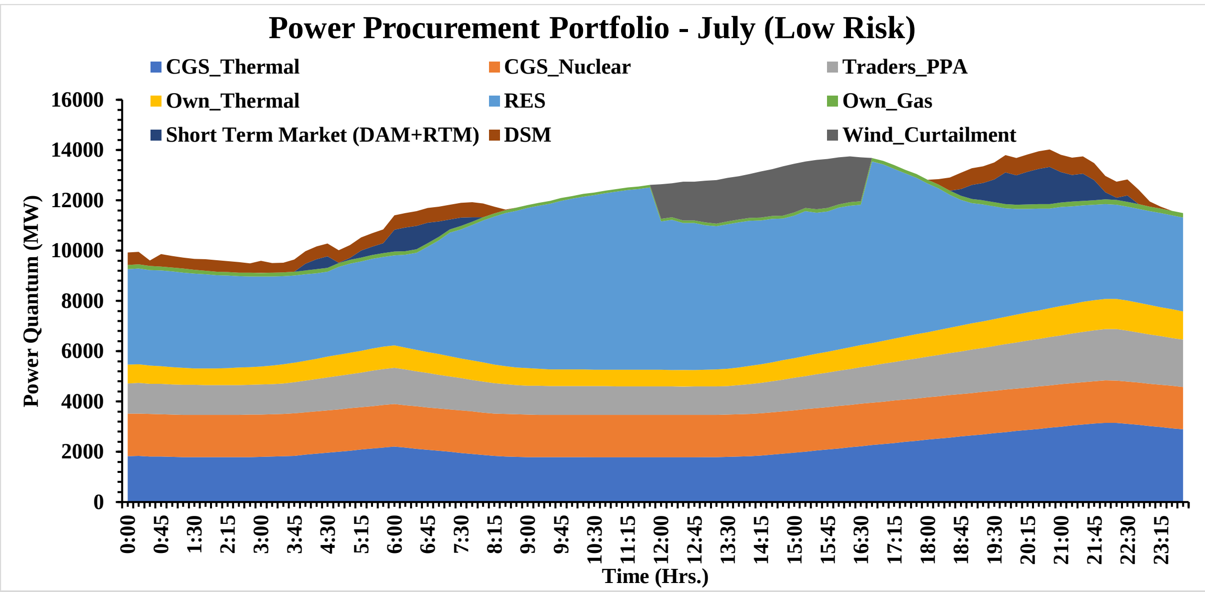


Figure 8.5 Power Procurement Portfolio (Low Risk) – High RE scenario

The risk analysis and power procurement portfolio for low RE scenario are given in **Fig.8.8** and **Fig. 8.9** respectively. From this it is inferred that maximum of 21% of total demand only is supplied from RES and the peak demand is met by procurement through short term market and drawl through DSM which amount close to 25%. The significant procurement here from GDAM is an important component in such a low RES scenario, as it helps to meet the demand and RPO mandate. The total procurement cost for a day varies from 176.926 crores at high risk to 183.2 crores at low risk taken by the DISCOM. Cost incurred to the DISCOM per annum is 77,857.7 crores at maximum risk consideration while it stands at 79,060.2 crores with the least level of risk being taken by the DISCOM in the short-term market procurement. This relation between risk and procurement is illustrated in **Fig. 8.6 and Fig. 8.8** below, with the procurement cost increasing with lesser risk preference by DISCOM.

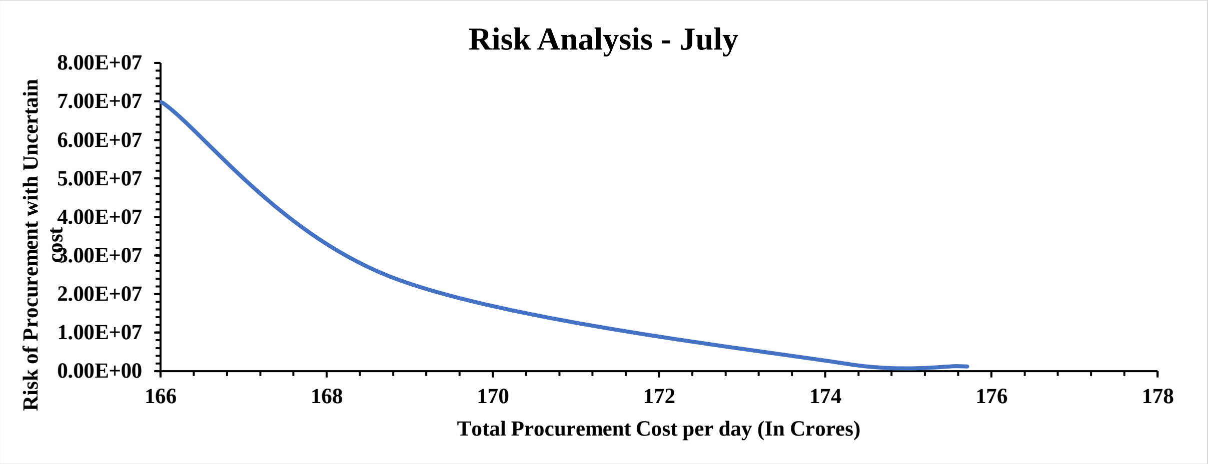


Figure 8.6 Risk Analysis of short-term procurement – High RE scenario

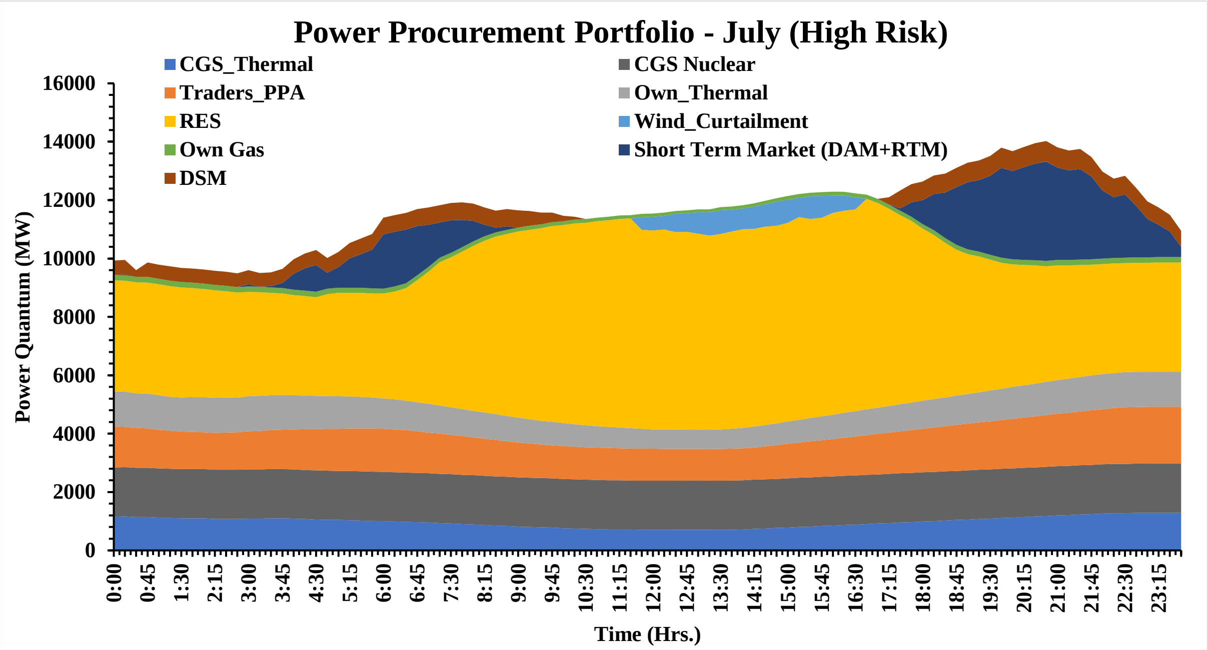


Figure 8.7. Power Procurement Portfolio (High Risk) – High RE scenario

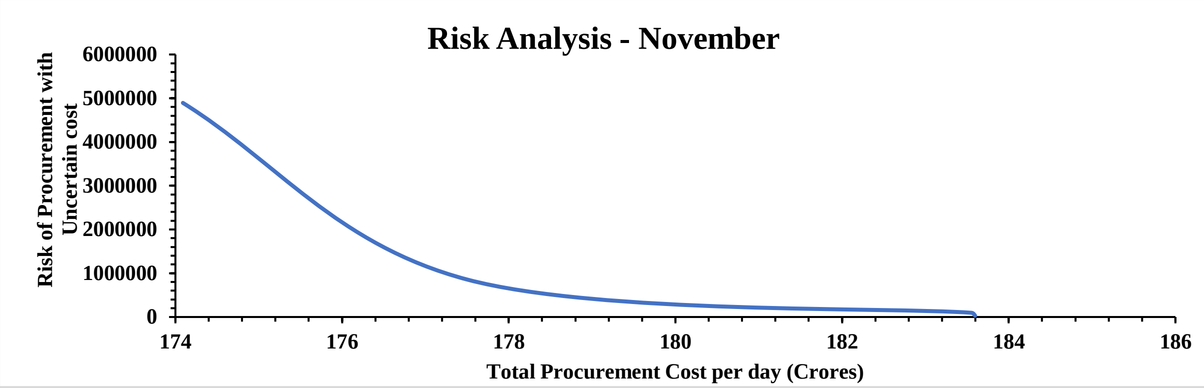


Figure 8.8 Risk Analysis of short-term procurement – Low RE scenario

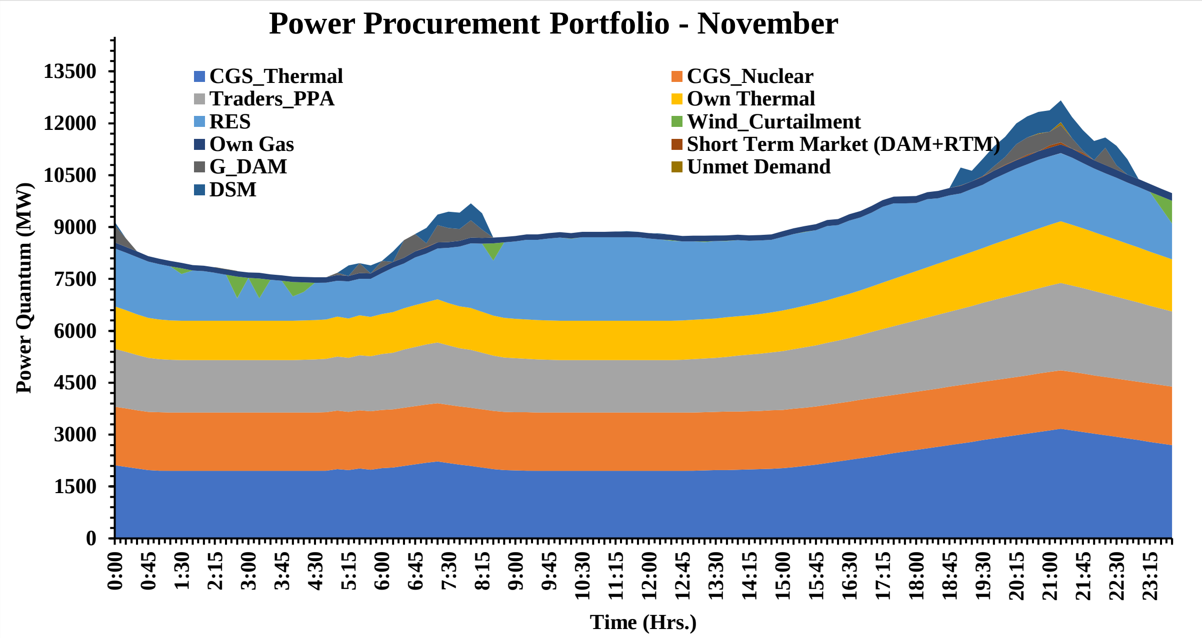


Figure 8.9. Power Procurement Portfolio – Low RE scenario

Thus, we can conclude that with existing conventional generation and its constraints, in a high RE scenario the model optimizes the procurement portfolio considering varying risk factors of short-term procurement. It is clearly indicated that the overall procurement cost is higher in low RE scenario due to comparatively higher cost of conventional generation. A substantial quantum of wind energy is curtailed even in low RE scenario along with some unmet demand during evening peak. This clearly shows the real scenario in a RE rich environment in a country like India.

8.2 Rajasthan

8.2.1 Mathematical Model

A DISCOM with high solar PV generation capacity along with substantial wind generation is considered to be procuring power to meet its demand. It is considered to have 47 conventional generators which includes thermal generators, gas generators and nuclear power plants. Apart from that it also has 21 hydro generators. To offset the intermittency and optimize the cost of procurement it is assumed to participate in the short-term electricity market. Power drawl under DSM is also considered up to 12% of the maximum demand as per latest DSM regulations. The procurement cost modelling, power balance, risk modelling of uncertainties in price and the objective function are similar to the previous case, modelled for the state of Tamil Nadu.

8.2.2 Input Data

The Generator details of conventional power plants consisting of the cost components, power limits, ramping rates, minimum up and down time are given as parameter inputs **[9, 10]** through Microsoft Excel. The wind, solar generation data and demand profile to be given as inputs are estimated from **[25]** and **[26]** respectively and they are depicted in **Fig. 8.10** for the month of November and **Fig. 8.11** for March.

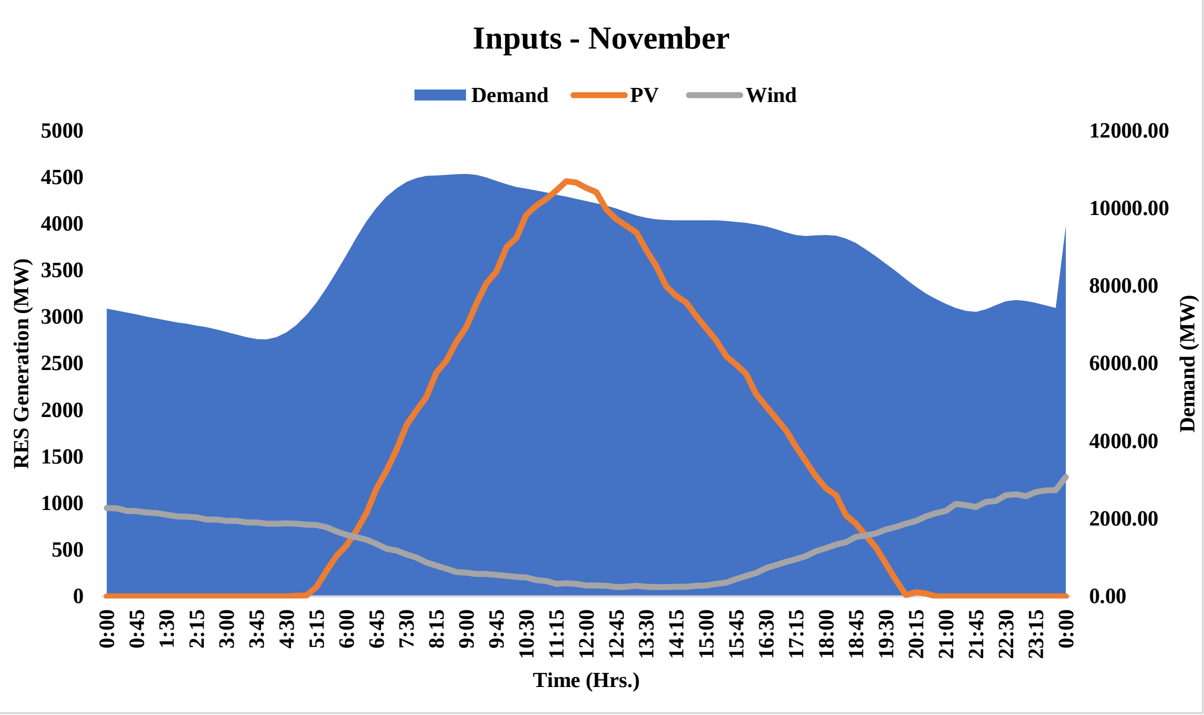


Figure 8.10 Input Data for Low RE scenario

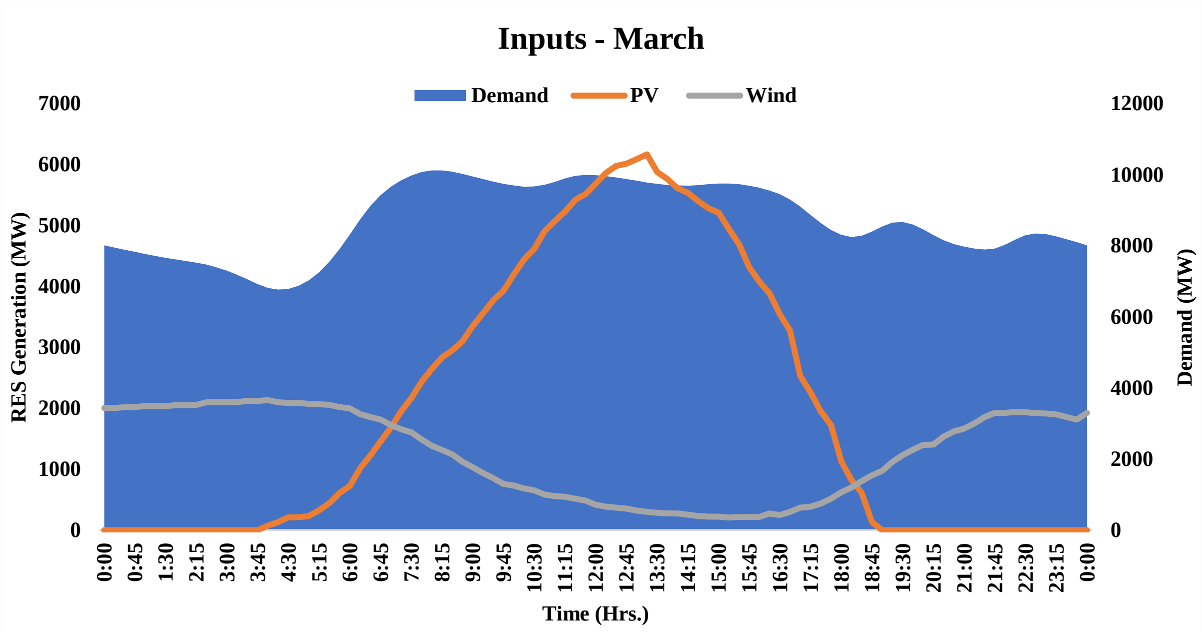


Figure 8.11 Input Data for High RE scenario

8.2.3 Uncertainty

The short-term procurement for the DISCOM is mainly from DAM and RTM, but with the introduction of G_DAM in October 2021, there began a more wider market option for meeting the variable demand while sticking to the RPO mandates. The quantum that is being scheduled under DSM due to the real time variations that could not be countered by these short-term procurements, has to be procured at the DSM rate based on the grid frequency at any instant. The problem with these procurement methods is the uncertainty in their prices over time which is calculated using the variance of cost approach and is illustrated in **Fig. 8.12** and **Fig. 8.13** below **[20], [25], [26]**.

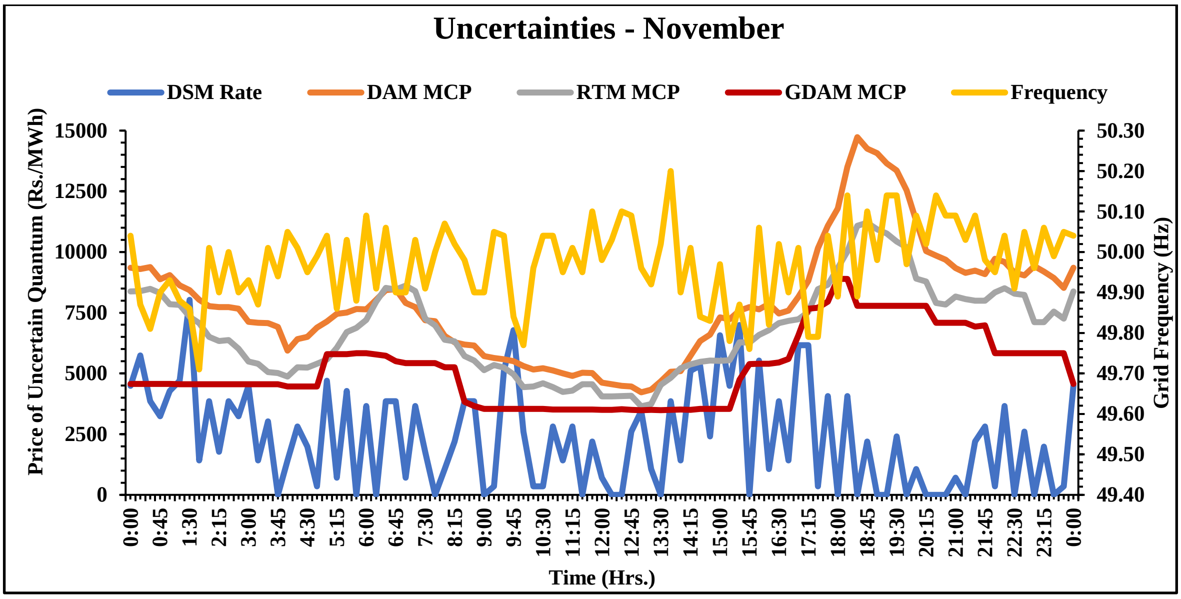


Figure 8.12 Uncertainties in MCP – Low RE scenario

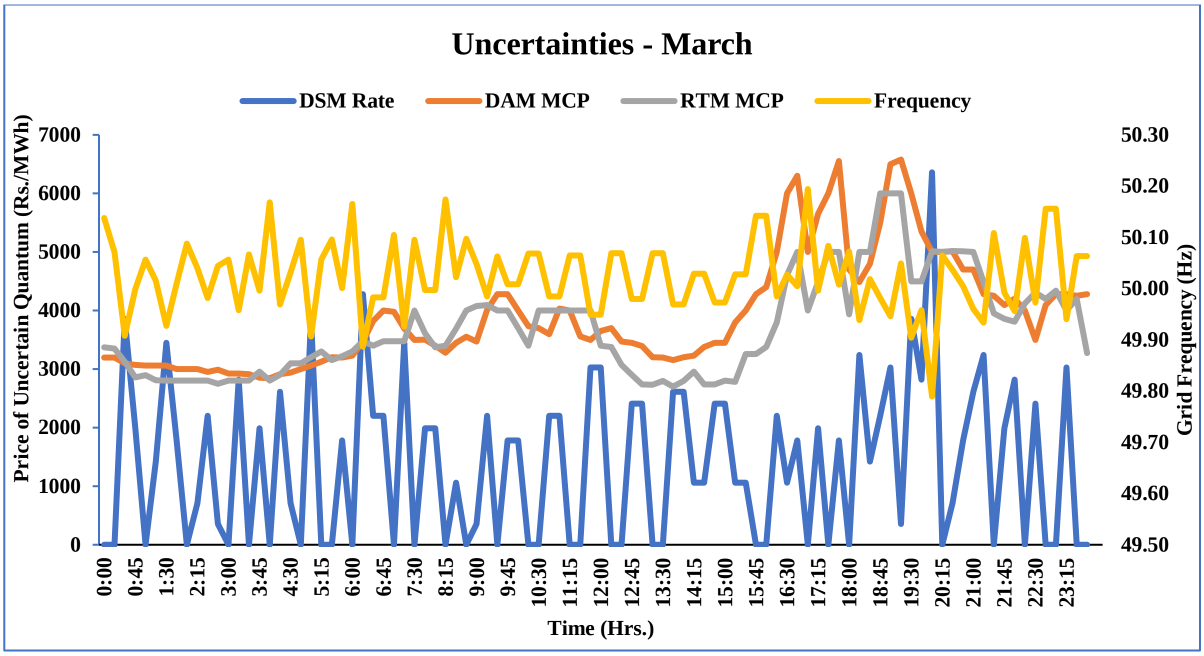


Figure 8.13 Uncertainties in MCP – High RE scenario

8.2.4 Simulation Details

The mathematical equations are modelled using the General Algebraic Modeling System (GAMS) software. This is a high-level modeling system available for mathematical optimization of linear, nonlinear and mixed integer type problems. This is a Mixed Integer Non Linear Programming (MINLP) type problem for which the SBB solver is used for the MIP optimization and the CONOPT for the NLP optimization. The inputs and outputs are given and obtained respectively using Microsoft Excel. All the simulations are carried out for 15-minute time interval.

8.2.5 Results and Discussion

The results are obtained separately for the two scenarios considered. The results for Low RE scenario in the form of procurement portfolio is given in **Fig. 8.14** and for High RE scenario is given in **Fig. 8.15** respectively. They indicate that a maximum of 45% and 60% of total demand is supplied from RES in the two cases of low and high RES generation respectively in the months of November and March. The peak demand in both the cases are met with procurement from short term markets, with Green DAM and DSM contributing in the former and in the latter when Green DAM feature was not available only DSM, DAM and RTM procurement were contributing to meet the peak demand. There is also substantial quantum of solar and wind generation curtailed in the month of March when there was a peak in solar generation. Total procurement cost is around 108.624 crores per day during the month of March when RES quantum is high against a procurement cost of 142.075 crores in the month of November with low RES generation.

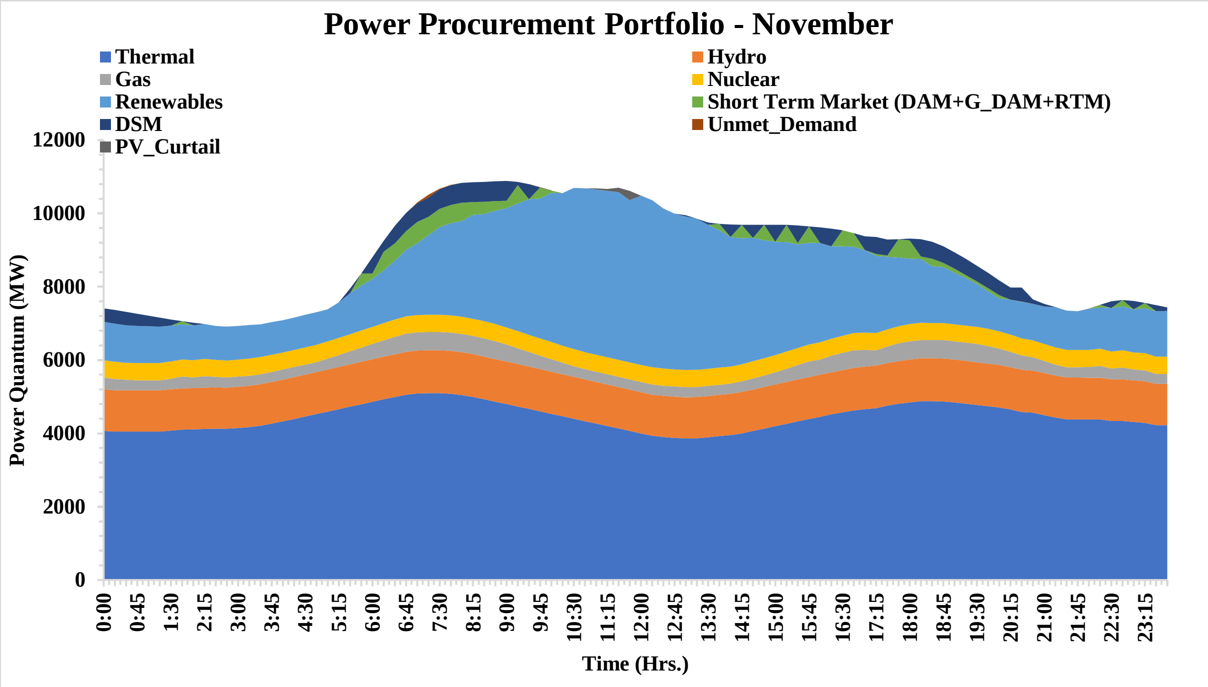


Figure 8.14. Power Procurement Portfolio – Low RE scenario

The demand met in both the cases are almost equal, so we can clearly see that when the quantum of RES is increasing the overall procurement cost can be reduced to a great extent with optimal procurement portfolio. Annual procurement cost comparisons stand at 70,407.554 crores for low RES scenario against 57,957.884 crores for high RES scenario.

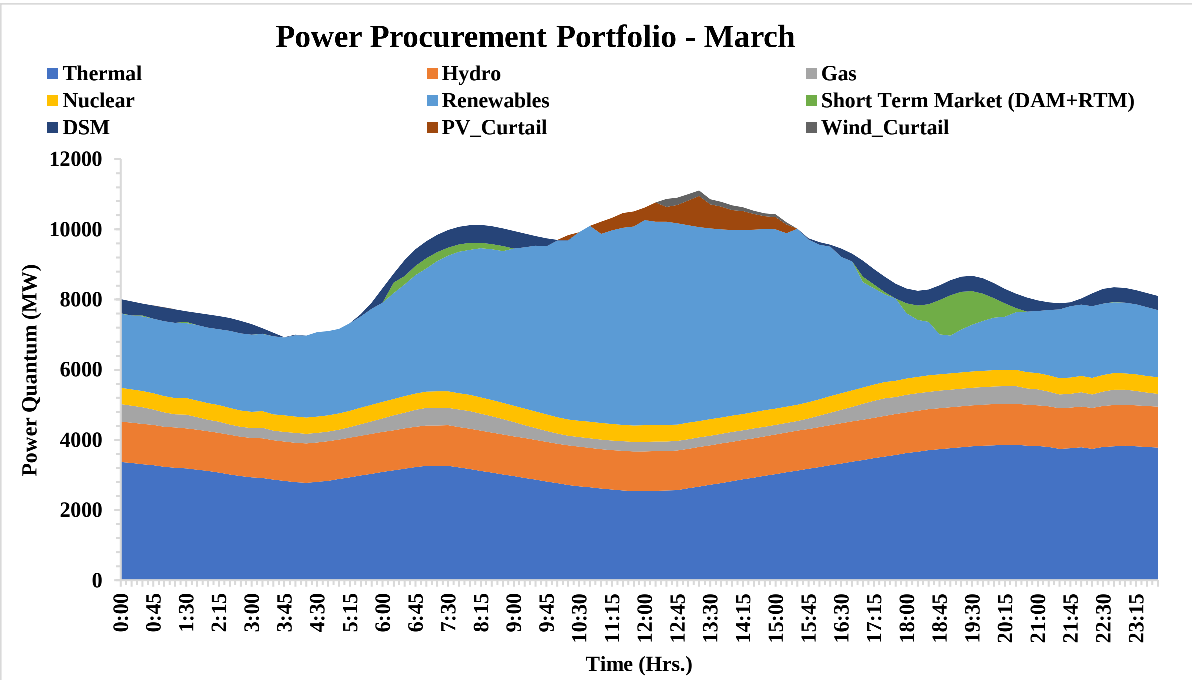


Figure 8.15. Power Procurement Portfolio – High RE scenario

From the results it can be inferred that even though the procurement cost is lower in high RES scenario, the overall cost could be further optimized if the significant quantum that is curtailed in both solar and wind generation can be avoided. Also, in the first case when RES penetration is comparatively less, there is load shedding during the morning peak time when there is sudden increase in the demand which could not be met by short term procurement completely. Such problems of load shedding and RES curtailment are challenging for the Discoms to deal with when there is substantial quantum of RES integration.

CHAPTER 9

IMPLICATIONS OF OPTIMAL POWER PROCUREMENT ON DISCOMs

From the results obtained for the two states having high wind and solar generations respectively in the months of July and March a comparative analysis can be made. The demand met are almost the same with the demand in Tamil Nadu being slightly on the higher side. But the profile is different in both the states with Tamil Nadu having peak demand in the late evening while Rajasthan has morning peak followed by steady increase in demand until mid-day. The demand profile and the RES generation profiles of both the states are illustrated in **Fig. 9.1**.

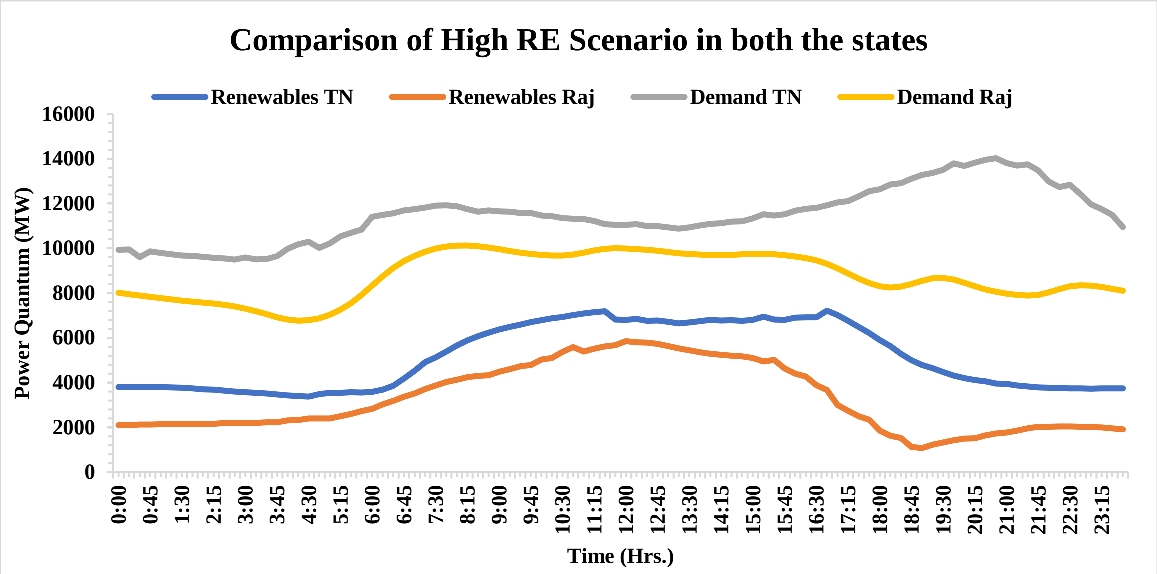


Figure 9.1 Demand and RES generation profiles for Tamil Nadu and Rajasthan

The RES generation profile is matching better comparatively, with the demand profile for the state of Rajasthan than Tamil Nadu. During its evening peak, the state of Tamil Nadu has its RES generation decreasing and so it has to opt for market procurement or turn on gas or pumped hydro generators if available. In the case of Rajasthan, handling the morning peak is a challenge as the RES generation is starting to increase by then. So again it has to be met by conventional or market procurement but as we move towards mid-day the increase in demand is countered by the increase in RES generation. But the problem in both the states of Tamil Nadu and Rajasthan is that, during their RES generation peaks the Discoms are forced to curtail wind and solar generation respectively which is close to mid-day in both the cases. In Tamil Nadu there is wind curtailment during mid-day when demand is low whereas in Rajasthan there is curtailment in both wind and solar generation during mid-day. The RES curtailment in both the states are given in **Fig. 9.2**.

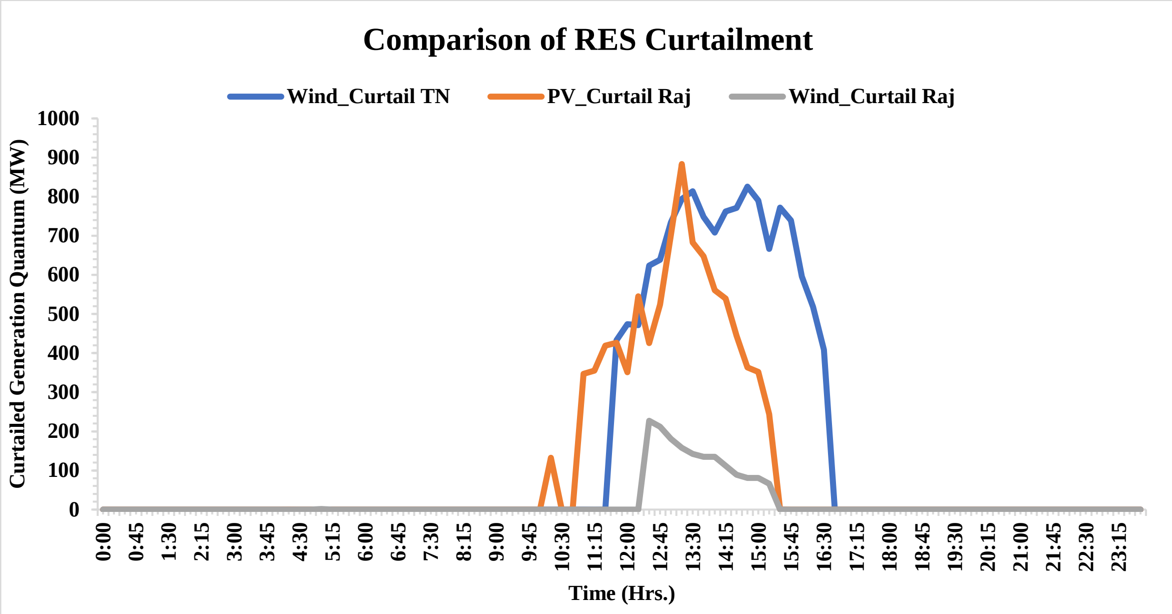


Figure 9.2 RES curtailment in Tamil Nadu and Rajasthan

The problem with such curtailment is that low-cost clean energy is wasted in place of costly conventional generation. Apart from this, if the RES generation is not handled properly it might result in stressing the ramping capabilities of the conventional generators which would cause adverse impacts for the Discoms in meeting the demand.

The entire process adopted by the Discoms right from planning stage till the finally stage of settling the accounts in optimal power procurement there are various implications at different levels to all the stakeholders involved. Say if a particular state has huge share of RES quantum it might easily meet the RPO mandates and need not bother about purchasing REC etc. But it should focus on two other major things such as keeping enough balancing reserves ready to compensate the intermittencies in the RES so that there is no load shedding required. Similarly reactive power management is one another area which gathers importance as the quantum of wind generation increases.

More and more RES integration mandates decommissioning conventional power plants before end of service life which means substantial quantum of inertial frequency response is lost. So alternate mechanisms have to be looked out for to ensure power system stability. Due to the increase in solar generation the ramping rate required from the conventional generation is also increasing on a daily basis between noon time where there is solar generation peak and evening load demand peak. But one advantage of having such distributed generation is due to the generation at the far end of the distribution system there is much improvement in the Aggregate

Technical & Commercial loss factor which is an indirect benefit for Discoms. Also, they relieve some of the transmission congestion in the tie lines and also support capacity deferral.

Off late many Discoms are in poor financial condition and an optimum power procurement would help them to reduce their gap between Average Cost of Supply (ACS) and Aggregate Revenue Realized (ARR). The overall power procurement cost for the two states can be seen to be less when there is high generation from RES and it is effectively integrated without any curtailment while taking into account the operating constraints of conventional generators. With the quantum of short-term procurement increasing the stranded fixed cost payable to the long term contracted generators won't be a problem in future as Discoms would be happy to buy cheaper power from electricity markets. But again, one major risk involved here is the uncertainty in the market clearing price which is dynamically varying based on the demand supply among the market participants. One more risk the Discoms may face is that with both Open Access and Trading Access given to consumers of 1 MW and above many industrial consumers might go for this option making Discoms lose their cross-subsidizing consumers which will directly affect the income to the Discoms.

CHAPTER 10
CONCLUSION

Thus, from this report the impact analysis of short-term power procurement planning for a renewable energy rich Discom is studied. An impact analysis model is also developed with regard to this work and it is used to analyse and understand the real scenario of the state of Tamil Nadu and Rajasthan. From the results of the model an optimal procurement portfolio is obtained taking into account all possible constraints that exist in the power system. This also compared two different scenarios of a RES rich state and how the portfolios and cost change between them. The two states having high wind and solar generation in the months of July and March respectively are compared and analysed with respect to the handling of RES generation quantum to meet the demand and the curtailment of the same. This model can be applied to any other state by using the corresponding set of data. Overall, from the study we can conclude that even though there might be some challenges in implementing, in future the quantum of short-term procurement would be dominating in the power purchase portfolio of any Discom which will give them flexibility in meeting the demand at optimum cost.

PUBLICATION FROM WORK

INTERNATIONAL CONFERENCE - SUBMITTED

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