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TRANSFORMING THE INDIAN POWER SECTOR

Distribution System Operators (DSOs): Need, Frameworks, and Regulatory Considerations

TRANSFORMING THE INDIAN POWER SECTOR

Distribution System Operators (DSOs) : Need, Frameworks, and Regulatory Considerations

2023

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Secretary
Government Of India
Ministry of Science and Technology
Department of Science and Technology

8TH December, 2022

MESSAGE

India is leading global efforts to address critical climate and clean energy challenges. India's ambitious climate goals include reaching 500 GW non-fossil energy capacity by 2030, reduction of total projected carbon emissions by one billion tonnes from now to 2030 and last but not the least, achieving net zero emissions by 2070.

With India now representing the 5th largest economy in the world, the increasing energy demand will pose a significant challenge to fulfilling the above goals. At the same time, this is an opportunistic period to accelerate the adoption of new technologies and systems to transform the power distribution system.

Over the years, Department of Science and Technology (DST) has played a pivotal role in Science & Technology innovation and has supported cutting-edge basic and translational R&D in areas such as power systems, smart grids, energy storage, and decision support systems. DST, India and the Department of Energy, U.S.A have also come together to support the "UI-ASSIST: U.S.-India collAborative for smart diStribution System with Storage" project under the umbrella of the Joint Clean Energy Research and Development Centre (JCERDC) initiative. This unique project seeks to address critical issues related to the adoption and deployment of smart grid concepts along with Distributed Energy Resources (DERs). One of the key research themes relates to investigating the role of Distribution System Operators (DSOs) along with their functions in the energy transition and understanding the regulatory as well as market issues.

This comprehensive report lays out a roadmap for implementation of DSOs in India and identifies the underlying technical and regulatory requirements. I hope that this report will be an excellent resource for regulators and policy makers tasked with implementing India's energy policy.

(S. Chandrasekhar)

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MESSAGE

India is transforming it's energy sector and emerging as a lead Nation to meet and exceed it's Nationally Determined Contributions. India is targeting a non – fossil energy share of 50% of its total installed capacity by 2030 and has embarked on transforming it's distribution systems through RDSS initiative.

The ever increasing demands and complexities due to inflexible and intermittent Renewable Energy Generation needs other new entities for balancing Grid Needs. The distribution system is thus going to transform into an active element from historical passive role. An active distribution system will be harbinger of fundamental changes and precursor to critical mass of consumers turning to prosumers. Prosumers are a crucial element for development of resilient local energy systems which may be leveraged to balance the increasing dependence of Grid on Renewable Energy resources.

In this background, I compliment initiative of DST in bringing together premier Indian and international institute in developing a comprehensive report of Distribution System Operators with nuances of organisation, technology and regulation all being addressed for this emerging area of Power System in India.

I look forward to a closer collaboration within Power System practitioners academic community to help adoption of DSO by DISCOMs and Regulators for enhancing their system reliability and effectively leading the goal of bringing down the SAIFI and SAIDI which is corner stone of consumer service motto for any power utility. This gels well with Ministry of Power's issued Rules on rights of consumer which can be served well with a dedicated entity like Distribution System operator.

DSOs can also accomplish a synergic integration of various entities, resources and consumer requirements to seamlessly transition for reduced dependence of Grid on fossil fuels Generators and can boost sustained enhancement of grid energy mix while boosting consumer confidence for quality service from Grid.

(Alok Kumar)

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सत्यमेव जयते

डॉ अखिलेश गुप्ता
Dr. Akhilesh Gupta

वरिष्ठ सलाहकार एवं प्रमुख
नीति समन्वय एवं कार्यक्रम प्रबंधन प्रभाग
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Foreword

As one of the fastest growing economies in the world, India is emerging as a global leader in addressing climate and clean energy challenges and is committed to increasing its Renewable Energy share to 50% of total requirements by 2030.

The ever increasing demand for energy and depleting supplies of fossil fuels, complexities of the distribution systems and the emergence of Prosumers warrant the need to increase renewable energy sources, build robust, reliable, and efficient infrastructure and distribution systems that seamlessly integrate India's Distribution Companies (DISCOMs) and Distributed Energy Resources (DERs).

To address these emerging challenges and to comply with the Panchamrit vision unveiled by Hon'ble Prime Minister at the Conference of Parties (COP 26) and India's National Electricity Policy 2021 (NEP 2021), a prosumer oriented, independent non-profit entity called Distribution System Operator (DSO) is proposed. The DSO will be responsible for real-time operation and distribution embedded with security, reliability and efficiency. The proposed DSO is expected to ensure a synergistic, interactive integration of DISCOMs and DERs with Transmission System Operators, take optimal network and investment decisions, and evolve into a secure, improved network system operator.

An institutional framework that can facilitate a smooth transition to DSO integrating existing and new entities in the energy sector needs to be developed. Addressing the challenge of protecting the interests, integrity and survival of all the entities in this process of will be an integral part of the DSO framework. Regulatory mechanisms will need to evolve to address the emerging trends and complexities of prosumers, new systems like EV charging, cyber security, system coordination, and forecasting market facilitation.

The introduction of DSOs will result in reduced dependence on fossil fuels, sustained development of renewable and alternate energy resources, boost private sector confidence and accelerate economic growth in the energy sector.

(Akhilesh Gupta)

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This report addresses the critical role of Distribution System Operators (DSOs) in transforming India's power sector and a detailed roadmap for implementation. The report builds on research carried out as part of the "US-India Collaborative for Smart Distribution System with Storage (UI-ASSIST)" project supported under the Joint Clean Energy Research and Development Centre initiative and jointly funded by the Department of Science & Technology (DST), Ministry of Science and Technology, Government of India and the U.S. Department of Energy.

We would like to express our gratitude to **Dr. Srivari Chandrasekhar**, Secretary, Department of Science and Technology, and **Shri Alok Kumar**, Secretary, Ministry of Power, for their support and encouragement.

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This report would not have been possible without the support of our collaborators, Ph.D. students, and technical experts who have provided valuable suggestions that have greatly improved the report.

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EXECUTIVE SUMMARY

As one of the fastest-growing economies in the world, India has set ambitious clean energy targets embracing sustainable alternatives to fulfil its energy requirements. The Panchamrit plan unveiled at COP26 calls for India to increase non-fossil energy capacity to 500 GW by 2030, meet 50 percent of its energy requirements from renewable energy by 2030, and achieve the Net Zero emissions target by 2070. This call to action will transform India's power sector, accelerating the pace of reforms and adoption of new technologies and systems.

The share of renewables in India's overall electricity generation mix has shown a substantial increase in the last few years. Distributed Energy Resources (DERs) have emerged as significant drivers of local sustainability because of their proximity to load centers, and play a pivotal role in achieving the Net Zero target while ensuring adequacy, reliability, and quality of supply even in remote areas. DERs can include rooftop Solar PV units, wind farms, combined heat and power plants, Battery Energy Storage Systems (BESS), small natural gas-fuelled generators, and Electric Vehicles (EVs). The Government of India has announced new policies and incentives to boost the installation of Solar PV units and increase the penetration of hybrid and electric vehicles.

The increasing installation of DERs in the distribution network, emergence of prosumers, and the availability of granular, real-time data are driving reforms in the power sector across the world. The traditional power grid is also transitioning to one that incorporates automation, information management, control and communication technologies allowing two-way information and data flow from utility companies and consumers. India's Distribution Companies (DISCOMs) must adapt to this changing landscape and implement much-needed reforms embracing new technologies and business models to ensure reliable and efficient network operation.

Strengthening or revamping existing entities and, in some cases, adding new players and regulatory approvals are critical to rolling out much-needed reforms. Many countries including the EU, Australia, USA, and Japan have embraced the notion of a Distribution System Operator (DSO), an entity that is responsible for the Development, Planning, and Operation of a DER-integrated Active Distribution Network in a Reliable, Secure, and Efficient manner.

Countries are at different stages of development in the implementation of DSO in their power distribution networks with DSO functions driven by the unique needs of each country/ region and prevailing market structure.

India's draft National Electricity Policy 2021 (NEP 2021) proposed introduction of an independent entity called the DSO for performing real-time operation of the distribution system and ensure security and reliability of supply to consumers as well as security of the grid. The introduction of a DSO-like entity will ensure reliable and quality supply to end consumers and be instrumental in bringing much-needed decarbonisation of power sector and contributing to power system flexibility to achieve India's ambitious renewable energy targets. India being a geographically diverse and large country, area-specific needs would primarily drive the evolution of DSO models.

In the Indian context, a DSO-like entity in the Indian context can provide the following critical functions:

- Address the challenges arising in the operation of active distribution systems and effectively service the consumers.
- Efficiently utilize flexibility available in the distribution system and behind the meter.
- Ensure synergistic interaction with Transmission System Operator.
- Take optimal network investment decisions.
- Enable use of data analytics for improved system operation.

The Current State of DISCOM

Before discussing the implementation of DSOs in the Indian context, it is critical to understand whether DISCOMs are in a position to handle the challenges of emerging active distribution systems. While it is difficult to respond with a 'Yes' or 'No' to the above question, it is clear that enhanced capabilities with the introduction of new/ redefined functionalities would be required for a system operator to handle the future active distribution networks. Existing regulations would need to be modified and new regulations framed to facilitate certain advanced functions.

Providing market avenues for trading electricity commodities of DERs would in turn require system operator or any DSO-like entity to be ideally neutral and independent. While it is clear that many existing DISCOMs with their legacy practices will find it difficult, if not impossible, to cater to the needs of emerging active distribution networks, others may be able to transition to DSOs in the future with the help of appropriate structural change and regulatory support. With the diversity of DISCOMs in terms of consumer mix and behaviour, DER penetration and potential, and operations and fiscal conditions, the definition or functionality of a DSO would be different in different regions.

Building Blocks for DSO Implementation

Technical Recommendations

State-of-art Supervisory Control and Data Acquisition (SCADA) system and software for data acquisition, monitoring, supervision, and control. Two-way strong and redundant communication network between the SCADA system and intelligent devices, such as Intelligent Electronics Devices (IEDs), Phasor Measurement Units (PMUs), and Internet of Things (IoT) devices for addressing real-time visualization, monitoring, and control of the power system network at control centre.

- Advanced Distribution Management System (ADMS) should be flexible and based on a plug and play architecture
- Information and Communication Technology (ICT) should be a full-fledged functional vertical and future technology ready.
- Advanced Metering Infrastructure (AMI) should enable easy sharing of data/information over multiple protocols with different applications
- Multi-layered approach should incorporate cyber security and system theory

Institutional Framework

Considering the prevailing structure of the Indian power sector and relevant learning from international practices, the following four alternatives of institutional frameworks are proposed:

- Separate Non-profit Entity
- Sub-State Load Despatch Centre (SLDC)/ Area Load Despatch Centre (ALDC) to DSO Transition
- DISCOM to DSO Transition.
- Repackaging of Existing and New Entities

Due to the diversity in generation and load patterns, ownership and operation models of DISCOMs, consumer mix, and state-specific regulations, different states will have different considerations for adopting any of the four suggested alternatives. While selecting a suitable DSO option, each state electricity regulatory commission will have to consider the current and anticipated electricity scenario in their respective State, especially the issues and challenges likely to be faced with large-scale penetration of DERs. The prevailing power system structure in a state will also serve as the main criteria for adopting a suitable DSO model.

Regulatory Requirements

Regulations need to spell out roles and responsibilities of DSOs and other entities having role in/bearing on distribution system operation taking note of emerging trends in end-use (prosumers, EV charging/support) demand response requirements, and cyber security for such active distribution systems.

Three options that may be considered for distribution system operations in the new paradigm are-

a) Distribution system operation under distribution licensee,

b) Distribution system operation under sub-SLDC

c) Distribution system operation through statutory provision.

Existing codes/regulations will need modifications/additions to address new functions and to perform existing functions in the manner or to the extent they need to be performed. These functions include scheduling and despatch, integrated network planning, cyber security, system coordination, forecasting, market facilitation and allied issues, and resource adequacy.

Structure of the Report

This report provides a detailed roadmap for DSO implementation in India, addressing the technical requirements, institutional frameworks, regulatory requirements, and long-term economic implications. The report is divided into six chapters, the first of which provides a background and an overview of the current Indian Power Distribution Sector. A section of the chapter also discusses the initiatives taken by different utilities across the globe to introduce DSOs and the associated learnings. The second chapter discusses the challenges involved in the transformation of the conventional (mostly passive) distribution networks into Active Distribution Networks (ADNs) with the integration of DERs, EV infrastructure, and BESSs. It addresses the technical requirements for implementation of the various functions envisaged to be performed in ADNs and the perceived role of DSO in the Indian context, followed by the definitions of DSO across the globe. Chapter 3 introduces the reader to the proposed institutional framework of DSOs in India. This chapter suggests four alternatives for introducing DSOs, considering the prevailing structure of the Indian power sector and international practices.

With the introduction of the local level electricity market in the Indian power sector, consumers and prosumers will be empowered not only in terms of having a choice of supply but will also have the option to sell it (in the form of demand response) either within the local-level electricity market or participate in the wholesale electricity market through an aggregator. Chapter 4 provides an overview of the electricity commodity trading opportunities under the DSO set-up.

The legal, policy, and regulatory landscape, as well as considerations pertinent to distribution system management, are presented in chapter 5 with a view to understanding the organisation of core activities and the way they are conducted under various legal and regulatory considerations. Based on the review of existing national and international learning and studies presented in the preceding chapters, recommendations on technical, regulatory, institutional manpower and skill requirements aspects, cost-benefit analysis, and implementation plan of DSO are presented in the final chapter.

The introduction of DSOs can be a game-changer in transforming the operational and financial state of the Indian power sector and boost private sector's confidence attracting much-needed investment and innovation in the industry. Regulators and utilities need to come forward to facilitate this transition that will ultimately result in the efficient operation of the overall distribution grid.

LIST OF ACRONYMS

ACS	Average Cost of Supply	FC	Flexibility Coordinator
ADMS	Advanced Distribution Management System	FoR	Forum of Regulators
ALDC	Area Load Despatch Centre	GoI	Government of India
AMI	Advanced Metering Infrastructure	ICT	Information and Communication Technology
ADN	Active Distribution Network	IEDs	Intelligent Electronics Devices
AT&C Losses	Aggregate Technical and Commercial Losses	IEGC	Indian Electricity Grid Code
BESS	Battery Energy Storage Systems	IoT	Internet of Things
BRPL	BSES Rajdhani Power Limited	IPDS	Integrated Power Development Scheme
CABIL	Capacity Building of Indian Load Despatch Centres	NDOA	Non-Discriminatory Open Access
CEA	Central Electricity Authority	NEP	National Electricity Policy
CERC	Central Electricity Regulatory Commission	NLDC	National Load Despatch Centre
CIM	Common Information Model	OA	Open Access
CTU	Central Transmission Utility	P2P	Peer-to-Peer
DCC	Distribution Control Centre	PMUs	Phasor Measurement Units
DERs	Distributed Energy Resources	POLR	Provider of Last Resort
DISCOM	Distribution Company	PPA	Power Purchase Agreements
DLMP	Distribution Locational Marginal Pricing	QCA	Qualified Coordinating Agency
DMO	Distribution Market Operator	RA	Resource Adequacy
DMS	Distribution Management System	RLDC	Regional Load Despatch Centres
DNC	Distribution Network Company	SAMAST	Scheduling, Accounting, Metering, and Settlement of Transactions in Electricity
DNI	Distribution Network Infrastructure	SCADA	Supervisory Control and Data Acquisition
DNO	Distribution Network Operator	SERC	State Electricity Regulatory Commission
DR	Demand Response	SLDC	State Load Despatch Centres
DSM	Deviation Settlement Mechanism	SOA	Service-oriented architecture
DSO	Distribution System Operator	STOA	Short-Term Open Access
EA	Electricity Act 2003	STU	State Transmission Utility
EMS	Energy Management System	TN	Transmission Network
ENA	Electricity Networks Association	TPWODL	TP Western Odisha Distribution Ltd.
ESB	Enterprise Service Bus	TSO	Transmission System Operator
EVs	Electric Vehicles	WEM	Wholesale Electricity Market

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1 INTRODUCTION

1.1 BACKGROUND

To address global environmental concerns, countries across the globe are transitioning to low-carbon economies and decarbonizing their electricity sector. As one of the fastest-growing economies and the second-most populous country, India also embraces sustainable options to fulfill its energy needs and has set ambitious targets to achieve 50 percent of its installed generation capacity with renewables by 2030 and meet the Net Zero emissions target by 2070 [1]. Due to the ambitious targets set, the renewables' share in India's overall electricity generation mix shows a substantial increase in the last few years. As of February 2022, around 159 GW of India's total installed generation capacity is non- fossil fuel-based generation [2]. Due to their clean operation and proximity to load, Distributed Energy Resources (DERs) have emerged as significant drivers for local sustainability.

DER's play a pivotal role in achieving the Net Zero target and help in achieving adequacy, reliability and quality of supply even in remote areas. DERs include rooftop Solar PV units, combined heat and power plants, Battery Energy Storage Systems (BESS), small natural gas-fuelled generators, Electric Vehicles (EVs), and controllable loads [3]. In the long term, DERs have the inherent potential to help achieve sustainable development goals and reduce environmental impacts. India's rooftop Solar PV market is also growing, and its installed capacity at the end of Q3 2022 is assessed to be 6.7 GW [4]. The commercial and industrial consumers, who are charged tariffs higher than the actual cost of supply, are more inclined to adopt rooftop Solar PV units to get electricity supply at considerably lower prices. The residential and agricultural consumers in India have been supplied electricity at subsidized rates; thus, they have little inclination to install rooftop Solar PV units. As the migration of high-paying commercial and industrial consumers affects the revenue of Distribution Companies (DISCOMs), they are not enthused in facilitating the grid-connected rooftops.

To overcome these challenges and boost rooftop Solar PV unit's installation at residential and commercial premises, the Ministry of New and Renewable Energy (MNRE) in 2019 announced guidelines on implementing Phase–II of the Grid Connected Rooftop Solar Programme [5]. It aimed to achieve 40 GW capacity from rooftop Solar PV units by 2022 and ease rooftop Solar PV adoption of grid-connected rooftops.

The rooftop Solar PV units and battery storage are complementary for fulfilling continuous electricity needs and are likely to get widely adopted. The grid-scale BESSs are also emerging as efficient contenders for providing grid services such as voltage and frequency regulation, black start, etc. However, they are still at the pilot stage [6], and E-Mobility is another operations sector on which the Government of India (GoI) is intensely focused, which will impact the distribution network. Compared to the conventional internal combustion engine-based vehicles, EVs have many advantages, particularly from environmental perspectives. As per the National Electric Mobility Mission Plan (NEMMP) 2020 [7], the target for sale of hybrid and electric vehicles by 2020 was 6-7 million. By 2030, the total charging capacity in India is anticipated to reach more than 18 GW deployed at both homes and commercial buildings [8]. As EVs and other DERs emerge as the primary behind-the-meter source/load, they will lead to the bi-directional power flow over the distribution network. As a result, DISCOMs will experience issues related to the power quality, protection, local congestion, voltage stability, voltage violation, and power losses.

Hence, the traditional fit and forget approach for integrating DERs will no longer suffice. For example, the uncoordinated charging of EVs will create significant stress to the distribution network as it may add further to the peak load rise and may affect the stability of the system. Thus, the charging pattern of EVs needs to be managed actively as per the real-time conditions of the network.

Electric cooking is another emerging sector with considerable potential to reduce the high demand for LPG and assist in achieving the net-zero goals. As per the India Residential Energy Survey (IRES) 2020, the adoption of electric cooking in India stands at a low five percent and mainly covers high-income urban households.

> DERs are emerging as a game-changer and key driver for local sustainability.

In Feb 2021, the Government of India launched the "Go Electric" campaign to spread awareness of e-mobility, EV charging infrastructure, and electric cooking in India. Multiple technology alternatives exist for electricity-based cooking, such as induction cooktops, electric pressure cookers, solar energy-based cooktops, etc. Their load varies typically from 700 W to 2 kW. Thus, a proper assessment of the readiness of the existing distribution network to support the widespread adoption of electric cooking needs to be carried out. One of the prerequisites for actively embracing electric cooking involves the availability of reliable and quality electricity supply. Thus, ensuring reliable distribution grid operation and gaining consumer confidence with quality power supply are the critical challenges for the distribution sector.

There are also growing concerns about the lack of DER visibility and the adequacy of planning for DER within the distribution network. As a result of a massive rollout of rooftop Solar PV units and encouragement for EVs, many consumers are likely to become Prosumers and then explore options to trade electricity as per their choice in a manner which is beneficial to them. However, getting appropriate price and network signals from markets/system operators are the prerequisites for facilitating these transactions duly taking care of security of distribution system.

A reliable information, communication and metering infrastructure must also be in place for seamless flow of data as well as supervisory control. Unfortunately, most of the DISCOMs lack the financial resources to modernize their infrastructure to efficiently handle the operational and reliability issues amidst the vast proliferation of DERs. In a nutshell, the role of modern-day DISCOMs under changing circumstances is becoming challenging and further evolving. Looking at the emerging trends, DISCOMs need to embrace new technologies and business models to ensure reliable and efficient network operation.

Facilitating the massive deployment of solar rooftops, solar irrigation pumps and decarbonizing the road transportation and cooking sector will significantly change the operating paradigm of the conventional distribution system. Most of the DERs have the intrinsic capability to modulate their generation or consumption pattern upon request by the owner/network operator. It is known as flexibility. The flexibility services provided by DERs are emerging as a promising tool for grid management and could be employed by both transmission and distribution system operators.

However, it needs to be explored and utilized via a suitable market mechanism in unison with other resources. Currently, the flexibility resources embedded within the distribution network are not used appropriately for various reasons. These include small/medium capacity and disaggregated nature of DERs, a lack of proper forecasting, metering, data telemetry, Information and Communication Technology (ICT) infrastructure, and an absence of regulatory framework and active network operator.

Also, exploring and utilizing the inherent flexibility requires a tariff that will enthuse the consumers to provide Demand Response (DR) for the benefit of the distribution system's safety, security, and reliability. Amidst this changing landscape, distribution utility's role becomes critical. Strengthening or revamping existing entities and, in some cases, adding new players and regulatory approvals are the prerequisites to rollout much-needed reforms. Apart from infusing capital, timely policy and regulatory facilitations/interventions and institutional support are also required to enable smooth energy transition. Globally, the Distribution System Operator (DSO) concept is envisioned to ensure reliable, resilient, and cost-effective electricity delivery with high DER penetration at the distribution level.

The need for DSO is paramount to shape the demand profile to maximize the use of sustainable sources of energy. It would help optimize the use of existing generation, transmission and distribution capacity, reduce losses across the supply chain, foster a new flexibility market to emerge, and offer a competitive trading platform for all entities involved in the supply and consumption of various flexibility services.

The availability of granular and behind-the-meter data and fair network and market access is vital in making network reinforcement-related decisions. There is a need to study customer behaviour and consumption trends proactively. Handling these activities by a neutral entity could boost the consumer's confidence and attract much-needed investment in the distribution sector. It could bring the necessary transformation and innovation swiftly.

> "Digitalization and decentralization are the enablers for achieving decarbonization."

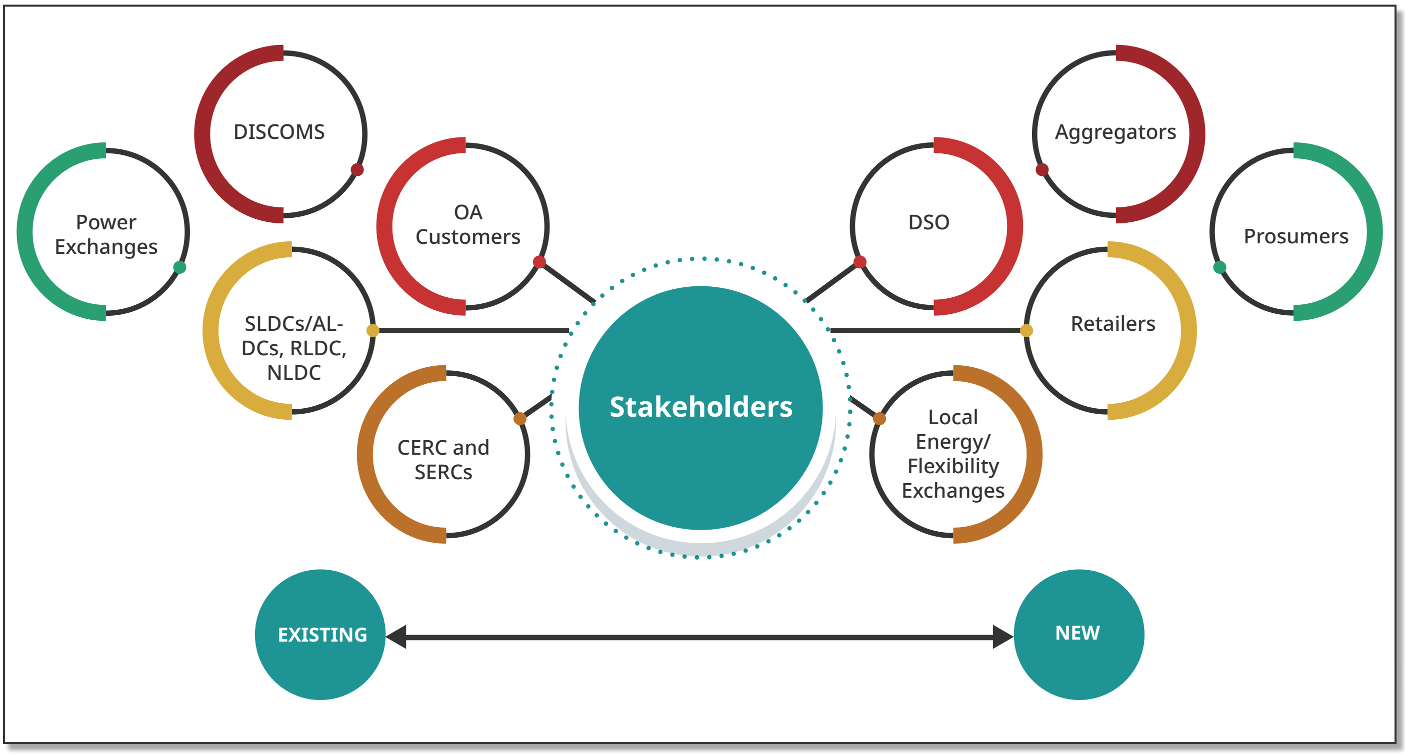


Figure 1.1 Existing and new stakeholders

The DSO could serve the purpose and make such data available to different entities transparently for business or investment purposes keeping privacy of consumer data in mind. A dedicated and proactive entity like DSO could also handle cyber security-related issues with the required degree of focus. It can also ensure complete visualization of the distribution network to manage local generation and load effectively.

To address the emerging challenges, the entry of new players is inevitable. As depicted in Fig.1.1, the anticipated new entities like DSO, aggregators, prosumers, retailers, and local energy/ flexibility trading platforms must work hand-in-hand with the existing ones to ensure the reliable and efficient operation of the low-carbon power grid.

1.2 INDIAN POWER DISTRIBUTION SECTOR AT A GLANCE

In India, the vertically integrated power sector has been unbundled to have a focused approach to planning, development, and operation across the value chain. Most of the DISCOMs handle the metering, billing, and collection of dues for the electricity supplied to end consumers and are thus referred to as the cash register for the entire power sector. They are responsible for distribution network operation and providing electricity to the end consumers. DISCOMs across the country are witnessing the vast proliferation of DERs.

The anticipated evolution of the distribution network with the increasing penetration level of DERs is shown in Fig. 1.2. Most of the DISCOMs in India are state-owned; the private DISCOMs serve nearly 10 percent of India's population [9]. This section has attempted to give a general view and highlight fundamental issues impacting the overall performance of the distribution sector.

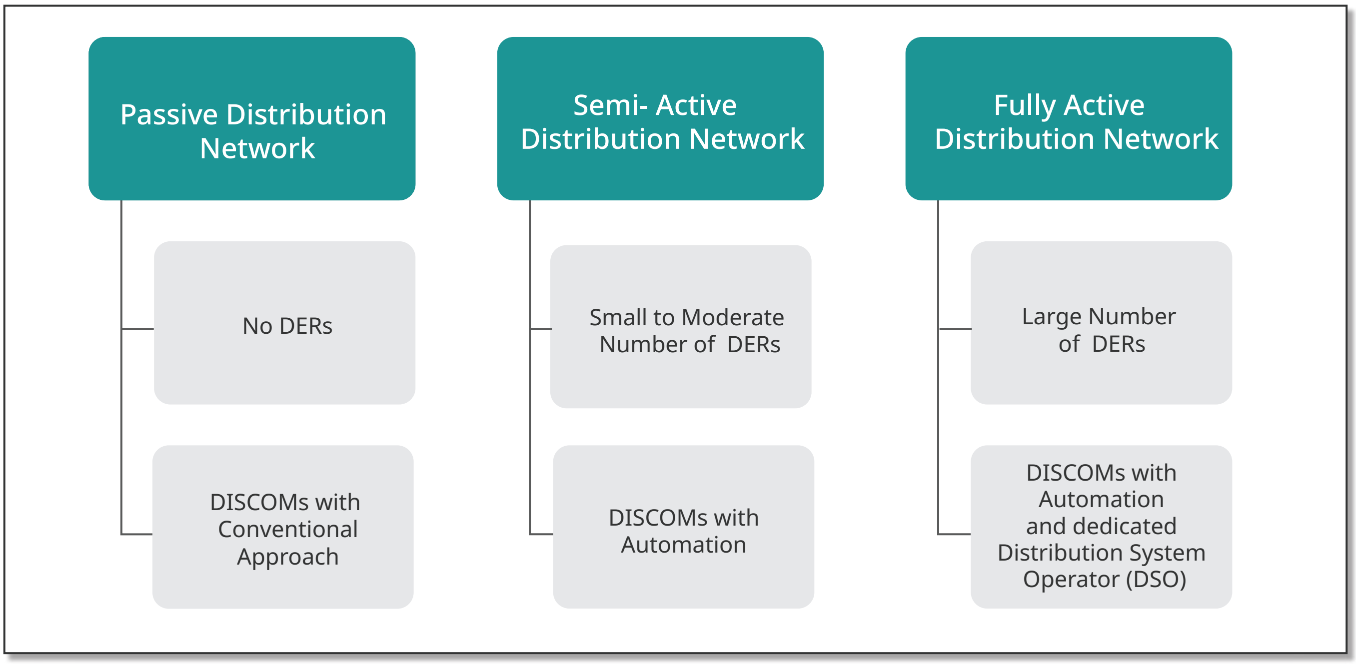


Figure 1.2: Evolution of distribution network

1.2.1 OPERATIONAL AND TECHNICAL CHALLENGES

The power purchase cost component comprises about 70% of the total cost of electricity supplied to end consumers by DISCOMs [10]. Traditionally, DISCOMs fulfill the energy requirements of their consumers through long-term Power Purchase Agreements (PPAs). As a result, around 87% of India's generation capacities are tied up in PPAs [11] and DISCOMs are not in a position to explore the more competitive opportunities, causing them to purchase power from the generating plants with a long- term PPA. It also results in a liquidity shortage in the Wholesale Electricity Market (WEM) and partial or sub-optimal utilization of lower-cost generation while relatively costly generation gets utilized.

Distribution utilities also need to invest more in metering at the distribution transformer and consumer level, along with automatic data collection systems. In the absence of such systems, energy auditing of loss-making DISCOMs becomes challenging [12]. The uptake of DERs such as solar rooftops and EVs, the lack of SCADA, modern telecommunications, data analysis tools, and dedicated distribution level system operator is likely to hinder DISCOM's ability to monitor behind the meter load and DER output (solar rooftop and EVs) properly and execute control actions. It may lead to mismanagement of the load, revenue loss, and nuisance to the customers.

A robust database could be maintained easily using India's Smart Meter National Programme (SMNP) which intends to substitute the country's 25 crore traditional meters with Advanced Metering Infrastructure (AMI) [13]. Such initiatives are the preliminary steps towards realizing the Smart Grid vision.

The AMI roll-out primarily focuses on improving billing and collection efficiency. However, smart meter data could be used to understand consumer behaviour and for efficient grid operation. Information and telecommunication solutions along with automation are pivotal for monitoring and controlling power flow over the distribution network in real-time. These technologies help in ensuring data transparency, better decision-making based on enhanced analytics, more trustworthy and granular tariff structure, and efficient load management.

In the absence of digitalization, keeping a complete record of all customers is challenging, especially in rural areas, resulting in direct revenue loss. Manual reading of energy meters and bill delivery have been prone to errors and delays. Still, it is routine in many DISCOMs. The routine monitoring and testing of critical assets such as 11kV and 415 V feeders, distribution transformers, etc., is paramount to ensure a reliable supply to end consumers. In the absence of real-time monitoring systems, most State-owned DISCOMs use mobile phones or radio communication for load management which directly affects the security of their network.

Additionally, DISCOMs need to maintain a proper digital asset database. In the presence of such a database, utilities could ensure the efficient management of their assets. It could help calculate Return on Equity (ROE), interest on the loan, interest on working capital, depreciation, etc., under annual revenue requirements. Implementing SCADA at the distribution level is the need of the hour. It becomes even more apparent due to the anticipated rapid integration of many DERs with the distribution network. DER integration needs to be handled diligently as it will affect the technical and financial operation of DISCOMs.

Due to the absence of a dedicated distribution level system operator, it is difficult for DISCOMs alone to monitor power flow, manage congestion, and execute load shedding and other instructions from the SLDC.

1.2.2 FINANCIAL ISSUES

Over the years, state-owned DISCOMs have suffered financially due to high Aggregate Technical & Commercial (AT&C) losses, non-cost reflective tariff structure, and delays in obtaining subsidies from the State governments. The dues from DISCOMs' to generation companies as of March 2021 were estimated to be ₹ 67,917 crores [9]. DISCOMs substantial chunk of revenue comes from commercial and industrial customers. However, due to the lockdown restrictions, they have seen a significant decline in revenues in Q1 FY2021 [14]. With the rapid integration of DERs, it will be challeninig for financially stressed DISCOMs to make adequate investments in network up-gradation to facilitate the smooth transition from passive to active network operation. Such investments are also necessary to ensure reliable and good quality power supply to all consumers. The states with private DISCOMs and those with abundant hydro resources are in a better position financially [15]. Improvement in billing and collection efficiency has resulted in a reduction in the country's overall AT&C losses to 22%.

However, as compared to the global average of 8%, these losses are still very high in India. Also, there is wide variation of AT&C losses across various states. Due to the rising Average Cost of Supply (ACS), commercial and industrial consumers explore other cheaper options to fulfill their electricity needs such as captive generation or non-DISCOM supply from solar and wind farms through Open Access (OA). It results in the migration of high-paying (cross- subsidizing) big consumers and ultimately loss in revenue for DISCOMs. This trend is going upward despite procedural hurdles, high cross-subsidy surcharge, and imposition of additional surcharges [16]. OA contracts are usually short-term and medium-term, and consumers are free to draw energy from the existing network. With an increasing number of OA customers, power procurement becomes a challenging task for DISCOMs, resulting in the inefficient operation of the DISCOMs. Lack of visibility of behind-the-meter generation is also a hurdle for DISCOMs in forecasting net load.

The network costs of transmission and distribution are growing substantially across states. The apparent reasons are capital investment in network reinforcement, high operation, and maintenance (O&M) cost, and partly accounting for inefficiencies. Due to costly PPAs and high network costs, the average supply cost is likely to increase by about 4 to 5% per annum in short to medium term [17].

A separate entity empowered with essential tools and skills could aid the DISCOMs to optimize power procurement by sharing granular data, shaping the demand profile as per system requirements, providing reliable and quality supply, which has the potential of not only improving revenue realization but also increasing the sale of electricity.

Traditionally, DISCOMs carry out distribution network reinforcement activities such as adding new lines, protection etc. and individual DER owners are accountable for DER planning. With large-scale DER installations, coordinated planning and investment in network reinforcement to evacuate renewable energy generation is required. The uncoordinated DER planning and network reinforcement may burden the end consumers in terms of extra network cost.

Under changing circumstances, a coordinated approach is required to make sure that the security constraints of the distribution system are not violated and optimal investment is made in network reinforcement. DISCOMs and DER owners should send plans of network reinforcement and DER planning to a neutral entity like DSO, which will then send economic signals, such as capacity and price signals, to DISCOMs and DER owners to yield a better economy [18].

1.2.3 ONGOING DISTRIBUTION SECTOR REFORMS

Aiming at rapid decarbonisation, decentralisation, and digitalisation of the power sector, the GoI, and various state governments have taken significant steps to introduce competition through market reforms and modernization of critical power infrastructure. Both the Central and State governments are funding numerous projects for improving the distribution sector. The GoI notified the Integrated Power Development Scheme (IPDS) [19] in December 2014 which carried forward the Restructured Accelerated Power Development & Reforms Program (R-APDRP). Its primary focus was on consumer indexing, asset mapping, strengthening sub-transmission and distribution networks in the urban areas & promoting the metering of distribution transformers/feeders/consumers in the urban areas. In 2015, the UDAY scheme [20] was launched to improve the operational and financial condition of the DISCOMs.

Under this scheme, states were encouraged to take over 75 percent of the DISCOM's debt. The scheme has adequately addressed and reduced the debts and the AT &C losses. However, the hurdles around cross-subsidy and power-procurement costs still need to be addressed. Under the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) scheme [21], the GoI planned to supply quality and reliable 24 x 7 power to rural homes and adequate power to agricultural consumers.

The PM-KUSUM Scheme [22] launched in 2019, aims to set up 10,000 MW of decentralized grid-connected renewable energy power plants on barren land, install 17.50 Lakh stand-alone solar agriculture pumps, and solarize 10 Lakh grid-connected agriculture pumps. The primary focus was to encourage farmers to use solar power to meet the irrigation load. DISCOMs are deemed to buy the excess solar energy at a pre-fixed tariff. The GoI recently announced a revamped, reforms-based result-linked power distribution scheme in the 2021-22 budget [23].

The scheme intends to assist DISCOMs in building modern infrastructure such as pre-paid smart metering and feeder separation, up-gradation of systems, etc.

The separation of residential and agricultural feeders is likely to yield better load management and increased supply to rural homes [16]. Solarisation of feeders and pumps would help farmers use electricity in the daytime and reduce the state governments' subsidy burden.

Under its flagship Atmanirbhar Bharat package, the GoI has announced liquidity support of ₹ 1.25 trillion in the form of loans against receivables for the DISCOMs [14] .Due to poor compliance to its terms, only ₹ 460 billion has been disbursed; thereby, DISCOMs dues to generation and transmission companies remain high.

The Revamped Distribution Sector Scheme (RDSS) [23] has been approved to help DISCOMs improve their operational efficiencies and financial sustainability by providing result-linked financial assistance to DISCOMs to strengthen supply infrastructure based on meeting pre-qualifying criteria and achieving basic minimum benchmarks.

The scheme has an outlay of Rs 3,03,758 Crore over 5 years, i.e., FY 2021- 22 to FY 2025-26. The scheme aims to meet the following objectives:

- Reduction of AT&C losses to pan-India levels of 12-15% by 2024-25.
- Reduction of Average Cost of Supply (ACS) - Average Realisable Revenue (ARR) gap to zero by 2024-25.
- Improvement in the quality, reliability, and affordability of power supply to consumers through a financially sustainable and operationally efficient distribution sector.

> PM's Mantra: Reform, Perform, and Transform

The components of the scheme are:

- Part A – Financial support for Prepaid Smart Metering & System Metering and up-gradation of the Distribution Infrastructure.

- Part B – Training, Capacity Building and other Enabling & Supporting Activities.

The GoI has also proposed privatization of the DISCOMs to strengthen the entire distribution sector. As a first step, privatization of DISCOMs in Union Territories (UTs) was announced in May 2020 [24], and the corresponding draft bidding guidelines [25] were also notified by the Ministry of Power. Subsequently, considering all stakeholders' interests, the GoI proposed to delicense distribution sector and allow various players to serve a given distribution area [9].

It was aimed at advancing towards a market-based approach for efficient distribution system operation. The subject matter of DSO has been under discussion in India for the last few years. The technical committee's report on large-scale integration of renewable energy, need for balancing, deviation settlement mechanism (DSM), and associated issues [26] has debated the need to study the viability of an independent (or existing) entity to assume the role of a DSO.

Such an entity is envisioned to perform a more comprehensive array of functions to ensure optimal utilization of DERs. The report envisages that the pro-active DSO should support consumers such as Prosumer, Aggregators, TSO, etc., with faster (real-time), more transparent, and granular data. It should also manage different contracts and new consumer relationships.

The Report on Scheduling, Accounting, Metering and Settlement of Transactions in Electricity (SAMAST) [27] of the Forum of Regulators (FoR) has emphasized the need to constitute a robust institution of DSOs in the Indian power system, which should be neutral, independent, transparent, non- discriminatory, and equipped with a skilled workforce. The concept of DSO on bylines of SLDC was envisaged. It was clarified that DSO would report to SLDC and the State Regulator. In a way, DSO may act as sub-SLDC. The DISCOM-level control centres in states like New Delhi (BSES, TPDDL, NDMC & MES) and in Mumbai (TPC, Chembur & RInfra, Aarey Colony) are already undertaking roles like that of a DSO.

The operation of the distribution grid, management of DER, coordination of operation between distribution and transmission grid for switching, managing bi-directional power flows, optimized shutdown, processes, etc., have been envisaged as potential functions of DSOs in Capacity Building of Indian Load Despatch Centres (CABIL) report [28]. It has also recommended the establishment of DSOs in each state which would interact with the state SLDCs to ensure system security.

As part of the deliberations made by the subcommittee with some of the load despatch centres to study the prevailing setup for scheduling, despatching, metering, energy accounting, and settlement system within the state brought forth some of the challenges relevant in the context of DSO.

A few initiatives at the State level have also started to emerge. The Tamil Nadu State Load Despatch Centre, in its Draft Procedure for Deviation Settlement of State Entities and Energy Accounting of the State [29] made a provision for the functions to be performed by the DSO as and when it comes into reality. Those functions, especially scheduling and despatch, are presently being assigned to the planning wing of Tamil Nadu Generation and Distribution Corporation (TANGEDCO).

The draft National Electricity Policy (NEP) 2021 [30] has also covered the discussion related to Distribution System Operator (DSO) and is given below for ready reference:

"Distribution SCADA system must be implemented by the utilities as a tool with the DSO, on a priority basis, to facilitate creation of network information and customer data base and to help in the management of load, improvement in quality, detection of theft and tampering, customer information and for prompt and correct billing and collection. The DSO would play a significant role in dealing with distributed generation resources rooftop Solar PV power connected to the grid to ensure the security and reliability of supply to consumers and the grid's security. DSO may be made a separate and independent entity if separation of carriage and content occurs."

As DSO is gaining attention in India, a review of DSO-related activities in various parts of the world is carried out in the next section. An attempt has been made to compare multiple DSO-related proposals and extract essential learnings in the Indian context.

1.3 DSO EVOLUTION: INTERNATIONAL EXPERIENCES

Extensive technological advancements have only served to augment the importance of DSO. Utilities and regulators across the globe are exploring the feasibility of introducing and implementing the DSO function to ensure optimal utilization of DERs and aiding new business models to emerge.

Many electricity markets, such as those in the UK, Australia, USA, Japan, and various European countries, are advancing towards embracing the DSO functions. There are diverse understandings of DSO. Hence, this section discusses the initiatives taken by different utilities across the globe in introducing DSO.

1.3.1 INITIATIVES IN UNITED KINGDOM (UK)

UK is one of the early countries that started privatizing the power sector and developing an electricity market. It has taken numerous measures to ensure a reliable and secure supply to its end consumers. Not all of their endeavors were successful, and some of these faced failures. However, they learned from each attempt and brought innovation and necessary changes into the sector [31]. In the UK, Distribution Network Operator (DNOs) handles the distribution wire business while Retailers handle the supply business. There are around 14 licensed DNOs in GB [32].

They are wires-only companies that own and run the distribution systems for a regional distribution services area. Six different groups hold the 14 DNOs. The operators of distributed generating stations can also operate as licensed suppliers. It resulted in a dramatic growth in the number of distributed generators seeking to connect to the distribution network. Currently, there are over 120 domestic and non-domestic supply licenses (retailers) [33]. The rollout of smart meters, started in April 2011, was expected to conclude by 2020.

The Data and Communications Company (DCC) license was issued to Smart DCC Ltd to establish and manage the smart metering data and communications infrastructure. Ofgem (regulator) regulates DCC. The DCC is responsible for linking smart meters in houses and small businesses with the systems of energy supplies, network operators, and energy service companies. The UK has witnessed a rapid proliferation of various DERs and has recognized them as a source of flexibility that both transmission and distribution system operators could utilize [34]. Unlike the conventional linear network, one-way flow of power from centralized generators to consumers, the system is increasingly becoming a two-way exchange network, enabling the exchange of energy & data and growing consumer choice. Increasing local generation portfolios and decentralization have instigated the UK's Distribution System Operator (DSO) concept. It was envisaged that the DSOs would act as the coordinator between network operators and the Prosumers, manage and facilitate electricity markets, and flexible loads in local areas they serve.

The UK's DNO to DSO transition program is ongoing and led by DNOs rather than the government or Ofgem [35] [36]. Trials are currently underway in several regions to explore the possibility of voltage controls at the household level, peer-to-peer trades between meters, and DSOs procuring grid services from local generators to help manage their system. Several pilot projects are also going on. Currently, Open Networks Project in the UK is led by the Electricity Networks Association (ENA) [37], which consists of the nine British and Irish electricity grid operators, the British Government, the energy regulator Ofgem, several academics, and NGOs. In 2018, the Open Networks Project showcased five potential industry structures, known as Future Worlds [38]. Extensive work was carried out with stakeholders to define these five Future Worlds.

They were modelled using the Smart Grid Architecture Model (SGAM) to explain further the information flows necessary for each world to operate. Many web-based tools (provided mainly by the third party like aggregators) are emerging in GB to facilitate the consumers and owners of DERs to participate in local flexibility markets.

In GB, DSO can procure local flexibility services for local congestion management, and Transmission System Operator (TSO) can also procure local flexibility services as a tertiary reserve. New market mechanisms are emerging to accommodate these services into the existing market structure. In GB, few pilot projects are going on to facilitate the entry of demand-side flexibility providers into the ancillary services market. Energy storage and other flexibility providers with units as small as 1 MW now have access to GB's core flexibility market' under National Grid ESO reforms. Since April 2019, aggregators can also play into the market for the first time without needing a supplier license.

One of the aggregators, Limejump [39] has already entered its virtual power plant into the Balancing Mechanism (BM). The aggregators can pool the local distributed energy resources and participate in electricity markets (both flexibility and energy markets) on behalf of small consumers. Currently, around 23 Commercial Aggregation Service Providers are present in the UK [40].

1.3.2 INITIATIVES IN AUSTRALIA

Australia has taken a substantial lead in the decentralization and digitalization of the electricity sector. It has recently witnessed massive integration of rooftop solar systems and now has more than 2.1 million residential rooftop solar systems [41]. Australia's transmission and distribution networks are owned and operated by a combination of 18 different publicly and privately-owned organizations. The Australian Energy Market Commission (AEMC) anticipates that more than half of all homes will have rooftop solar PV systems, and a third of them will have energy storage by 2050. As traditional distribution networks were not designed to accommodate so many rooftop solar systems, a debate is going on in Australia on managing the substantial penetration of solar and battery systems and their interaction with the grid.

The urgent need for new rules and markets to effectively utilize these new resources has been identified. The need for the DSO has been recognized to address the challenges of high DER penetration. In this regard, Australian Energy Market Operator (AEMO) and Energy Networks Australia (ENA) had initiated an Open Energy Networks (OpEN) consultation program in June 2018. It endeavored to elaborate various DSO functions and collect stakeholder inputs on efficiently integrating DERs. The rapid penetration of DERs causes technical difficulties, thus cause of concern for both the AEMO and Distribution Network Service Providers (DNSPs). The OpEN consultation program has explored various options to optimize and effectively manage DERs and facilitate their entry into the Wholesale Electricity Market (WEM).

In its interim report [42] published in July 2019, OpEN has proposed four frameworks along with data, key milestones, and actions for integrating DERs into Australia's electricity system. Those four frameworks are:

- Single Integrated Platform (SIP) (Managed by Energy Market Operator)
- Two-Step Tiered Platform (TST) (Managed by DNSP)
- Independent Distribution System Operator (IDSO) (Entry of a new player to manage the integration and despatch of DERs in a distribution market).
- Hybrid (Market operation handled by AEMO, and the DNSP handles the network optimization)

A detailed cost-benefit analysis of each framework and modelling of each framework's implementation under multiple DER-uptake scenarios produced by AEMO has been done. All four frameworks envisage the creation of two new entities to deliver a distribution market: the Distribution System Operator (DSO) and the Distribution Market Operator (DMO).

1.3.3 INITIATIVES IN CALIFORNIA

California's WEM and transmission operations are managed by the California Independent System Operator (CAISO). The Transmission and Distribution owners and Operators (TDOs) in California do not hold generation and profit from the electricity sale. The electricity supply to end consumers is taken care of by independent retailers. Community Choice Aggregators (CCAs) also serve as retailers. All these entities are also attributed as Load Serving Entities (LSEs). The Transmission Operator (TO) is the owner and is responsible for the operation and routine or emergency switching for the transmission system. It operates under the guidance and supervision of the CAISO. Similarly, the Distribution Operator (DO) is the owner and is responsible for the operation and handling of routine and emergency switching for distribution networks.

Each of the three investor-owned utilities handles TO and DO functions in California; however, these functions are separated as per the regulations. The TDOs also have an obligation to supply power to end consumers as Provider of Last Resort (POLR). The day-ahead energy scheduling and settling with the CAISO are managed by the scheduling coordinator [43]. It also manages any real-time deviations on behalf of LSEs, wholesale suppliers, and DER aggregators. California has witnessed a substantial growth of DERs and now has a significant share of variable energy resources in its generation mix. It has taken many initiatives such as 50% renewable portfolio standard, solar and electric vehicle (EV) incentives, feed-in and net energy metering tariffs, 1300 MW energy storage mandate, and extensive expenditure on energy efficiency and demand response programs ($1 billion annually) [44]. It is anticipated that DERs will constitute about 45% of the total energy mix by 2025. To ensure an efficient and reliable system operation, the corresponding stakeholders have recognized the need for a coordination framework between transmission and distribution operators [45].

As DERs are emerging as potential players to enter the wholesale market, the need for a Hybrid DSO model has been recognized to deal with complex coordination issues. The hybrid DSO will play an essential role in providing timely information such as available network capacity to all DERs or their aggregators. Such information is critical to them to place appropriate energy or capacity bids on the CAISO market. Such a DSO function would also help CAISO assess the probable response level at all pricing nodes for its market despatches. The ongoing discussion also suggests using the extended version of the prevailing model as a viable option, giving direct access to wholesale markets. However, its feasibility is doubtful for future scenarios as DER proliferation will surpass 40% of the system peak by 2025. The need for a clear distinction between the role of DSO and the current distribution operator has been recognized. The idea of creating an independent DSO under the umbrella of the Total DSO model has also emerged.

However, the regulator's role has been paramount to ensure the timely introduction of an entity like DSO in California. It is expected that the rigorous discussions on DSO will eventually commence when despatchable DERs like batteries reach substantial levels and customers are encouraged to actively participate in market and sell excess energy to other parties.

1.3.4 INITIATIVES IN NEW YORK

The New York Independent System Operator (NYISO) is an independent real-time wholesale electricity market and transmission system operator. New York has five investor-owned utilities that are also TDOs. They do not own any generation. Retailers handle the retail business of supplying electricity to end consumers. The TDOs also act as POLR and are bound to secure resources to match the customers' demands. NYISO foresees allowing aggregated resources up to 100 kW to participate in wholesale markets for energy, ancillary services, and capacity against the existing limit of 1 MW. Unlike California, NYISO intends to let such aggregations be solely within a single pricing node [44]. DOs have been developing contract-based acquisition models for DER to provide distribution-level services and avoid costly network reinforcements. NYISO and DO have been involved in designing rules for the DER service hierarchy. Such practices need to be in place to provide the right singles to participating DERs and to ensure excellent orchestration.

The New York regulator under the Reforming the Energy Vision (REV) [46] has set ambitious targets such as a 40% reduction in GHG emissions from 1990 levels by 2030. It also includes 50% of generation from renewable energy resources and a 23% reduction in building energy consumption levels from those in 2012. The New York state regulator has taken measures to enable the transition to accomplish these targets. In 2014, they defined the role of the TDO as a distribution system platform provider (DSPP). A DSPP is like a DSO [47]. The NY regulator also directed that the TDOs would initially be the DSO. However, if the TDOs could not perform the role as required, the regulators have mentioned the possibility of introducing an independent DSO in its place.

1.3.5 INITIATIVES IN EUROPEAN UNION (EU)

Due to changing dynamics of the energy sector, the European Commission is also examining various matters concerning DSOs such as market design, DSO-TSO coordination, flexibility utilization, integration of DERs, deployment of smart grids, demand response, digitalisation, and cyber security [48]. In Europe, retailers are responsible for serving load. They also act as Balancing Responsible Parties (BRPs) and ensure supply-demand balance in each settlement period. Traditionally, regional TSOs are accountable for ensuring grid stability. Earlier, the focus was on developing inter-regional linkages between the power exchanges in Europe to allow more effective inter-region balancing. Within EU, there exist many regional electricity markets which get cleared locally. So far, TSOs have played a pivotal role in bringing much-needed reforms and promoting the integration of renewable energy sources.

European Commission's Clean Energy Package [49] has identified the potential of Flexibility embedded within the system. With growing maturity and a well-defined role of aggregation, the corresponding demand response (DR) markets in EU are emerging. With the rapidly increasing number of DERs, the distribution grid is facing challenges such as hitting grid constraints and congestion on the local network. So far, there is no consensus on possible DSO roles and architecture in EU. However, over the last few years, there have been many trials in the EU to investigate future DSO models. Though the European Commission legislation has framed EU-wide guidelines, detailed policies and programs are supposed to be worked out by each member-state. DSO associations in its whitepaper [48] provided insights on the structure of possible future power systems and their role and responsibilities. The European Commission has also proposed EU DSO [50] to ensure harmonization of rules at EU level and develop the technical aspects of DER coordination.

Various options are being explored across Europe to utilize DER Flexibility. One such option suggests aggregating active and reactive power flexibility from downstream distribution networks at the corresponding substation and passing this input to the optimization problem to find optimal flexibility activation signals and cost. In another attempt, the traffic light concept is proposed in [51] to avoid potential cross-impact of flexibility activation. A green market signal from DSO indicates no limitation in utilizing DER services. A red signal from DSO indicates serious stability threats and thus stop utilizing DER services. Considering the vast penetration of DERs, an amber intermediate stage is also proposed if a network bottleneck exists in a given area. During amber stage, DSO can use the flexibility services offered by other market parties to avoid entering possible red state. In Italy, to ensure network reliability, TSO can request medium voltage DER-shedding. However, such requests need to be executed by DSO, and they are free to take the final call, keeping in mind the security and reliability of its network.

DSOs in Germany are also involved in these types of activities under the "DSO 2.0" tag [52]. In Germany, DSO acts as both active system managers and neutral market supporters. German DOs are investing in the controllability and visibility of their networks. They use various tools such as state estimation, dynamic load flow calculations, IoTs, smart meters, etc. The proposed solutions are similar to the traffic light approach and consist of both an automated 'DSO re-despatch process' and 'DSO reflag process'. The automatic 'DSO re-despatch process' operates DERs based on minimum cost, and a 'DSO reflag process' is used to limit the flexible use of this DER when they cross any system constraint. A futuristic layered and decentralized structure is also proposed in the German context [44]. In the proposed design, balancing and congestion management occurs at different layers such as BRP/DSO/TSO.

If one section has a constraint, it will be isolated from the rest of the system. Due to the rise in the number of DERs and their potential to support overall system operation, DOs in the EU have started transitioning towards new roles such as active system operators and neutral market facilitators. However, this endeavor is not uniform, and countries within Europe are advancing at different paces to make the DO to DSO transition. In general, there is mounting international acceptance for DSO in the backdrop of the high penetration of DERs and their possible participation in wholesale and/or distribution level electricity markets. Across the globe, many pilots are going on.

Thus, it will take time to reach a certain degree of maturity in designing and implementing the DER coordination and despatch optimization mechanism using DSO.

1.4 LEARNINGS FROM INTERNATIONAL EXPERIENCES

A comparison of ongoing DSO-related activities across various countries/regions is presented in Table 1.1. Within the EU, the DSO concept is shaped based on country-specific needs and is not uniform. However, under the SmartNet project [53] with 9 European countries involved, an attempt was made to provide solutions and architectures for interaction between TSOs and DSOs to monitor and acquire ancillary services for local needs and the whole European system. The primary driver for transitioning towards more active DSO in the EU and the UK is the flexibility embedded within the distribution network. They have envisaged DSO as an entity to exploit the local flexibility efficiently. On the other hand, Australia is facing grid stability issues due to DERs, and therefore, DSO is considered a suitable solution to address stability-related challenges. Thus, on the one hand, the UK Open Networks Project predominantly focused on local flexibility services, thereby, reducing net carbon emissions. On the other hand, Australia's Open Networks Project (OpEN) [42] is inspired by grid instability issues caused by the high penetration of DERs such as rooftop solar PV. In California and New York, DSO is deemed to ensure reliable system operation. The distribution sector in India is also likely to face similar types of challenges soon.

Table 1.1: Sample of DSO related activities across various countries/regions

Labels	UK	Australia	USA: California	USA: New York	EU
Driver	Flexibility	Grid Instability Issues	Reliable System Operation	Reliable System Operation	Flexibility
Lead By	Utilities	Australian Energy Market Operator (AEMO)	California Independent System Operator (CAISO)	New York Independent System Operator (NYISO)	Utilities
Potential Coordination Schemes	❖ World A: DSO Coordinates ❖ World B: Coordinated DSO-ESO Procurement and Despatch ❖ World C: Price Driven Flexibility ❖ World D: ESO Coordinates ❖ World E: Flexibility Coordinator(s)	❖ Single Integrated Platform (SIP) ❖ Two-step Tiered Platform(TST) (Managed by DNSP) ❖ Independent Distribution System Operator(IDSO) ❖ Hybrid	❖ An Independent DSO ❖ Hybrid ❖ Extended version of the prevailing model	❖ Distribution System Platform Provider (DSPP)	❖ Centralized AS Market Model ❖ Local AS Market Model ❖ Shared Balancing Responsibility AS Market Model ❖ Common TSO-DSO AS Market Model ❖ Integrated Flexibility Market Model
Evolution	DNO to DSO Transition	Separate Entity	Separate Entity	TDO to DSPP Transition	Passive to Active DSO

DNO: Distribution Network Operator; DNSP: Distributed Network Service Provider; ESO: Electricity System Operator; TDO: The Transmission and Distribution Owners and Operation

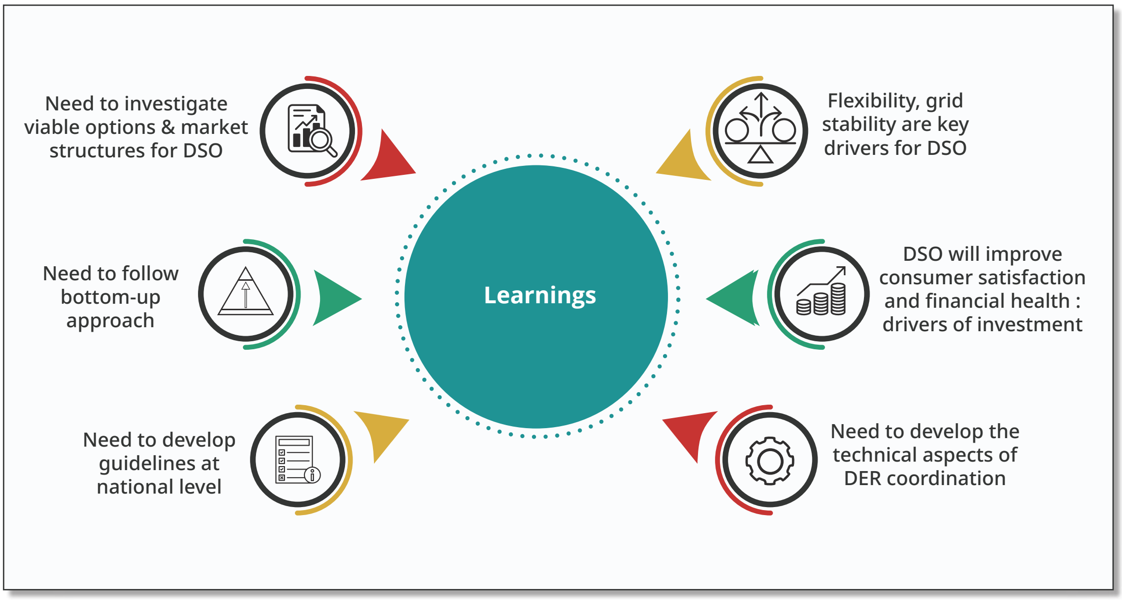


Figure 1.3 Key learnings from international experiences

Thus, the learnings from the international experiences could be exploited by the regulators and utilities in India. The key learnings from the above international experiences are listed in Fig. 1.3. The utilities themselves have taken the lead in the UK and most of the EU countries in transitioning towards DSO. In contrast, the DSO concept in the rest of the regions is driven by the market operators. Various industry structures are evolving in different parts of the world to realize the DSO. It mainly depends on the local requirements and the prevailing market structure. As evident from international experiences, DSO functions and evolution would be region/area-specific, and there is no unique model for the DSO that fits all. The transitioning from the existing entity to DSO is happening in the UK, Europe, and New York, whereas a new separate entity is conceived as DSO in Australia and California.

The regulators and policymakers have also recognized the need for DSO in the Indian context. Most of the DISCOMs in India lack the visibility and controllability of behind the meter generation. Hence, DSO could effectively perform the task of gathering such temporal and spatial granular data for maintaining reliable distribution system operation. Most of the households in India are supplied electricity by State-owned DISCOMs. Private DISCOMs have been mostly limited to a few metropolitan areas, and it has been governed by two models—the licensee model and the franchisee model. There is no separation of retail electricity and wire business in India. Thus, the international DSO models discussed earlier may not be directly relevant to India and need further customization to implement those in the Indian context. India being a geographically diverse and large country, area-specific needs would primarily drive the evolution of DSO models. However, an attempt similar to the UK and Australia could be carried out in the Indian context, where few tentative industry structures can be proposed. In due course, each state commission (SERC), following the well-established consultative process, can decide appropriate option. The big States like Maharashtra can opt for multiple options for different areas within their area of jurisdiction. Likewise, India may have multiple DSOs in a single State. However, an exercise similar to that of the European Commission needs to be carried out by CERC to ensure harmonization of rules at the National level and develop the technical aspects of DER coordination. As DSO is not a mere concept anymore, base work for introducing distribution system operators in India needs to be completed at earliest, following a bottom-up approach. Many utilities and regulators across the globe have recognized its importance and are actively pursuing the DSO concept to make it a reality.

The introduction of DSO like entity will yield reliable and quality supply to end consumers and be instrumental in bringing much-needed decarbonisation of power sector and contributing to power system flexibility which is expected to gain critical dimensions with the ambitious renewable energy targets the country has. As a DER orchestrator, DSO will be a game-changer in transforming the operational and financial state of the Indian power sector. Irrespective of the segregation of wire or supply business of existing DISCOMs, the introduction of DSO seems inevitable. It will facilitate entry of new players and services and help in transparently gather the granular level details to ensure complete visibility and controllability of the distribution network. Such exercise will boost the private sector's confidence and attract much-needed investment and innovation in the industry. Regulators and utilities need to come forward to make this change happen. Eventually, it will result in the efficient operation of the overall distribution grid. Thus, similar to their international counterparts, regulators and utilities in India should engage actively and take the lead in introducing DSOs.

1.5 DISTRIBUTION SYSTEM OPERATOR: WHETHER A CREDIBLE SOLUTION FOR THE INDIAN POWER SECTOR?

Retail electricity supply in India is currently being ensured by a mix of stakeholders, including distribution licensee(s), State or Sub/Area Load Despatch Centre (SLDC/Sub-SLDC/ALDC), SERC, and other relevant entities. However, the Indian distribution sector is witnessing several challenges that are affecting the operational and planning practices in an area of retail supply, such as:

- The DISCOMs communicate power demand within their area of supply to SLDC. Due to the lack of visibility of behind-the-meter generation and the stochastic nature of renewables, forecasting net load is challenging for DISCOMs. The forecast error leads to sudden changes in power flow over the distribution network.

- Even if the granular forecasts are available, it is necessary to exercise control within an area of retail supply so that the power flows are within limits and the system is secure.

- The possibility of power flow reversal needs real-time advanced monitoring and protection. It could be achieved using modern technologies such as AMI, SCADA, PMUs, etc.

- Increasing power electronic interfaced loads and generators require power quality monitoring and mitigation of harmonics. It needs to be dealt with rigorously.

> Distribution network reinforcement and DER planning decisions need a coordinated approach.

Along with network operation at the distribution level, DISCOMs are also involved in the trading business. Even though the SERC has already proposed open access at the distribution level, it faces many hurdles. It has not been implemented in true spirit as it conflicts with the profit-maximizing interests of a DISCOM. Hence, a need for an independent entity is envisaged to ensure non- discriminatory OA (NDOA) to the distribution network. The flexibility embedded within the distribution grid could be utilized to provide system support services, i.e., ancillary services.

It is expected that the flexibility in India could reduce total system electricity supply costs by up to 5% on average [55] and could be used to manage the load curve better. Storage could emerge as a game-changer with falling prices.

The CERC's draft on Ancillary Services Regulations [56], 2021, extensively discusses market- based mechanisms for deployment and payment of Primary, Secondary, and Tertiary Ancillary Services. It suggests that regional entities like energy storage and demand-side resources could provide such services. Hence, it opens the door for DERs and Prosumers to earn revenue by delivering flexibility services. It could facilitate network operators (transmission and distribution level) to use local resources efficiently in grid operations. An entity like DSO is thus conceived to act as a flexibility administrator at the distribution level.

The uncoordinated activation of DER services can also affect transmission system operations. Therefore, appropriate framework for Transmission and Distribution level coordination need to be developed to maintain reliable system and market operation. The task will become easier with the introduction of new entities to manage DERs viz. Prosumers, Qualified Coordinating Agencies (QCA) [57], intermediary procurers [58], etc.

However, the optimal coordination among all stakeholders will become a rather challenging task without the DSO. Irrespective of the segregation of the content and carriage business of the existing DISCOMs, the role of DSO in the Indian power sector is inevitable. The DSO is envisioned as the orchestrator of DERs with the obligation to ensure reliable, resilient, secure and cost-effective electricity supply. It will use State-of-Art technologies, including SCADA, to create network information and consumer database and ensure "TSO-DSO Coordination".

DSO will play a prominent role in despatching DERs similar to SLDC. It will facilitate many functions, such as ensuring non-discriminatory open access, managing bidirectional power flow, local congestion management, utilization of demand-side flexibility, network reinforcement, granular data collection and analysis, and other operational/planning decisions.

However, this calls for new amendments to existing regulations covering various aspects, including a comprehensive coordination mechanism with other stakeholders such as State and Central regulators (SERC, CERC), STU, CTU, DISCOMs, NLDC/RLDC/SLDC, Aggregators, customers, etc. DSO is envisaged in the Indian context to bring in required alterations, facilitate the smooth low carbon transition and make the distribution business more systematic and equitable.

A detailed discussion on DSO in the Indian context is presented in the subsequent chapters. Chapter 2 lists various functions carried out by DSO and examines technical aspects and the expected role of DSO in the Indian context. The four feasible alternatives for introducing DSOs in India are presented in Chapter 3 considering the prevailing structure of the Indian power sector and international practices. Chapter 4 portrays the need for the local level electricity market, different models, local-level market design, and possible phase-wise implementation in the Indian context.

The existing legal/regulatory provisions relevant to DSO promotion in India are covered in Chapter 5. It also highlights the opportunities in legal/regulatory systems to adapt to the emergence of DSO. Chapter 6 gives recommendations on the technical, regulatory, and institutional framework, workforce and skill requirements, financial implications, and a phased implementation plan for introducing DSOs in India.

> "DSO may not be a panacea but it could serve the power sector efficiently."

2 ACTIVE DISTRIBUTION NETWORK AND PATHWAY TO DSO

2.1 INTRODUCTION

The various initiatives undertaken by different utilities across the globe in introducing DSO and the associated important learnings for evolution of DSO in the Indian context are discussed in Chapter 1. In this Chapter, the challenges involved in the transformation of the conventional (mostly passive) distribution networks into Active Distribution Networks (ADNs) with the integration of DERs, EV infrastructure, and BESSs, have been discussed. This discussion is followed by suggestive technical requirements for implementation of the various functions envisaged to be performed in ADNs and the perceived role of DSO in the Indian context including the different accepted definitions of DSO across the globe. Although various countries have defined DSO differently, the primary function and role of DSO does not differ significantly. Typically, the DSO can be perceived as an entity responsible for coordinating the various operations of the present-day ADN. It can enable efficient integration and operation of DERs, EVs and BESSs, while facilitating the provision of demand response and energy accounting for all stakeholders associated with the distribution network. This chapter concludes with a mapping of the various functions envisaged to be performed by a DSO in the DER integrated ADNs.

2.2 TRANSFORMATION OF A CONVENTIONAL DISTRIBUTION NETWORK INTO AN ADN

Conventionally, the distribution systems were designed to be passive networks that received bulk power supplied via the transmission network from large, centralized generating units for distribution among the consumers having almost inflexible demand. However, the proliferation of distributed generation technologies, EVs, BESSs, and flexible loads within the distribution network is transforming the traditional passive distribution network to an active network.

Besides, an increase in the use of Information and Communication Technology (ICT) applications, Supervisory Control and Data Acquisition (SCADA) systems, Advanced Distribution Management Systems (ADMS), Advanced Metering Infrastructure (AMI), Phasor Measurement Units (PMUs) etc., to automate the process of monitoring and control has activated a new landscape of planning and operation functions in the ADNs.

2.2.1 PROLIFERATION OF ACTIVE ELEMENTS IN THE DISTRIBUTION NETWORK

Traditionally, the distribution systems were designed as passive radial networks with unidirectional power flow. The proliferation of DERs, EVs, BESSs and flexible loads has rendered bi-directional flow of power in the existing distribution networks.

Besides, the advancements in ICT based applications have enabled fast and reliable bi-directional exchange of information and data. Since the last decade, the share of DERs has increased rapidly in India owing to the sustainability concerns.

Amongst them, the solar PV integration has grown at an exponential rate, as shown below in Fig. 2.1, due to the benign government policies followed by a steep reduction in the price of electricity generated through solar energy.

The previous target to install 175 GW of Renewable Energy (RE) based generation capacity in India by 2022, including 40GW of rooftop solar and 60GW of ground-based solar have partially been met, and the targets have been upgraded to 500 GW by 2030 [1].

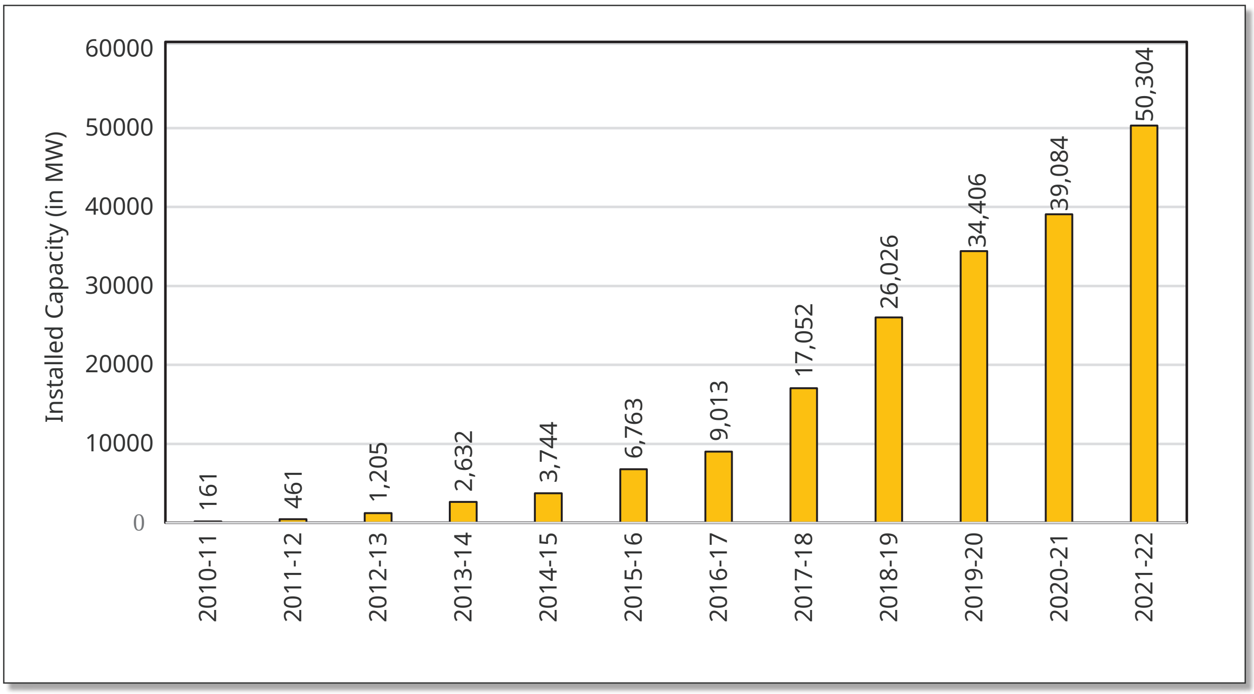


Figure2.1. Installed solar capacity in India (Data Source: CEA [59])

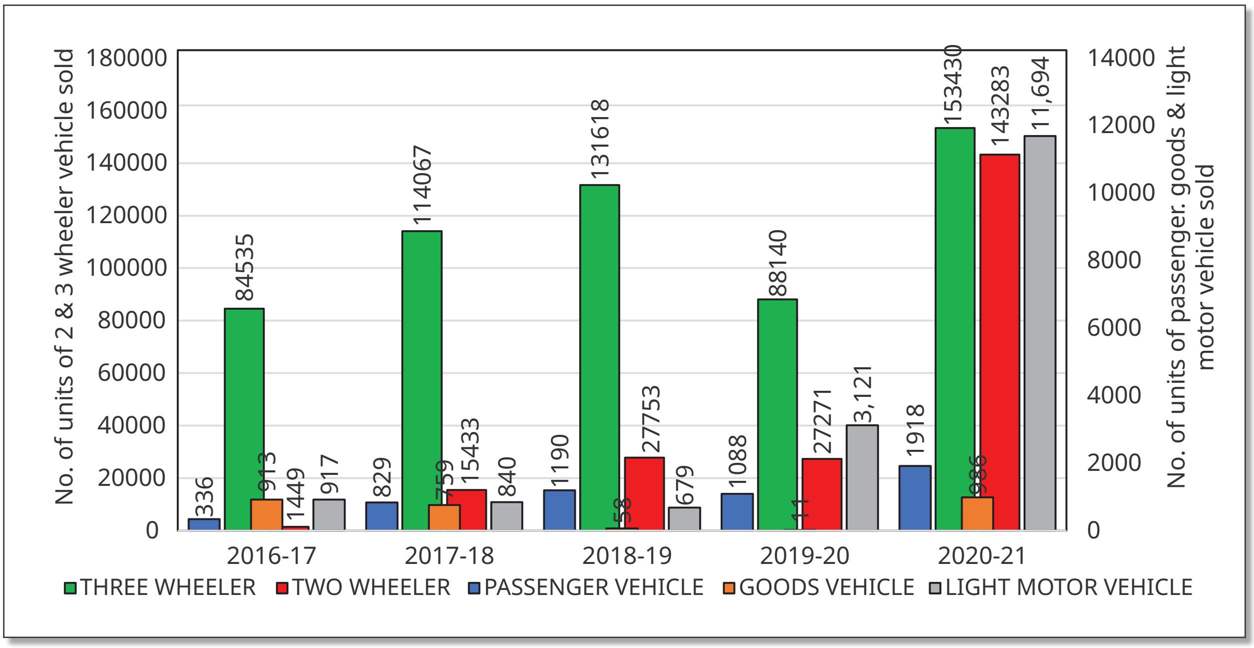


Figure 2.2. EV sales across different categories in India (Data Source: VAHAN Portal [60])

Apart from DERs, ESSs have also been recognized as a viable solution that complements the operation of DERs. Although, the transportation in India has been fossil dependent ever since, the ground for adoption of EVs was set with the rollout of the National Electricity Mobility Mission Plan 2020 (NEMMP) [61].

Besides, the scheme for Faster Adoption and Manufacturing of EVs, (FAME) I [62] and II [63], released in 2015 and 2018 respectively, aimed at subsidizing the purchase of EVs. The proliferation of EVs in India is evident from the trend of EV adoption in India as shown in Fig. 2.2.

2.2.2 NON-DISCRIMINATORY OPEN ACCESS (NDOA)

Non-discriminatory open access (NDOA) to the transmission and distribution networks, introduced in the Electricity Act 2003, is one of the major reasons behind rapid transformation of passive distribution networks to ADNs. Although the NDOA was introduced in phases over time across the different states in India [64], the number of open access consumers on power exchanges in the wholesale electricity market has increased rapidly over the last decade as evident from Fig. 2.3. Although hurdles do persist, NDOA to the distribution network has become more accessible, since its inception, in several DER rich states of our country [65].

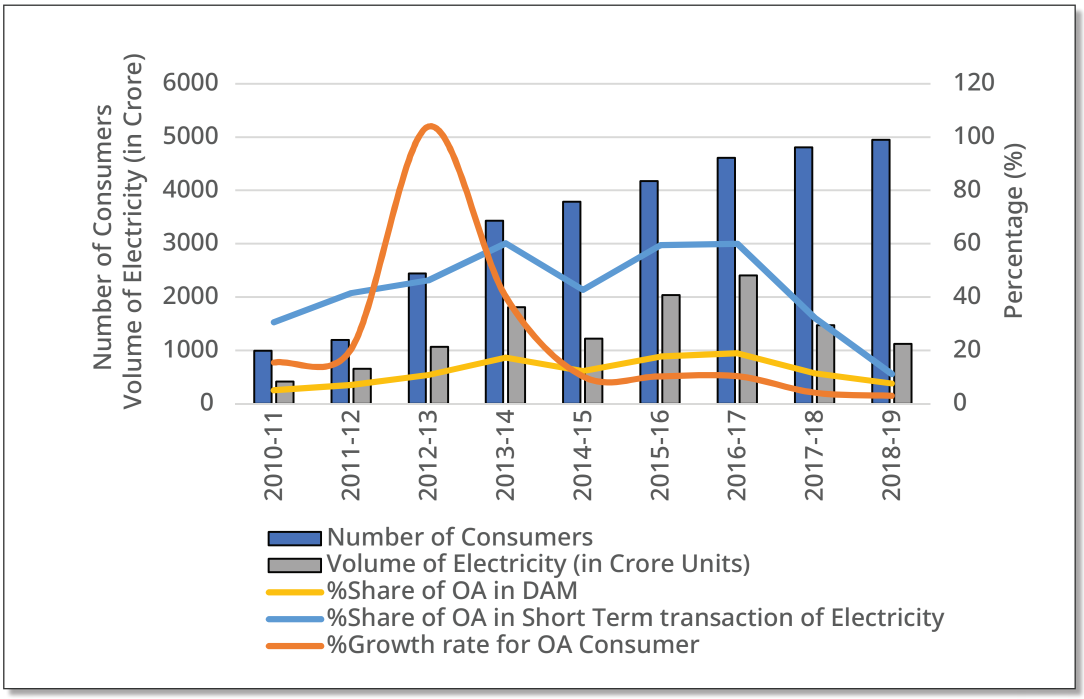


Figure 2.3. Participation of Open Access Consumers in Power Exchanges in India. (Data Source: CERC Report on Short-Term Power Market in India: 2018-19 [66])

2.2.3 ISSUES IN RAPID TRANSFORMATION OF THE EXISTING DISTRIBUTION NETWORK

The above-stated transformations are taking place in the power distribution networks worldwide. However, one important and critical question that needs to be addressed during this transformation is "Are the conventional existing power distribution networks capable of absorbing such changes?". A case study [67] has indicated that if the rate of upgradation of the existing distribution network infrastructure is not coherent with the rate of adoption of EVs, distribution networks in several metro cities of India may get overloaded. On the other hand, an increase in the presence of localized generation may enable the existing distribution networks to inject power back to the transmission network. Such rapidly changing power flow patterns will require enhanced coordination and sharing of data from either side of the transmission – distribution interface to the other, while respecting the privacy concerns. Another side-effect of the bi-directional power flow is the overloading and maintenance of the existing distribution transformers. The conventional distribution transformers were never designed to operate in a bi-directional mode. Additionally, the flow of power from the distribution network to the sub-distribution or transmission network at times overloads the distribution transformer, due to which the efficiency and life expectancy of the distribution transformer may go down.

Besides, many power quality concerns have also become evident including voltage regulation, since the end consumer must always be supplied at voltages within acceptable limits. Traditionally, voltage drop over long radial feeders has been a serious concern. However, the possibility of reverse power flow, particularly during peak DER generation and low loading levels may cause the voltage to rise, which coupled with the intermittent nature of DER output, is changing the traditional voltage regulation problem. Besides, the conventional voltage regulation schemes involving sparsely located slow acting traditional electromechanical devices, such as On-Load Tap Changers (OLTCs), series voltage regulators, and switched capacitor banks, are no longer adequate due to their limited frequency of operation. An increase in the electronic interfaced DERs and loads has also raised concerns over growing Total Harmonic Distortion (THD) levels in the supply voltages and currents. For secure and stable operation of the ADNs while extracting the flexibility aspects of the DERs, ESSs, EVs, and loads, behind the meter granular data forecasts are essential. In the existing distribution network infrastructure, granular behind the meter forecasts and segregation of load demand and DER generation is missing, which becomes even more crucial with an expected increase in the penetration level of DERs in the ADNs.

2.3 FUNCTIONS IN DER INTEGRATED ADNs

The typical functions, which are required to be performed for the optimal, reliable, secure, efficient, and stable operation and planning of the ADN with the integration of DERs, EVs and ESSs are shown in Fig. 2.4. Each of these functions are explained in the subsequent subsections. It is to be noted that these are the functions, which are envisaged to be performed by a DSO in the Indian context. Also, depending on the adopted institutional framework of DSO in the various operating utilities in India, a few of these functions need not fall in the operational domain of the DSO.

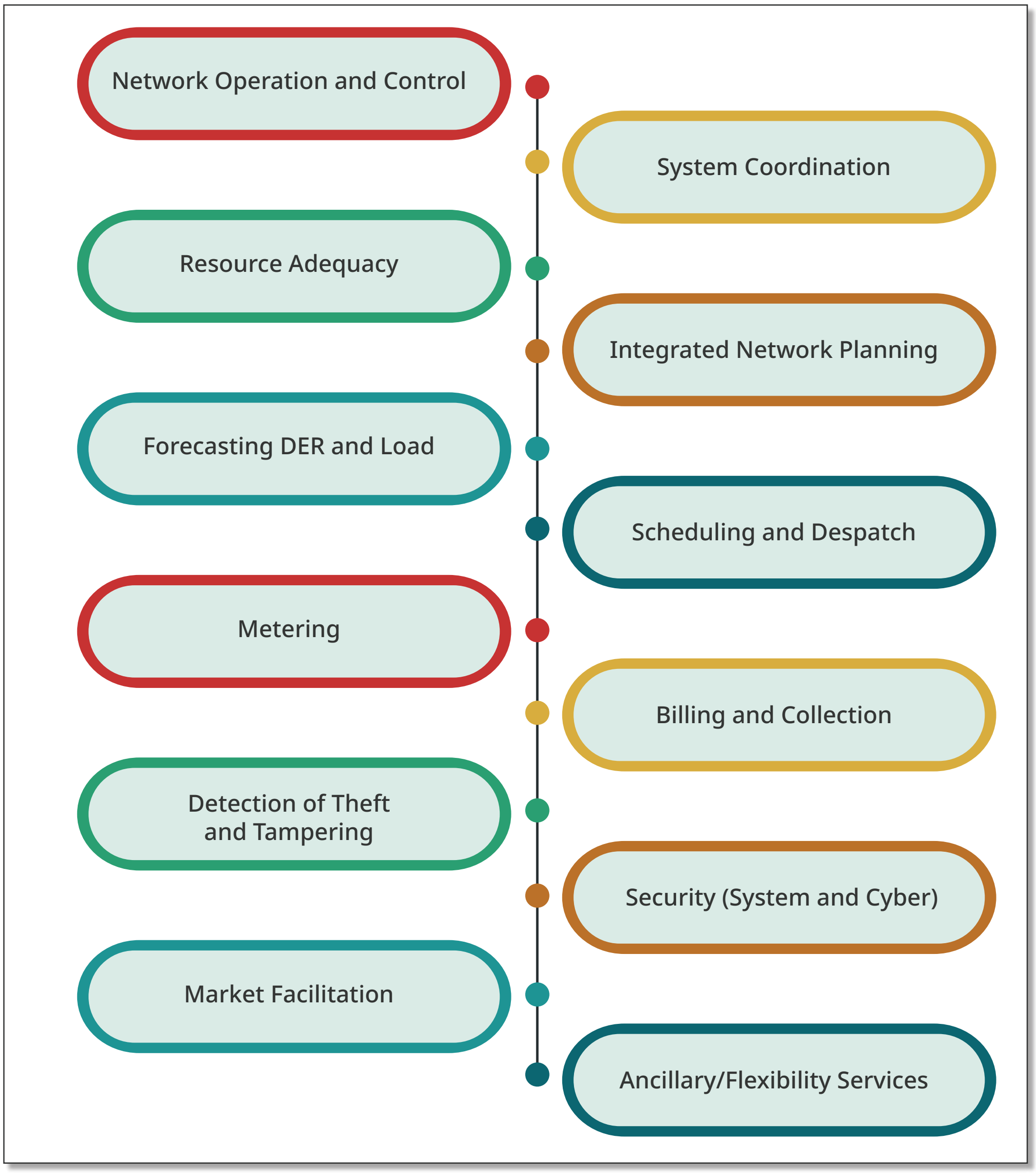


Figure 2.4: Typical functions to be done in DER integrated ADNs

2.3.1 NETWORK OPERATION AND CONTROL

The electrical power distribution network serves to evacuate the power from various DERs and the upstream transmission network and distribute it among the connected loads. Hence, adhering to the steady state operating limits is of utmost importance to ensure the security and reliability of the distribution network. The operational constraints emerging due to high peak loads, large in-feeds of renewables, unbalanced loading, spatial-temporal congestions, etc. require due attention.

For exercising controls to relieve congestion/ stress in the network, robust equipment should be installed in the field along with a reliable communication system. In the current distribution systems, fuses are placed at many places, instead we need to resort to circuit breakers, isolators, disconnectors, and ring main units.

2.3.1.1 Demand Management

Demand management is one practical strategy to address exigencies. It also attracts techno- economic benefits, such as reduction in the operating cost and feeder losses, and deferment of the capital-intensive expansion and infrastructure development plans. In the demand management programs, the customers participate voluntarily, primarily driven by the time-varying tariffs or incentives. Hence, simple, transparent, and specific load management programs are required to be designed for accommodating the diversity of consumption behaviours among the industrial, commercial, and residential customers/ prosumers. Besides, customer participation should be encouraged through imparting awareness about tariffs, tools and mechanisms. Intelligent meters with bidirectional communication possibilities must be deployed at the end-user premises to record the timely energy consumption and/ or production and channel the conveyance of electricity price signals.

2.3.1.2 Volt-Var and Volt-Watt Control

Apart from the load management schemes, fast voltage control and topology adaptations are also helpful. Volt-Var control can be exercised to regulate node voltages with the help of reactive power injections from DERs, BESSs and capacitor banks, and the regulating transformers' tap settings. The active power injections, especially from DERs and BESSs, can also be varied along with voltage control devices like OLTCs and in-line voltage regulators for exercising Volt-Watt control. Towards this, it is needed to facilitate proper installation and timely maintenance of such devices.

Along with the node-voltage regulation, it is also necessary to simultaneously update optimal settings corresponding to minimum losses, reduced unbalances, and improved stability. In distribution networks, since DR and voltage regulation are phase-specific, unbalance management is to be prioritized while exercising such controls. Suitable monitoring devices, multi-way communication facilities, and large-scale IT support is required to facilitate all such control schemes. Most importantly, coordinated optimization at various levels is needed to balance the costs and returns.

2.3.1.3 Fault/ Disturbance Detection, Isolation and System Restoration

Appropriate adaptive strategies are required to be prepared for the unplanned network events. While preparing a protection and restoration strategy, it is necessary to consider fault detection, identification of zones with proper coordination logic between protective relays, localization of fault (exact location for maintenance purpose) and isolation of faulty section(s).

The first and critical protection function is to detect the fault in a proper zone setting of the relay. If the primary relay or zone cannot see the fault for some reason, the secondary or backup relay should detect it. Then, switches/ breakers should be operated to isolate the faulty section from healthy part of the network. In some cases, the local protection issues (e.g., line faults) may also be communicated to the system operators/ network operators in the higher level of hierarchy to obtain support from resources connected to the transmission network. However, advanced network codes are needed to incorporate new actions and procedures in emergency situations and establish communication protocols between operators.

The implementation of power headroom can play a crucial role during service restoration. Power headroom of a DER indicates the additional maximum power that can be extracted from the DER over and above its current power output. Such a power headroom can be created by operating solar PV at off peak capacity (Off MPPT) or using ESS. By doing so, the power output of despatchable DERs can be controlled for ramp up and ramp down needs, based on the requirement.

In case of a fault or grid outage, an island can be created in the distribution network and the controllable DERs can be operated at their peak capacity. In a sustainable power island DERs should be capable of fulfilling the local energy demand.

Hence, it is required to ensure that DERs connected in the island exhibit such capability. Creation of such a sustainable power island also helps in restoration of the system in a gradual manner. Another way of restoration is by grid forming control using islanding information. However, to implement such functions high-speed communication may be required. Besides, detection of a self-sustainable island requires wide-area system information and an accurate detection algorithm with a study on the possibility of cyber-attacks.

2.3.2 SYSTEM COORDINATION

There exists a hierarchy in the integrated operation of the power network as dictated in the Indian Electricity Grid Code. A user of the distribution network must perform its functions while coordinating with other operators, authorities, regulators, DERs, intermediary procurers, QCAs, consumers, licensees, aggregators, retailers, prosumers, and other relevant stakeholders in the higher and lower levels of hierarchy. Not only for performing system operation and operational planning functions, but also, on a regular basis, coordination is required among the relevant stakeholders typically for

- the provision of open access, and connection/ disconnection of DERs
- load forecasting and behind the meter generation forecasting
- demand-side management and demand response
- communication of despatch schedules and price signals (dynamic market prices/ Time of Day (ToD) tariff, etc.)
- revenue realization
- procurement of flexibility and ancillary services

Besides, a proper coordination is needed between the respective entities while performing protection, stability, and planning studies and the associated functions. All the profit maximizing market players must comply with such requirements, since coordinated decisions have to be taken in the interest of social welfare maximization.

2.3.3 RESOURCE ADEQUACY

For reliable, secured, and economic operation of the power network, resource planning is an essential exercise. It is presently being applied to the bulk power sector, specifically to ensure stability and reliability of generation and transmission system. However, as DERs increasingly proliferate on evolving grid architecture, resource adequacy needs to be ensured for the distribution network as well.

It is essential to know if there are enough resources available to meet load while accounting for uncertainty and variability in renewable generation, availability of transmission, distribution, and imbalances in load.

Some degree of distribution resource adequacy (e.g., network planning) is currently being performed. To drive grid modernization and integration of DERs, ADN need to be capable of handling as well as balancing the future demand and generation capacities in an economic and secure fashion.

For resource adequacy assessment, along with existing metrics, namely, Loss of Load Expectation (LOLE), Loss of Load Hours (LOLH), and Expected Unserved Energy (EUS), inclusion of scenarios such as extreme weather, high peak loads, high generator outages, renewable intermittences like low wind, solar output, etc., and other conditions and their combination is essential.

Similarly, inclusion of resources from ADN such as demand response, behind-the meter impact of DER, extreme condition forecasting, need to be incorporated to ensure (address) resource adequacy.

2.3.4 INTEGRATED NETWORK PLANNING

The existing distribution network, with the massive integration of various renewable energy sources, has observed a significant paradigm shift in its operation. Bi-directional power flow is emerging as a common pattern in the distribution network, which, conventionally, experienced uni-directional power flow. With the integration of renewable DERs, the distribution network has not been appropriately planned.

To extract the maximum potential advantages in light of the environmental, economic, and technical aspects, the optimal installation and sizing of DERs in the distribution network are crucial. The optimal installation of DERs in the distribution network shall aid in achieving proper operation of ADNs with minimization of the system losses, improvement of the voltage profile, enhanced system reliability, voltage stability, loadability, and power security.

In addition, the optimal siting, sizing, and placement of energy sources can alleviate the issues arising out of bidirectional power flow with respect to the distribution system's protection and overloading of the distribution transformer, so that the network expansion plans to meet the expected load growth can be deferred to some extent. Random placement of huge energy sources in the distribution network leads to increased system loss and reduced stability margin. As the penetration of DERs increases, network expansion planning will be critical for the reliable and economic operation of the ADN. With the optimal decision of cost-effective and timely installation of new elements (feeders, lines, distribution transformers, capacitors, regulators, etc.) in the existing network, the ADN will be capable of handling the future demand and generation capacities in an economic and secure fashion.

2.3.5 FORECASTING DER AND LOAD

Forecasting is a procedure in which the historical data is utilized for estimating the trends expected in future. Forecasts of renewable power generation and load demand are needed for optimal planning and operation of the distribution system. The time horizon of forecasts can vary from short-term to long-term depending upon the application requirement.

Short term forecasts are required for managing the variability and ramp events in renewable power generation, demand-side management, day-ahead market operations, Volt-Var and Volt-Watt control, and reserve management. On the other hand, long-term forecasts are required for optimal expansion of resources and assets present in the system.

During expansion planning in particular, overestimation may lead to underutilization of resources, whereas underestimation may cause insufficient generation and unsatisfied load demand. Hence, forecasting is important from both the technical and financial perspectives in the short as well as the long run.

Currently, the DISCOMs perform only load forecasting exercise, that too for aggregated net consumption. However, granular behind the meter forecasts and segregation of load demand and DER generation is missing, which becomes even more crucial with an expected increase in the penetration level of DERs in the ADNs.

2.3.6 SCHEDULING AND DESPATCH

The injection and drawal schedules are always prepared in advance with due regards to the system economy and security for optimal load despatch. Day-ahead scheduling of DERs and prosumers' assets to optimize the financial and technical objectives while considering perspectives of multiple stakeholders can help in load management. However, large-scale integration of renewable DERs and spatial-temporal loads may give rise to uncertainty and variability in power flows during real-time despatch. The resulting deviations from schedules and congestion, if any, can be met by procuring ancillary and flexibility services based on real-time system calculations through use of computers, communication, and control devices. Coordinated decisions have to be taken while ensuring adequate transparency in the information being shared between stakeholders, so that trust among all is maintained.

Besides, a proper coordination with DERs is needed for stable, reliable, and optimal operation of an ADN in the islanded mode, if the need for islanded mode of operation arises. Grid-forming units, who can mimic the role of utility grid for off-grid distribution networks, i.e., can export/import excess/needed supply, are a fundamental requirement for the islanded mode of operation. Gas based generators, microturbines, or BESSs are preferred candidates for such grid forming units. However, unlike the utility grid, such units have pre-defined rated capacities with limited available reserves for handling the system uncertainties and exigencies. Therefore, a coordinated operation comprising the following functions is needed.

- The power output of all non-despatchable DERs (solar PV panels, wind turbine generators, etc.) in the network must be real-time optimal according to system load so that the burden on the grid forming unit is minimum.
- Day-ahead scheduling of all despatchable DERs and loads in a distribution network must be exercised in advance to optimize utilization of the grid forming units' reserve capacities.
- DERs will have to be rescheduled in real-time for handling network contingencies, unplanned generator/feeder outages, system faults, etc. to ensure that power flows are real-time optimal.
- The voltage-dependent loads can also be managed using conservation voltage reduction or demand management programs for avoiding the load-shedding in off grid ADNs.

2.3.7 METERING

Traditionally, metering simply refers to the accounting of net amount of energy passing through any given point at which the meter is installed. This is essential for proper accounting of the electrical energy consumed and the associated price to be paid by the consumers in the distribution network. With the consumers having power production capability due to local energy sources, such as rooftop solar PV and ESS, behind the meter monitoring is furthermore crucial for proper accounting of energy consumed and the energy produced. Hence, the metering advancements may also act an enabler for DERs to participate in the widespread implementation of demand management programs.

2.3.8 BILLING AND COLLECTION

Currently, available billing applications in the distribution network are being implemented, considering utility grid as the only source. However, with the above stated transformations in the distribution networks, billing applications may be planned to accommodate multiple DERs based on the ToD based tariffs or dynamic market prices. For better revenue realization and ease of payment to consumers, IT based infrastructure need to be set up. Automatic metering, billing and collection are need of the hour so that the billing efficiency and collection efficiency is improved, commercial loss component in the Aggregate Technical and Commercial (AT&C) losses is minimized and the Average Cost of Supply (ACS)–Average Revenue Requirement (ARR) gap is reduced. Timely availability of revenues is also necessary for better upkeep of the existing distribution network infrastructure. In this context, the billing applications may be configurable for varying prices of different energy resources and varying rate of benefits to end consumers with Service Oriented Architecture (SOA) for exchanging data over the Enterprise Service Bus (ESB). Such and other provisions should be in coherence with the regulations, e.g., Central Electricity Authority (Installation and Operation of Meters) and standards in such regards.

2.3.9 DETECTION OF THEFT AND TAMPERING

The power theft and meter tampering significantly affect the power supply efficiency, unaccountable rise in peak demand and loss of revenue. Hence, detection of power theft and meter tampering is of utmost importance. The shift to a centralized metering infrastructure for many consumers may not be a feasible solution. Instead, deploying smart low-cost energy meters may be a better alternative to detect and communicate power theft to the metering utility. The utility's or DISCOM's billing database can be analyzed for consumers with high past arrears or invalid geographical mapping to verify the energy billed from metered consumers in case of meter tampering. A comparison of consumption patterns can help identify consumers with abnormal power consumptions. In this regard, advanced ICT infrastructure, smart energy meters, machine learning based techniques or algorithms for database analysis, and increase in social awareness may altogether help minimize and detect the power theft and tampering. However, it is necessary that all the relevant policies, regulations, standards and guidelines in these regards are duly complied with while augmenting or deploying such new infrastructures.

2.3.10 SECURITY

2.3.10.1 System Security

Power system network is a critical infrastructure whose security from credible contingencies is of critical importance to ensure the reliability of power supply. System security reflects the ability of the power network to operate reliably at the present operating condition as well as during scheduled and unscheduled contingencies so that no power network related variables, such as bus voltage magnitudes, and line currents, violate their physical or operational limits, and all system loads are being met or satisfied. Although, the term "Power System Security" was coined during 1970's for the generation – transmission systems, retaining the power system in a secure state has become more challenging with increasing penetration of DERs in the low voltage distribution networks. Hence, the need for a multi – level control to bring the system back to secure or normal state from alert state (preventive control), emergency state (emergency control) and restorative state (restorative control) becomes even more evident.

As stated earlier, the normal or secure state of the network is when the power demands of all system loads are met and there are no violations of any of the physical or operational constraints of the network. Depending on the current operating state, a system operator must exercise control functions for ensuring minimum cost of operation (secure and alert state), maximum satisfaction of demand (emergency state) or minimum interruption duration (restorative state).
Such functions would be performed in hierarchical levels, i.e., at the global and local levels, while being adaptive to uncertainties and variabilities introduced by DERs and other small and large changes taking place in the power system network. The typical states of the distribution network from the perspective of system security (inspired by the model given by Fink and Karlsen in 1978 [68]) can be seen in Fig. 2.5, where C indicates satisfaction of constraints, $\bar{C}$ indicates atleast one system constraint is on the verge of violation, and $\bar{C}$ represents violation of atleast one constraint. A similar inference can be made for satisfaction of system loads (L).

Periodic assessment of the system state and exercise of the various control functions necessitates availability of a reliable database. This requirement is met by the SCADA system. State estimator is the most important component of a SCADA system that not only filters out small random errors in the measurements but also performs observability analysis, fills up missing data, and processes the bad data. Extreme random errors are eliminated by a filtering process prior to state estimation. The resulting set of reliable measurements are utilized for identifying the system state followed by security analysis. If the system turns out to be under alert, emergency or restorative state, the first course of action is aimed at relieving stress on the system by exercising the respective controls followed by restoration of the secure state. The security analysis carried out under secure state involves two stages, i.e., outage analysis and contingency analysis. The outage analysis involves preparation of a relative list

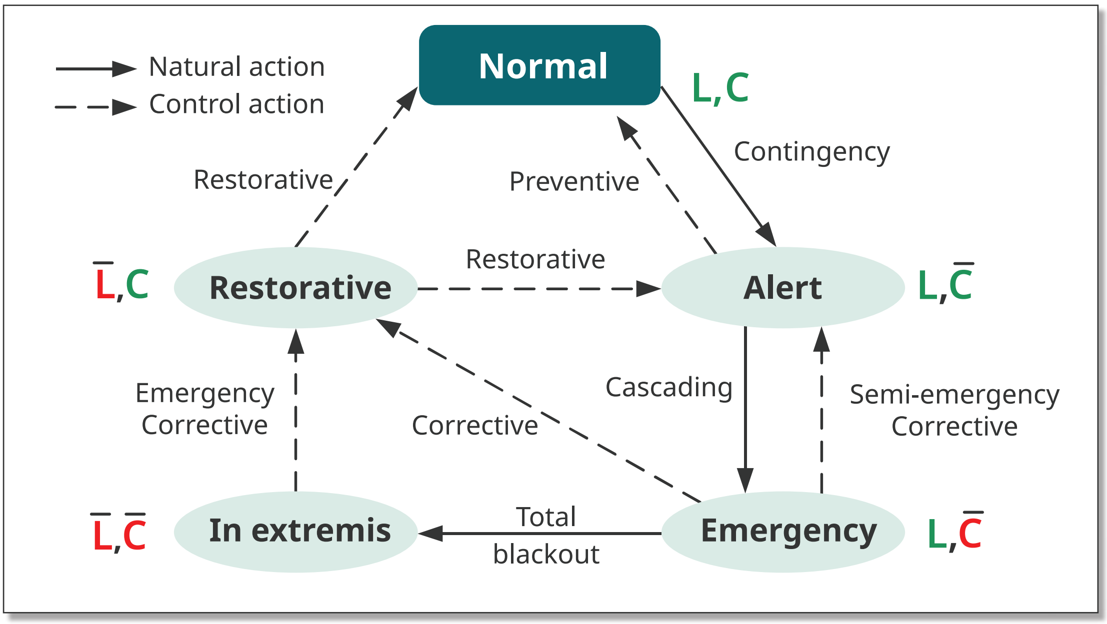


Figure 2.5: Distribution System Operating States

of credible contingencies quickly, based on the steady state and dynamic security criteria. The most credible contingencies so identified are simulated offline in contingency analysis to test how much stress the system can withstand. If the system state is an alert state (see Fig. 2.5), preventive control action can be the desired option, where control action is taken before the occurrence of the credible and severe contingency so that system constraints are within their limits. Preventive control actions involve activation of low cost and economic generation and voltage support devices to provide additional security margin. For severe system states, such as emergency, in extremis, and restorative in Fig. 2.5, emergency and corrective control actions are the possibility, i.e., control action is implemented after the system state has been achieved. The focus of corrective actions, such as load shedding and consequent restoration, is to bring the system state to a normal operating mode. Security analysis is currently being performed at the generation – transmission level however, a need of the hour is to extend the exercise at the distribution level. Distribution SCADA and distribution state estimators can leverage granular behind the meter forecasts for segregated load demand and DER generation while creating the much–needed reliable database at the low and medium voltage levels.

However, a trade–off between the investment so required in the distribution networks and the enhancement in security/ reduction in risk thus envisaged (cost benefit analysis) is quite necessary.

2.3.10.2 Cyber Security

The target of cyber security is to improve confidentiality (i.e., information is accessible only to authorized persons or entities), integrity (i.e., data or information can be trusted) and availability of the system. In terms of protection functions, this implies enabling, for example, user authentication, security logging and secure communication functionalities.

> No technology that's connected to the internet is unhackable – Abhijit Naskar

Reliance on the communication infrastructure for SCADA applications leaves the grid vulnerable to cyber-attacks. If the network information and database are maliciously altered, it may affect the reliability, resiliency, stability, security of power supply, as well as the power quality. A cyber-attack on the distribution network will affect all stakeholders connected to the network. A cyber-attack can be launched from various vulnerable entry points.

The cyber risk should be assessed based on criticality of the function and its impact on national security, economy, and safety of the ICT infrastructure. Risk assessment of cyber-attacks can help system operators make the system resilient, by identifying its impact. Any denial-of-service attack, data privacy issue or man-in-middle attack is a prominent concern in the distribution system.

However, the standard cyber security tools are inadequate for distribution networks since they cannot remove all attack surfaces due to the grid's size, connectivity, and heterogeneity. Even the established barriers like firewalls can be breached, leaving aside the fact that the available security tools do not account for physical attacks on the grid, since firewalls and authenticated encryption can't stop an attacker with physical access from changing commands. With physical attacks, an encrypted sensor's secrecy can also be breached, by placing another unencrypted sensor nearby. A meter's integrity can also be compromised by a shunt, allowing electricity to bypass the device.

To avoid such attacks if the sensors/ meters are physically shielded, then the availability gets compromised. A lack of prescriptive tools for dealing with the physical layer of the smart grid also affects cyber security. For example, if a software system is compromised, a reboot is a common solution; however, the grid's inertia and dynamics make this risky.

- **Protection Against Cyber Vulnerability**
  The first step in responding to an attack is detection, and distinct detection strategies should be in place for different threat vectors. Field measurements, control input, and other variables should be used to monitor the grid for distinguishing between observed behaviour during an attack and expected behaviour during normal operation.

Both active and passive methods of attack detection should be used, where passive detection entails validating the statistical properties of the measurements, whereas active detection entails approach such as benchmarking and moving targets

Although no security strategy can provide 100% safeguarding against potential cyberattacks, proper planning can undoubtedly reduce the adverse effects of an attack and help the system recover from them quickly. The overall security of the distribution grid from the cyber-physical power system perspective can only be strengthened by utilizing tools from the electric system theory. Different types of firewalls with appropriate configuration viz. boundary firewalls or packet filters, host firewalls, application-level firewalls and SCADA hardware firewalls should be deployed. For scenarios in which a group of malicious sensors is isolated, the trade-off between performance and security must be audited. Audits should be conducted to determine how changing the security properties of individual cyber and physical subsystems affect the entire connected cyber physical power system.

- **Cyber Resilient Operation**
  A baseline cybersecurity requirement is necessary to be implemented for critical assets like smart meters and data concentrators. The guidelines will govern the procurement, testing and installation of smart meters to minimize the risk of cyber intrusion. The following standards address the concerns regarding cyber intrusion in power systems (BIS: Bureau of Indian Standards, IEC: International Electrotechnical Commission, ISO: International Organization for Standardization)

> **BIS 16335** (Power control system security requirement standard)

> **IEC/ ISO 27001** (International standard on information security management)

> **IEC 62351** (A specific standard related to data and communication security in power systems and other related systems such as EMS, SCADA, distribution automation & protection)

> **IEC 62443** (Secure industrial automation and control system standard)

2.3.11 MARKET FACILITATION

End consumers in India have not been able to exploit NDOA to the extent leading to a perfectly competitive local market. With an expected segregation of the roles and responsibilities of DISCOMs, NDOA will become more accessible to end consumers, DERs and prosumers, and hence the local electricity market(s) will flourish. A market for procuring the following typical services from DERs and prosumers can be facilitated at the distribution level, details of which can be found in Chapter 4.

The wholesale electricity market has evolved in India however, the local electricity market is yet to be designed with appropriate spatial and temporal granularity. Besides, the products to be traded in the market, i.e., energy and/ or capacity-based contracts, smart contracts, and additional market players are yet to be introduced.

Microgrids can play a major role in facilitation of peer – to – peer trading of electricity and demand response. Virtual power plants can also become a facilitator of several products that can be traded in the local and wholesale market. New load types, such as, EV charging stations, battery charging and swapping stations, having the capability to provide vehicle to grid support and the corresponding tariff categories have to be accommodated.

The concept of Blockchain can be leveraged for transactions and contractual agreements between stakeholders of the local market to increase the visibility and promote data security. A perfectly competitive electricity market will result in optimal utilization of the capabilities of DERs and flexible loads present in the ADNs.

2.3.12 ANCILLARY/ FLEXIBILITY SERVICES

The sources (DERs and BESSs) and sinks (EVs, BESSs and flexible loads) of energy present within the distribution network periphery exhibit certain amount of flexibility. Such capabilities of resources located in distribution networks can be exploited for maintaining power quality, reliability and security of the power system, and support the grid operations. Such system support services that can be scheduled through flexibility market and/ or as an ancillary service are listed below

2.3.12.1 Demand Response and Flexibility Services

The DERs, BESSs, EVs and flexible loads available at the consumer premises or those available within the distribution network periphery can be scheduled in day-ahead/ real-time through the flexibility market. For the purpose, an appropriate co-ordination directly with the prosumers will be required, who must be incentivised to provide the flexibility available with them as an ancillary service. Large consumers can also be directly coordinated with for shedding their load in the event of an exigency.

2.3.12.2 Frequency Response Ancillary Services

The inertial response of eligible DERs and primary control (automatic), if the DER is equipped with droop control characteristics, may not be sufficient to provide frequency response ancillary services. However, secondary (manual) control for maintaining frequency within the specified band and tertiary control may be exercised in case of immediate ramp-up/ ramp-down requirement.

2.3.12.3 Non-Frequency Response Ancillary Services

- **Voltage Support Ancillary Services:** The reactive power support from eligible DERs and prosumers can be procured, and the active power drawl/ injection of a user connected to distribution network can be curtailed in the event of abnormal system voltages. The provision of LVRT and HVRT must also be enabled through prosumer participation. LVRT is currently mandatory for wind turbine-generators connected at 66kV and above [69].

- **Power Quality Management Services:** With an increase in the power electronic interfaced devices and large inductive loads, it becomes necessary to exercise supervision on distortion in power quality due to harmonics injected by them and take appropriate measures towards their reduction. It may include provisions of financial penalties for degrading the quality of power supplied and incentives towards participating in power quality improvement and power factor improvement programs.

2.4 CONFORMITY TO THE STANDARDS RELATED TO CONNECTIVITY

The DERs, EVs and BESSs connected to an ADN must comply with the connectivity requirements for reliable, secure, safe and integrated operation of the entire grid. Although, standards in such regards have been notified and amended from time to time [70], [71], they are applicable for connectivity at a voltage level of 33kV and above, i.e. transmission network [72]. For the connectivity standards pertaining to connection with primary and secondary distribution networks, [73] can be referred to. A connection agreement between the distribution licensee/ system operator and the interconnection requester will contain all the details regarding interconnection. The distribution licensee/ system operator should carry out an interconnection study, prior to the date of commercial operation, incorporating mathematical model of the requester's equipment. Coordination with the Regional Power Committee and system operator is also required for protection coordination and execution of emergency/ restorative controls. Measurements of the dependent and independent variables at the point of interconnection with the ADN should be telemetered to SCADA and ADMS for on-line and off-line system studies to be performed by system operators and other competent authorities. It must be ensured that the limits imposed by capability curve of a DER/ BESSs are always adhered to. Besides, the control loops enabling provision of Low Voltage Ride Through (LVRT) and High Voltage Ride Through (HVRT) must also be provided with an appropriate range of voltage level and the corresponding duration of ride through. Above a certain aggregate installed capacity, DERs must also be equipped with primary control (~ 5% droop) and secondary control loops. If feasible, dynamic voltage support and Rate of Change of Frequency (ROCOF) ride through support may also be provided.

The power quality parameters, i.e., Total Harmonic Distortion (THD), DC current injection, flicker, rapid changes in voltage amplitude and others should be measured periodically at the interconnection point and kept within the specified range. The interconnected resource(s) should be capable of operating in intentional/ unintentional islanded mode of operation while possessing adequate reactive power supply capability. Short circuit ratio at the interconnection point should be above a certain specified level. Compliance with the standards/guidelines/ regulations including, but not limited to, the following must also be ensured

- **Central Electricity Authority (Measures relating to Safety and Electricity Supply) Regulations, 2010** and subsequent amendments thereof (Safety)
- **IEEE 80** (Grounding)
- **IEC 61000-4-30 and Central Electricity Authority (Installation and Operation of Meters) Regulations 2006** and subsequent amendments thereof (Metering)
- **IEC 61000 – Relevant standards and IEEE 1453** (Flicker, Rapid Voltage Changes)
- **IEEE 519** (Harmonics)
- **IEEE 1547 and NERC DERs Task Force Report (Distributed Energy Resources: Connection Modelling and Reliability Considerations)** (Connectivity standards in general)

2.5 ADVANCED DISTRIBUTION MANAGEMENT SYSTEM (ADMS) FOR ADN

To perform the above functions in ADNs, a state-of-art SCADA system and Advanced Distribution Management System (ADMS) is required. To cater for the demand of real-time visualization, monitoring, and control of distribution network at the control centre, a two-way strong and redundant communication network between SCADA and fast responding devices, such as Intelligent Electronics Devices (IEDs), PMUs, and Internet of Things (IoT) devices, is needed.

Seamless data interoperability among these devices, using different supported protocols, is also required to be ensured. Further, some of legacy devices, such as old energy meters communicating over old communication technologies, need to be modified to make them communicable using the latest communication technology.

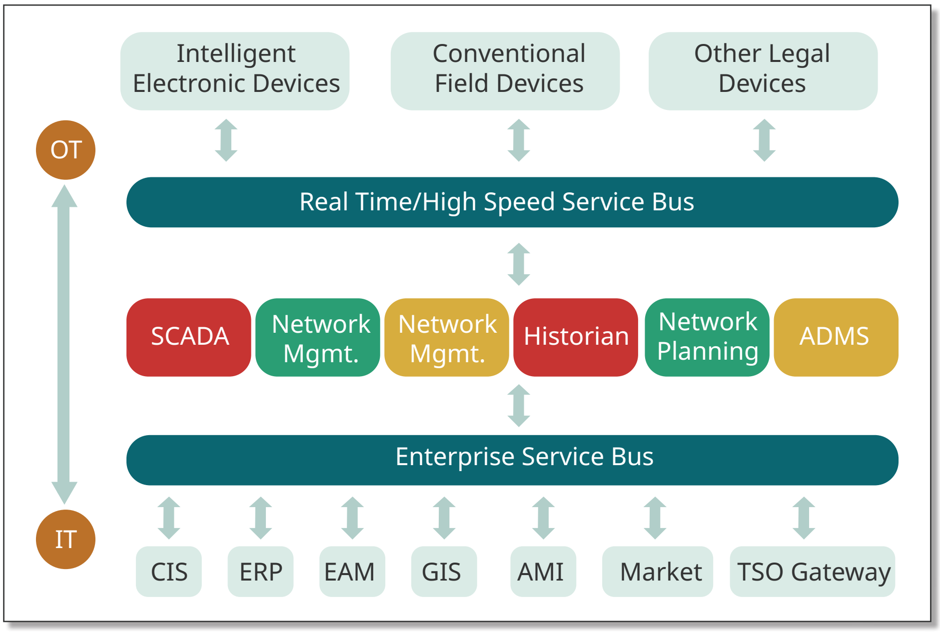
The ADMS should be flexible and should adopt a plug and play architecture. Keeping in mind the future addition of new functions, it is suggested that the ADMS is based on open standard such as IEC CIM (IEC 61968). The technical aspects involved in ADMS, ICT requirement and Advanced Metering Infrastructure (AMI) for proper implementation of the above functions are discussed next.

2.5.1 ICT ARCHITECTURE

To automatically control high voltage substations adjacent to generating stations, engineers started installing early SCADA systems by 1920's. The utilities started interconnecting their networks by 1930's. This mandated the need for a closer generation control and analog computers were installed for monitoring and control applications. With the advent of the digital computers and software in the 1960's, analog systems were replaced by modern Energy Management Systems (EMSs). This led to the evolution of the power networks and power system automation process started to mature as a new domain. However, the lack of proper ICT hindered the growth of the traditional power networks and this trend continued till early 1990's. The introduction of TCP/IP protocol in 1983 gave birth to the modern internet and paved way for advanced communication where all networks could now be connected through a common language.

The internet together with the mobile network revolution, which began in 1990's, led to advances in ICT, as we know it today.

The penetration of DER's into the distribution network, for well-known reasons, has introduced a certain flexibility at the distribution level. This calls for the installation of smart devices and advanced ICT at the distribution utility end, for exploiting the available flexibility, which shall lead to the emergence of active distribution system/ network operators. The ICT at the distribution level shall allow seamless communication between the entities connected to it by ensuring smooth information transfer. The generalized architecture of ICT at the distribution level is illustrated in Fig. 2.5. The Operational Technology (OT) applications at the top end of the figure and the Information Technology (IT) applications at the bottom end of the figure communicate seamlessly through the service buses. The IEC 62357 standard, developed by IEC, for power system management and information exchange is illustrated in Fig. 2.6. The ICT functions which had hitherto been part of the decision support department (SCADA/ EMS) may be handled by a full-fledged functional division to meet the future challenges. High obsolescence rates, cyber security, third party software versus in-housen capability besides vendor development should be suitably factored. The ICT architecture has to be built in such a way that any future technology upgradation is easy and cost effective. The critical components of ICT architecture should have redundancy with fallback capability, service continuity, and no data loss.



CIS: Customer Information System
ERP: Enterprise Resource Planning
GIS: Geographical Information System
TSO: Transmission System Operator
DMS: Distribution Management System
ACSI: Abstract Communication Service Interface
RTU: Remote Terminal Unit
IED: Intelligent Electronic Device
CT: Current Transformer
VT: Voltage Transformer
TCP: Transmission Control Protocol
IP: Internet Protocol
XML: Extensible Markup Language
MMS: Multimedia Messaging Service
EAM: Enterprise Asset Management

Figure 2.6: Generalized architecture of ICT at the distribution level

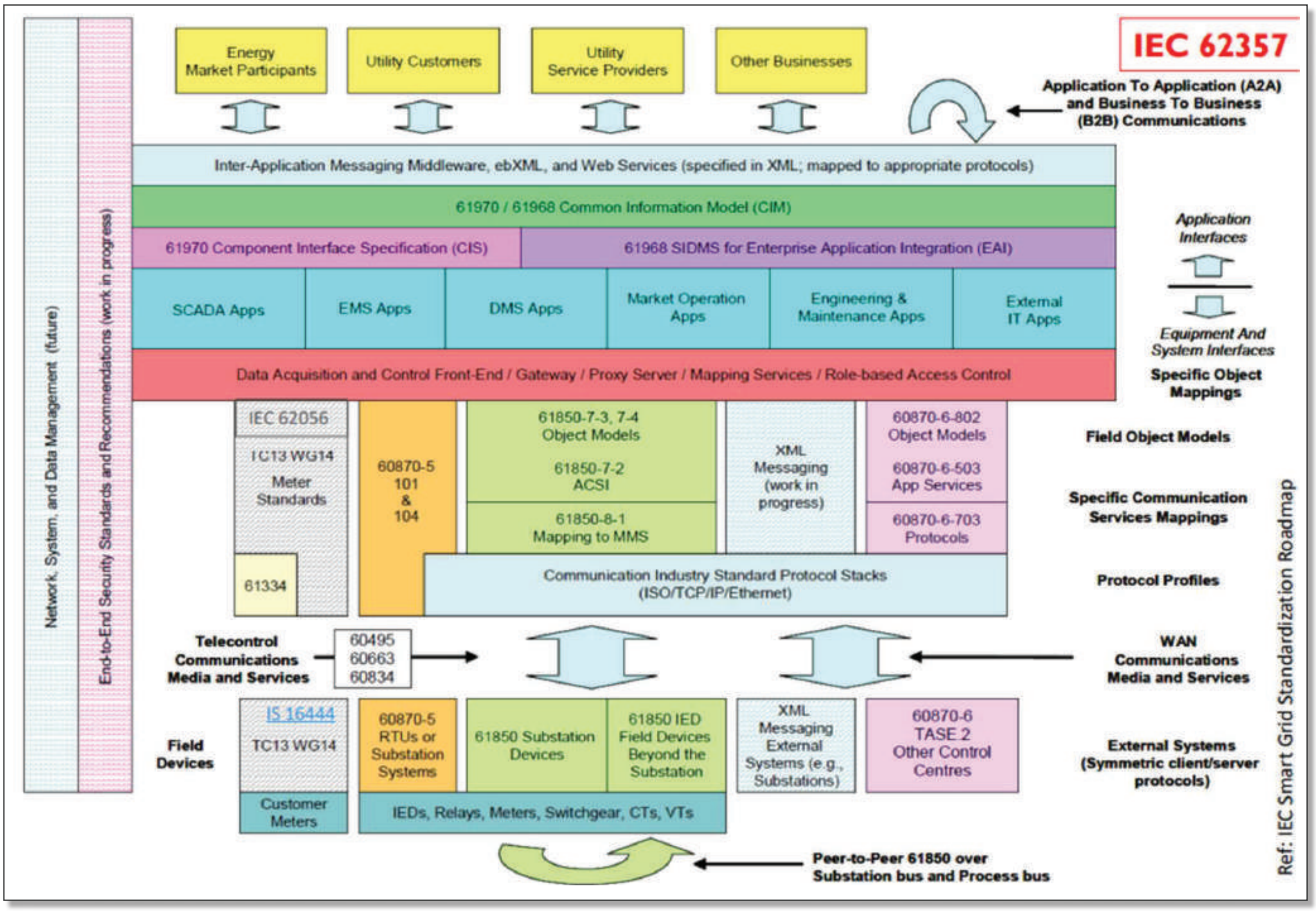


Figure 2.7: IEC 62357 standard for power system management and information exchange

2.5.2 ADVANCED METERING INFRASTRUCTURE (AMI)

The AMI system offers several benefits to the utility as well as the end consumers. It comprises of various hardware and software components which are used for measuring the energy consumption of different energy meters. Communication system is basic and important component of the AMI system. AMI system provides bidirectional communication between smart meters and the headend system.

Currently many AMI solutions are available in the market, but most of the manufacturers provide proprietary solutions. Existing AMI is designed in such a way that headend system can communicate to a specific make of smart meters only, which makes it a proprietary and closed solution. Also, categorisation of smart meter parameters into different sub-categories has complicated the processing of smart meters data for analytics etc. Besides, some of the parameters are stored into the memory available with the meter while some are not. This kind of architecture creates many data interoperability issues. The following new components can be added to the existing AMI to overcome the above challenges.

- Smart Meters at consumer end
- Smart Meter communication network
- Meter data management system (MDMS)
- IT infrastructure for the MDMS

The headend system shall be capable of integrating any make of meters with the above AMI solution. Further, if the headend and MDMS have a flexible SOA based architecture and are configurable for exchanging data over Common Information Model (CIM)/ ESB, the AMI system shall be able to easily share data/ information over multiple protocols with different applications. Smart meters should be developed with the capability of data reporting rate as low as 30 seconds to ensure near real-time data acquisition for better analytics, monitoring, and control. The proposed architecture for AMI is given in Fig. 2.8.

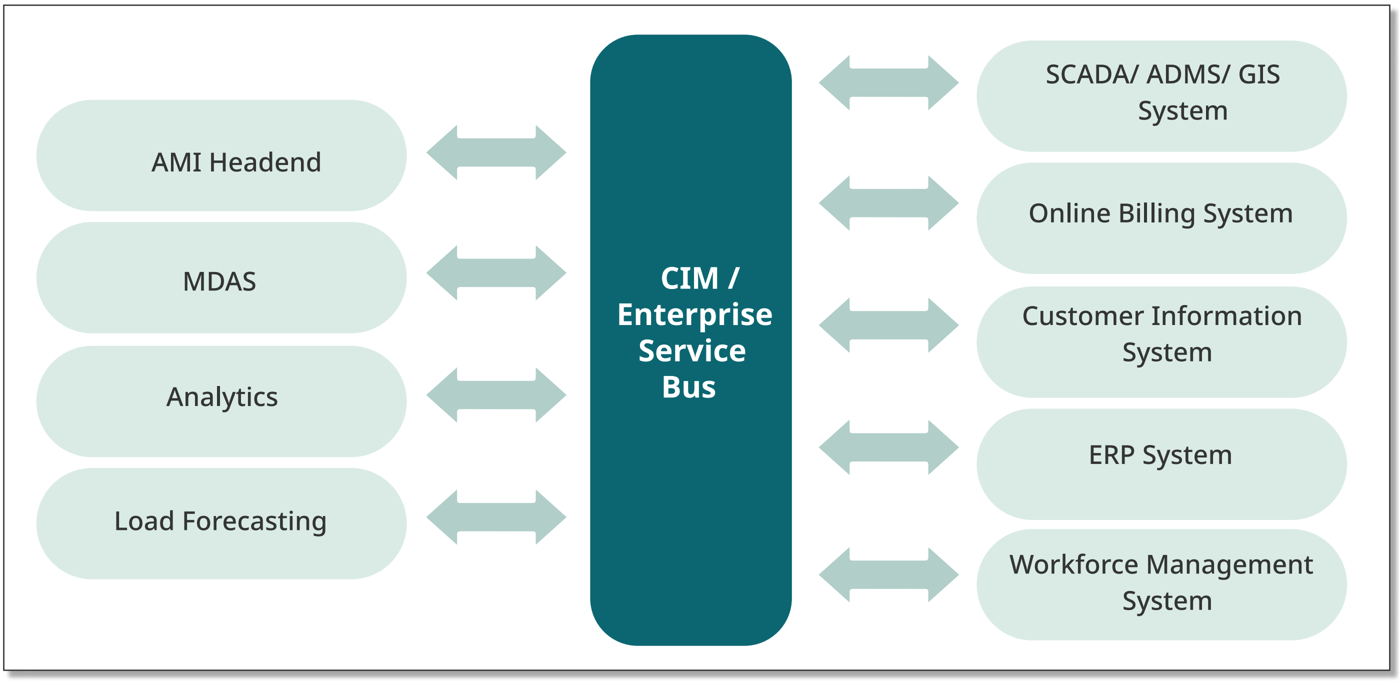


Figure 2.8: Typical AMI architecture

2.5.3 DATA PRIVACY

Prosumers should be actively engaged through appropriate ICT infrastructure for enabling them to become active participants in the network operation. Smart phone apps can be used to engage with them for allowing them to check their consumption, pay bills, mange contracts, etc with ease. The data exchanged among ADMS applications and devices should be via ESB (middleware) for standardization purposes. Overall, the huge volume of data so generated can be used to improve network operation and plan the network expansion more efficiently. However, the data so collected and archived, if shared with third parties to obtain useful insights, should in no way breach the privacy of stakeholders, end users in particular. Customers should also be able to decide how their data is being collected and used. Besides to ensure cyber security the roles assigned to various users of the data should be updated on a regular basis, as are the passwords and access levels.

Security patches should be applied as and when required to various cyber and physical components. Firmware and software used by various stakeholders always should be kept updated to the latest available version.

2.5.4 ADMS ALGORITHMS

The ADMS algorithms built using open-source languages, such as Python shall be capable of easily and cost effectively managing future modification, expansion, and conversion. Proprietary software applications will have to be avoided to ensure easy, fast, and cost-effective changes in the applications. The ADMS architecture should have various data analytics and predictive capabilities, so that the course of actions against any event can also be suggested. The future ADMS should be built to work in auto-pilot mode also, if needed. The algorithms that govern distribution system operations should also be resilient to cyber-physical attacks, so that corrective actions can be taken in the event of an attack while ensuring that the grid meets critical performance objectives.

2.6 ENVISIONING DSO IN THE INDIAN CONTEXT

Many International utilities/ systems have already taken cognizance of the changes that would come into effect when the distribution systems become active and, in the process, have recommended introduction of a new entity called DSO to handle active distribution systems optimally/ effectively. Chapter 1 provides the summary of efforts in this direction. The international efforts have resulted in culmination of defining DSOs as per the needs. The following sections provides a few such definitions.

2.6.1 DSO DEFINITIONS

Different countries/ group of countries are at different stages of development in the implementation of DSO in their power distribution networks. Some of them have already notified these definitions in their laws and policies, while most of them are still researching the practical implications and have defined the DSO in their white papers. Here, the highlight of the buzz around DSO is given by stating the adopted definitions of DSO in different countries across the globe.

1. **The National Association of Regulatory Utility Commissioners, United States,** 2018 in their working paper [74] defines the DSO as: The entity responsible for planning and operational functions associated with a distribution system that is modernized for high levels of DERs. The DSO denotes a new electric system paradigm and an expanded functional role for the distribution utility. DSO refers to the entity handling operations, and not as a platform enabling distribution-level energy market, where energy services can be easily transacted.
2. **Energy Networks Australia, 2020** in their position paper [75] defines the DSO as: An entity having visibility of power flows and DER in real-time, responsible to manage, maintain and operate the network and its assets, supporting optimal use of DERs for benefits of all consumers, ensuring reliability and safety of distribution network, while identifying and supporting the operations of the network using DER or via aggregator, retailers and third parties in case of emerging issues within the network.
3. **Electricity Directive of European Union, 2003 (2003/54/EC)** [76] defines the DSO as: A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

4. **The Energy Law, Journal of Laws - Poland, 1997** [77] defines the DSO as: An energy enterprise dealing with the distribution of gaseous fuels or electricity, responsible for grid operation in the gas or electricity distribution system, the ongoing long term operational security of that system, the use, maintenance and repair and the necessary expansion of the distribution grid, including its connections to other gas or electricity systems.

5. **Law of Ukraine on Electricity Market, 2003** [78] defines the DSO as: A legal entity responsible for secure, reliable and efficient operating, ensuring the maintenance and development of the distribution system and ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity with due regard to environment and energy efficiency.

> Distribution System Operator (DSO): 'Develop', 'Plan' and 'Operate' the 'DER' integrated 'Active Distribution Network' in a 'Reliable', 'Secure' and 'Efficient' manner

2.6.2 EARLY DISCUSSIONS / DEVELOPMENTS OF DSO IN THE INDIAN PERSPECTIVE

Modest efforts have been made in regard to ADNs in the Indian power sector. The need and relevance of DSO in the Indian distribution sector can be understood from the fact that several committees formed under the Ministry of Power (MoP) have already emphasised on the gravity of DSO implementation and have highlighted the drawn conclusion, which also form a broader framework of DSO implementation and functioning in India.

Some of the reports and policies highlighting the DSO implementation are the SAMAST report, the CABIL report, and NEP 2021, which are already discussed in Chapter 1.Not all, but a majority of the functions envisaged to be performed by a DSO in DER, EV infrastructure, and ESSs integrated ADNs discussed in the above sections of this chapter are currently being performed-by the respective distribution licensee (DISCOM) in coordination with other stakeholders viz. SLDC, ALDC, STU, QCAs, SERC and the relevant others.

However, the proliferation of DERs, EVs, BESSs and prosumers in ADNs of the future is going to change the operation and planning landscape. Hence it is required to set up an entity called DSO in the Indian distribution sector to address such concerns.

It is to be noted that the roles and responsibilities entrusted to a DSO will eventually depend on what type of institutional and regulatory framework gets adopted in such regards in the different Indian utilities. Nevertheless, the expected functions to be performed by a DSO are listed below depending on whether the wire and supply business are recognized as separated business activities or not.

Table 2.1: Functions to be performed by DSO in the Indian context

<table>
<tr><th rowspan="2">Functions</th><th rowspan="2">Presently performed by</th><th colspan="2">To be performed at the distribution level by</th></tr>
<tr><th>(Without wire and supply seggregation)</th><th>(After wire and supply seggregation)</th></tr>
<tr><td>Network Operation and Control</td><td>At Distribution Level-DISCOMs
At state transmission level-SLDC/Sub-SLDC</td><td>DISCOM/ DSO</td><td>Other relevant entity in coordination with DSO/ DSO</td></tr>
<tr><td>System Coordination</td><td>At Distribution Level-DISCOMs</td><td>DSO in coordination with DISCOM/ DSO</td><td>DSO</td></tr>
<tr><td>Resource Adequacy</td><td>At National Level- Central Electricity Authority</td><td>DSO in coordination with DISCOM</td><td>DSO in coordination with other relevant entity</td></tr>
<tr><td>Integrated Network Planning</td><td>At Distribution Level-DISCOMs
At State Transmission Level - SLDC</td><td>DISCOM in coordination with DSO/ DSO</td><td>Other relevant entity in coordination with DSO/ DSO</td></tr>
<tr><td>Forecasting (DER and Load)</td><td>At Distribution Level- DISCOMs
At State Transmission Level- SLDC</td><td colspan="2" rowspan="2">DSO</td></tr>
<tr><td>Scheduling and Despatch</td><td>SLDC</td></tr>
<tr><td>Metering</td><td>DISCOM
For Open Access at state transmission level- SLDC</td><td>DISCOM/ DSO</td><td>Other relevant entity</td></tr>
<tr><td>Billing and Collection</td><td>DISCOM</td><td rowspan="2">DISCOM in coordination with DSO</td><td rowspan="2">Other relevant entities in coordination with DSO</td></tr>
<tr><td>Detection of Theft and Tampering</td><td>DISCOM</td></tr>
<tr><td>Cyber – Security</td><td>SLDC</td><td colspan="2" rowspan="2">DSO</td></tr>
<tr><td>Market Facilitation</td><td>-</td></tr>
<tr><td>Ancillary/ Flexibility Services</td><td>-</td><td>DSO in coordination with DISCOM</td><td>DSO in coordination with other relevant entity</td></tr>
</table>

Most of the functions listed in section 2.3, except scheduling and despatch, market related activities and cyber security are currently being performed by DISCOMS at the distribution level. With the advent of the DSO, the functions excluded above as well as forecasting of DER and load are expected to be performed solely by the DSO, irrespective of the wire and supply segregation. DSO should also facilitate the ancillary/ flexibility services in coordination with DISCOM or other relevant entity. Integrated network planning, billing, collection and detection of theft and tampering should always be a joint effort between the DISCOM/ other relevant entities and the DSO, however the DSO may solely be entrusted with the planning activities. Metering should always be carried out by a single entity. The remaining functions viz. network operation and control, and system coordination could either to be carried out by the DSO or as a coordinated activity, depending on wire and supply segregation as well as the DSO framework adopted. The different institutional frameworks for the implementation of DSO in the Indian context are discussed in the next chapter.

3 INSTITUTIONAL FRAMEWORK OF DSOs IN INDIA: POSSIBLE ALTERNATIVES

3.1 INTRODUCTION

The review of international experiences in Chapter 1 has helped understand the ongoing distribution sector transition in various countries. Different countries have proposed and embraced the various DSO options depending on the prevailing power system structure, local needs, the degree of penetration of DERs, and the level of liberalization of electricity markets. India, too, is on the top of the transformation of the electricity distribution system. The introduction of DSO is a natural corollary. Taking forward the deliberations/discussions of FoR and technical committee's as mentioned in Chapter 1, an attempt needs to be made to introduce DSOs considering various aspects such as learnings from international experiences, and the current state of the Indian power sector, etc. The DSO's role, responsibilities, and functions have been discussed earlier. In a nutshell, the DSO requirement in the Indian context is recognized for the following reasons:

- To efficiently utilize flexibility available in the distribution network: This includes peak load management, network congestion management, etc., by using DERs connected to the distribution network. Provision of a retail market for capacity, energy and ancillary services is to be incorporated in the existing electricity market design,
- To ensure synergistic interaction with TSO – DSOs: It can provide active-reactive power support to TSO and facilitate the participation of DERs in dedicated markets. DSOs can also cooperate with the TSO to procure voltage support for improved network performance,
- To take optimal network investment decisions: Optimal Management of DERs connected to distribution network and peak load management using these flexible resources allows DSOs to avoid congestion and costly network investments,
- To enable use of data analytics for improved system operation: A large volume of data available with the DSOs can be utilized to obtain better forecasts, resulting in enhanced system operation and efficient planning.

This chapter suggests four alternatives for introducing DSOs, considering the prevailing structure of the Indian power sector and international practices. It is expected that the new entities, including DSOs, would work in unison with the existing ones.

Strengthening the SLDCs/Sub-SLDCs/ALDCs with modern technologies, including skilled human resources, is the prerequisite for introducing DSOs. SLDC has been envisioned as an independent system operator in the State. However, its organic linkage with State sector entities such as State Transmission Utilities (STUs) does not make them autonomous/independent in many States.

Making SLDCs truly independent is the need of the hour. Without reforms at the SLDC level, the DSO would not be able to assume the role as is expected to play. Smart metering is paramount, though it will increase the average cost of supply and retail tariffs. Implementing the recommendations provided in the CABIL [28] and SAMAST report [27] would be an excellent start. The following subsection gives an overview of four possible alternatives for introducing DSOs in India. Due to diversity in generation/load patterns, ownership and operation models of DISCOMs, consumer mix, and state-specific regulations, States would have different motives for picking any of the four suggested alternatives as shown in Fig. 3.1.

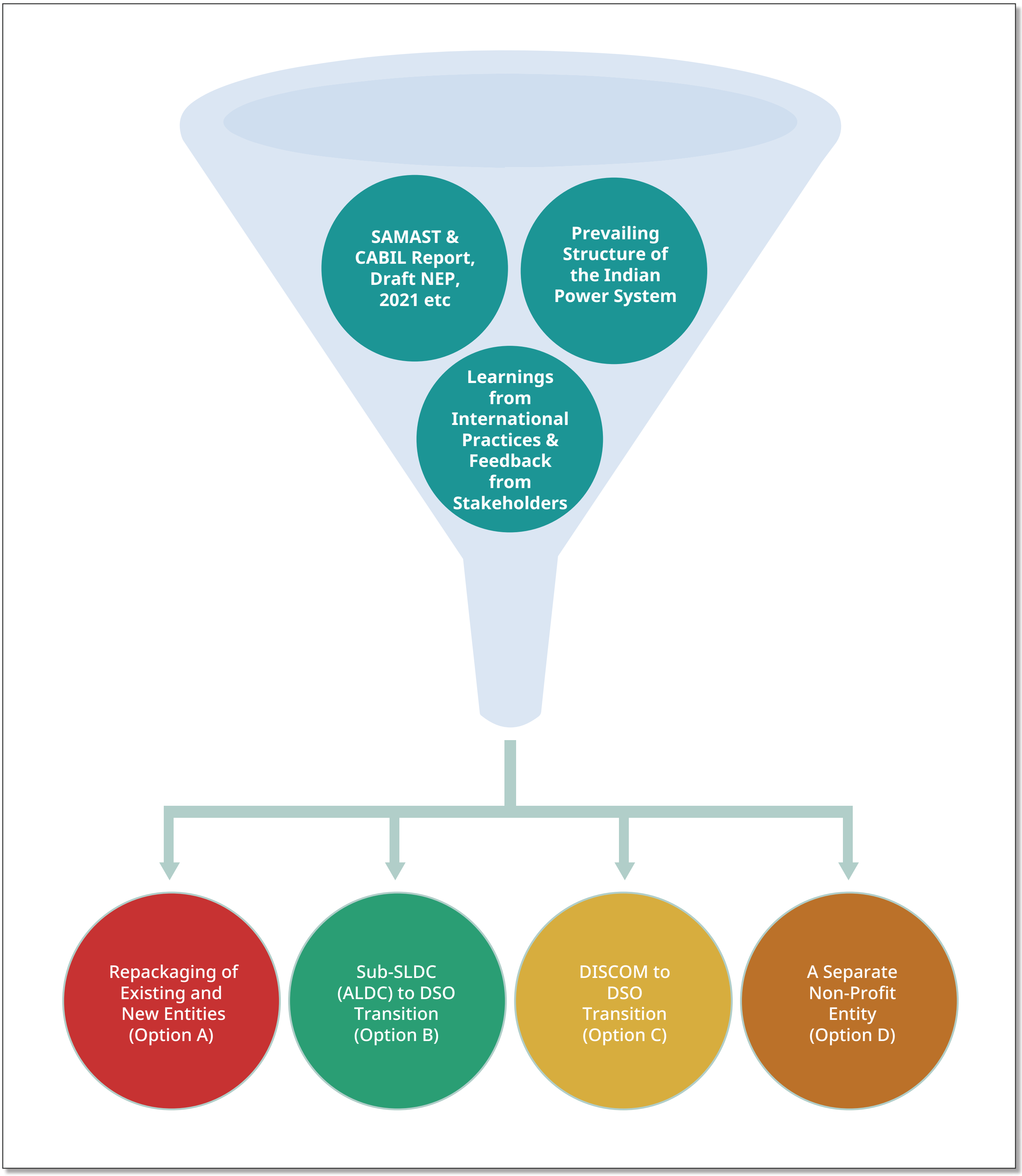


Figure 3.1 Alternatives for creating DSOs in India

3.2 ALTERNATIVES FOR CREATING DSOs

3.2.1 Repackaging of Existing and New Entities (Option A)

It may be worthwhile to examine segregation or combination of various functions carried out by an individual or multiple entities to mitigate the challenges and ensure reliable and efficient system operation. Such decisions are inevitable in modern days. Due to advancements in technology and ambitious carbon emission reduction targets, the above-mentioned practices have been widely followed by the regulators across the globe. For example, in the UK, Ofgem (regulator) has identified the need for a new and independent transmission system operator which does not own any energy networks. Thus, from 1st April 2019, National Grid Electricity Transmission (ET) and the Electricity System Operator (ESO) are now separate businesses operating within the National Grid group. Such segregation was crucial to help steer the UK towards its climate targets. DNO to DSO transition of distribution utilities in the UK is another example.

In India, such activities have also been carried out in the past. Earlier, RLDCs were owned and operated by the Central Electricity Authority (CEA) and later transferred to Power Grid Corporation of India Limited (POWERGRID). After the creation of CERC, the tariff regulatory function of CEA was assigned to them. Similarly, the regulatory power of the State government was moved to SERC after its creation. POSOCO got separated from its parent company POWERGRID and emerged as an independent company that operates the NLDC and RLDCs w.e.f. 3rd January 2017. Most recently, as part of the "Green Energy Corridors" scheme, 11 Renewable Energy Management centers (REMC) have been established for renewable energy integration. These are co-located with SLDCs in Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Madhya Pradesh, Gujarat & Rajasthan, and in RLDCs at Bengaluru, Mumbai, and New Delhi and at the NLDC [79]. By March 2020, these 11 REMCs were monitoring around 55 GW of Renewable units (Solar and Wind). These centers are equipped with state-of-the-art monitoring, forecasting, and scheduling system to handle variability, intermittency & ramping aspect of the Renewable Units. It is envisaged that these centers would support grid operators to accomplish efficient power system operations with reliability & security. In the absence of any wire and supply business segregation, DSO could also be formed by assigning additional functions to Distribution Control Centres/Load Management Units of DISCOMs and converting them into DSO.

Another option could be to introduce DSO as a subsidiary of REMCs in the initial stage. It can use the tools available with REMCs to carry out a few of its functions. Later on, a DSO could be separated. All these options need thorough investigation, and their adoption favorably relies upon the state's geographical, economic and regulatory format.

Acknowledging the existing functions of SLDC and the anticipated segregation of DISCOM, the new DSO entity could emerge at the intra-state level after combining the roles of the current state-level transmission and distribution network operation and planning functions with the new DSO. Subsequently, the retail electricity supply business could be opened for the competition.

> Future DSO design should envisage the existing institutions to perform their respective functions in harmony with the new entities.

> Change is situational. Transition, on the other hand, is psychological.
> - William Bridges

3.2.2 Sub-SLDC / ALDC to DSO Transition (Option B)

A few large States like Maharashtra and Gujarat have embraced the concept of Sub-SLDC or ALDC to deal with the issues emerging due to the diversity of load, network expansion, and integration of DERs, etc. For coordinated system operation, optimal scheduling, and despatch, SLDCs communicate directly with the RLDCs. Likewise, the SLDCs also interact with sub-SLDCs or ALDCs which act as an extended arm of the SLDC and help in managing the grid operation in their area of jurisdiction. The various functions carried out by the Sub-SLDC/ALDCs to support the SLDC are [28]:

- Monitoring grid operations within their area of jurisdiction (below 220 kV level in Maharashtra).
- Supervision and control over the intra-State transmission system within their area of jurisdiction.
- Coordination with SLDC/ Load Management Unit (LMU) of DISCOM/Other users.
- Maintenance of SCADA system & other equipment installed at its control centre.
- Remedial actions for upkeep of telemetry systems.
- RTU installation, maintenance, commissioning, and integration with the existing SCADA system.
- Monitoring of all communication equipment & links within their area of jurisdiction.
- Coordination with various intra-state entities for planned/emergency outages (for grid elements of 132 kV and below in Maharashtra)
- Monitoring and control of RES within their area of jurisdiction and reporting daily injection data to SLDC.
- Data collection, maintaining database and records of various electrical parameters of the power system, and preparing various reports.

The functions of Sub-SLDC/ALDCs are more state-specific and are not uniform. However, many of the operations carried out by these Sub-LDCs/ALDCs match the envisioned DSO functions. Due to limited area coverage, Sub-SLDCs/ ALDCs would have better visibility and they would promptly gather the granular data, including behind the meter generation. Qualified human resources and necessary tools have helped them carryout the required functions for many years now, and it will also help them discharge their new duty under the DSO tag. They could take over and start operating as DSO within a shorter time frame with a modest investment. Therefore, in States where an entity like Sub-SLDC/ALDC already exists, they fit well as a legitimate candidate for the DSO.

3.2.3 DISCOM to DSO Transition (Option C)

Most of the DISCOMs in India are State-owned, and they charge residential and agriculture customers at subsidized tariff rates. As per the recent announcement, the central government is exploring options for privatizing all Union Territories' DISCOMs and some States, such as Uttar Pradesh [9]. It is seen as an attempt to improve overall power sector efficiency. Following this changing scenario, private DISCOMs would emerge as a key player with a large consumer base. However, mere privatization would not yield the desired results. It needs to be supported with the appropriate market and structural/regulatory reforms.

As far as existing private DISCOMs are concerned, they operate in various parts of the country, such as Mumbai, Delhi, Surat, Ahmedabad, and Kolkata. They have also emerged as efficient operators and served to reduce distribution losses significantly with better reliability and quality of supply. Most of these private DISCOMs own and maintain the distribution network and are also involved in the retail supply business.

They have adopted and invested significantly in modern technologies such as Information Technology (IT), Supervisory Control and Data Acquisition (SCADA), Outage Management System (OMS), Geographic Information System (GIS), Automatic Meter Reading (AMR), SAP's Industry Specific Solution for Utilities Industry (SAP-ISU), 24*7*365 Centralized Call Center and Capacity Building.

Many of the private DISCOMs also took the lead in implementing various pilots such as Automated Demand Response (ADR), Demand Side Management (DSM), Solar Rooftop PV Projects, etc. However, at the same time, they are facing many challenges concerning DER accommodation, network capacity expansion, and coordination with traditional devices, etc. With the increasing flexibility requirements and the need for better reactive power support and voltage control, few private DISCOMs started executing functions such as active distribution network management.

> "It is not the strongest or the most intelligent who will survive but those who can best manage change." - Charles Darwin

As a result, many private distribution utilities, especially in the urban areas such as Tata Power Delhi Distribution Ltd (TPDDL) and BSES Rajdhani Power Ltd. (BRPL) in Delhi, have already started discharging many duties DSO is supposed to do.

Most private DISCOMS have invested heavily to achieve complete network visibility and controllability. Ultimately, the transition from private DISCOM to DSO is already happening on the distribution side. Therefore, regulatory action is required to formalize the activities of the current private DISCOMs under the umbrella of the new DSO. Urge for such intervention has been shown by the private utilities as well [80]. Likewise, private DISCOMs with necessary tools could be transformed into DSO.

3.2.4 A Separate Non-profit Entity (Option D)

As per the Electricity Act 2003 [4], the entities associated with the system operation or network management shall not involve in the electricity trading business. Such a provision is essential to ensure fair and non-discriminatory network access and a level playing field for all players.

The entities like NLDC, RLDCs, SLDCs and CTU are the shining examples. Similarly, introducing a separate non-profit entity as DSO will help to improve the operation of distribution network and facilitate non- discriminatory open access to DER owners and consumers. It will be instrumental in gaining the investors' confidence and promoting new products and services.

In the draft NEP 2021 [30], the DSO is envisaged as a separate and independent entity if carriage and content are separated.

However, irrespective of such segregation, the large-scale penetration of DERs and flexible commodities available in the system along with conventional units demands a coordinated framework and a separate entity.

Thus, irrespective of the separation of wire and supply business, Regulators can introduce DSO as a separate non-profit intra-state entity. Regardless of the institutional framework adopted initially (Model A-C), ultimately, it should converge over time to a separate Non-profit Entity. It should address the conflict of interest between existing and emerging distribution system entities.

The newly formed DSO is expected to be a coordinating agency between SLDCs and DISCOMs, as shown in Fig. 3.2. In case DISCOMs get segregated to wire and supply business, the DSO will coordinate with the Distribution Network Company (DNC), Aggregators, Retailers, and SLDC for efficient and reliable intra-state power system operation.

In the end, in all the four options, the Qualified Coordinating Agency (QCA)/ Aggregators could act as a single point of contact between the newly formed DSO and DERs to represent it in the pooling substation. However, many additional options of combining or separating various functions of other intra-state entities to create an entity like DSO are possible and could be explored further.

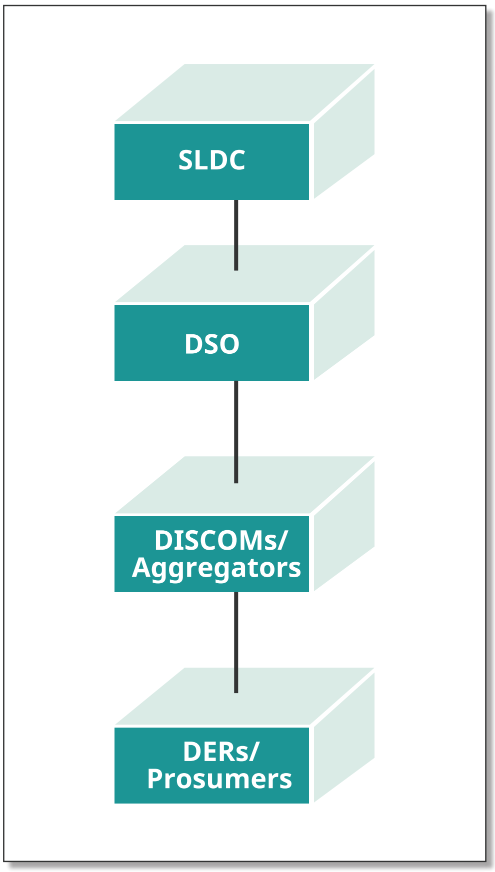


Figure 3.2 Hierarchy of distribution system operation in the presence of DSO

3.3 COMPARISON OF POSSIBLE DSO ALTERNATIVES IN THE INDIAN CONTEXT

After presenting four options for introducing DSOs and considering the prevailing network structure in India, it is possible to compare them based on various considerations. Irrespective of the segregation of the carriage and supply business of the existing DISCOMs, the emergence of DSO is inevitable. Thus, we have presented the comparison under both scenarios. Such comparison is essential to highlight the functions carried out by various entities under different choices.

3.3.1 CASE 1 (WITHOUT WIRE AND SUPPLY SEPARATION)

DISCOMs, in their current avatar (incarnation), handles the wire and retail supply business in most states. Hence, securing non-discriminatory open access to the DERs and bulk consumers is challenging as it affects DISOCMs' own business. Under such circumstances, DSO will provide such approvals in a Non-discriminatory manner.

While the existing DISCOMs still carry out their usual business activities such as retail supply, metering, billing, and collection, the DSO will ensure that the distribution level performance gets improved via Active Distribution Network Management in coordination with DISCOMs.

Table 3.1 List of key functions carried out by various entities under Case-1

Labels	Option A	Option B	Option C	Option D
Ownership of Distribution Network	◍	◍	▲	◍
Handling of Retail Business	◍	◍	▲	◍
Network Operation and Control	◍	◍	▲	◍
System Coordination (coordination among different players - Prosumers, Aggregators, SLDC, Active Consumers etc.)	▲◍	▲◍	▲	▲◍
Integrated Network Planning (augmentation, expansion, placement, sizing)	◍▲	◍▲	▲	◍▲
Forecasting (DER and Load)	▲	▲	▲	▲
Scheduling and Despatch	▲	▲	▲	▲
Market Facilitation	▲	▲	▲	▲
Handling Flexibility and Ancillary Services	▲◍	▲◍	▲	▲◍
Resource Adequacy	▲◍	▲◍	▲	▲◍
Metering	◍	◍	▲	◍
Billing, Collection, Detection of Theft and Tampering	◍	◍▲	▲	◍▲
Provider of Last Resort (POLR)	▲	▲	▲	▲
Cyber - Security (prediction, identification and mitigation strategies against cyber-attacks)	▲	▲	▲	▲

▲ DSO ◍ DISCOM

DSO will ensure fairness and transparency by giving non-discriminatory OA permission to eligible candidates. The granular data collection at the distribution level, including the behind-the-meter generation such as rooftop PV, EV charging stations, etc., will fall under the purview of DSO. The forecasted net load by DSO will add value to the decision-making and can be shared readily with all interested parties, including DISCOMS, for investment and business purposes fairly and transparently.

The anticipated DSO under this case will act as an enabler for distribution-level energy and flexibility markets. The DSO will coordinate with DISCOMs to ensure the reliable and efficient operation of the overall distribution network.

The list of activities carried out by DISCOMs and DSO under Case-1 is shown in Table. 3.1. There is no wire and supply business segregation.

Therefore, DISCOMs will continue to own and operate the distribution network and handle retail business in all options, except Option C, where DISCOM will transform into DSO. As a result, in Option C, DSO will own and operate a distribution network and get involved in the retail electricity supply business as well. Due to uptake in DERs, the distribution network will likely face reverse power flow and congestion.

With all necessary tools at its disposal, DSO will have complete real-time visibility of the distribution network. Hence, DSOs will manage congestion over the distribution network and coordinate such activities with corresponding DISCOMs.

The DSO will maintain coordination among various players such as Prosumers, DERs, Aggregators, SLDC, etc., in all four options. The decisions related to the Integrated Network Planning (augmentation, expansion, placement, sizing) require the detailed study and data related to anticipated load and availability of local flexibility resources.

A trade-off between local flexibility resources and network expansion could yield better economics. Hence DISCOMs could handle the network capacity augmentation-related matters more effectively in coordination with DSO.

The DSO will also ensure forecasting of net load and enable market participation of the various players in a non-discriminatory manner without violating distribution network constraints. The DISCOM, in coordination with DSO, will handle the metering, billing, and collection activities in all options except in Option C, where DSO itself will be engaged in all such activities. With more granular data at its disposal, DISCOM and DSO could detect theft and tampering of meters more effectively.

DSO as DER orchestrator, will handle the DER forecasting, scheduling, and despatch activities. The flexibility embedded within the distribution network could be utilized by DSO or Transmission System Operators as per their requirement. DISCOMS and DSO will cooperatively handle such transactions.

The coordinated planning for the communication infrastructure will fall under the DSO jurisdiction. The DSO will operate as Provider of Last Resort (POLR) in all options. Contingency planning needs blended efforts. Thus, DSO and DISCOMs will actively restore the system after a severe fault and utilize local resources to provide black start capability. DSO will maintain data privacy and security using modern- day technologies in all four options.

3.3.2 CASE 2 (AFTER WIRE AND SUPPLY SEPARATION)

The GoI had proposed the segregation of electricity carriage and content business of DISCOMs, and it was made part of the Electricity Amendment Bill 2014. The Forum of Regulators (FoR) has also published a report [81] and presented a blueprint for introducing retail electricity competition in India. Many liberalized European electricity markets have made such an attempt. Their main motive was to bring competition and give consumers a choice to select their retail electricity supplier. Reducing retail electricity prices via introducing competition was another objective. This move was also expected to attract more investment and innovation in the retail electricity sector.

A futuristic case has been considered here where DISCOM’s wire and supply business has been segregated. The wire or network business will be handled by a regulated entity called Distribution Network Company (DNC), and competition in the retail sector will be introduced via private retailers.

Activities like buying electricity from generators, selling electricity to the consumers, customer services, etc., will fall under the purview of the Retail supply business. DNC would handle the technical aspect and build a physical distribution network to deliver electricity to consumer premises. A separate new metering company is also considered, addressing smart metering-related activities. It will provide products and services to facilitate the efficient sharing of energy data and information between consumers, energy retailers, network operators, and other interested parties. A list of functions carried out by various entities under Case-2 is presented in Table 3.2.

Table 3.2 List of key functions carried out by various entities under Case-2

Labels	Option A	Option B	Option C	Option D
Ownership of Distribution Network	◍	◍	▲	◍
Handling of Retail Business	○	○	○	○
Network Operation and Control	◍ ▲	◍ ▲	▲	◍ ▲
System Coordination (coordination among different players - Prosumers, Aggregators, Retailers, SLDC, Active Consumers etc.)	▲	▲	▲	▲
Integrated Network Planning (augmentation, expansion, placement, sizing)	◍ ▲	◍ ▲	▲	◍ ▲
Forecasting (DER and Load)	▲	▲	▲	▲
Scheduling and Despatch	▲	▲	▲	▲
Market Facilitation	▲	▲	▲	▲
Handling Flexibility and Ancillary Services	▲ ◍	▲ ◍	▲	▲ ◍
Resource Adequacy	▲ ○	▲ ○	▲ ○	▲ ○
Metering	■	■	■	■
Billing, Collection, Detection of Theft and Tampering	○ ▲ ■	○ ▲ ■	○ ▲ ■	○ ▲ ■
Provider of Last Resort (POLR)	▲ ○	▲ ○	▲ ○	▲ ○
Cyber - Security (prediction, identification and mitigation strategies against cyber-attacks)	▲	▲	▲	▲

▲ DSO ◍ Distribution Network Company ○ Private Retailers ■ New Metering Company

After the segregation of DISCOMs, DNC will handle network operations, whereas retailers will be involved in the retail business of electricity supply. In case of Option C, the erstwhile private DISCOMs network business will become DSO, and the retail unit would be segregated and compete with the other retailers. To avoid conflict of interest, the regulators need to play a proactive role in framing regulations to ensure a level playing field for all players. Network operation and control services would be handled by DNC in coordination with DSO. System coordination involves coordinating with various Intra-state entities like Prosumers, Aggregators, Retailers, etc., and thus DSO needs to coordinate activities with all concerned parties.

Long-term Integrated Network Planning decisions such as distribution network reinforcement or capacity augmentation need to be taken considering the availability of local flexibility. Hence, DNC and DSO needs to work jointly on these functions. Forecasting, scheduling, and settlement of DERs could be possible only in the presence of visibility and controllability of such resources. DSO will be well-equipped with the necessary tools. Thus, it will be responsible for carrying out all these functions. Market participation of distribution level entities into either energy or ancillary services needs DSO approval to avoid violation of any network constraints. The new metering company will handle metering. Due to the introduction of the retailers and new metering company, billing and collection activities will need coordinated efforts among them, including DSO.

> "Selection must be driven by requirements."

Detection of theft and tampering of meters could be achieved via a coordinated approach among concerned parties. DSO itself or any retailer as directed by DSO may act as POLR subject to approval from the concerned regulators. For system restoration after a major fault, DSO and DNC need to work in unison and may take help from local players including aggregators, retailers etc. With access to diverse and granular data, DSO would ensure that the stored/shared data is safe and protected against any cyber-attack.

3.4 COMMENTARY ON SELECTION OF ALTERNATIVES

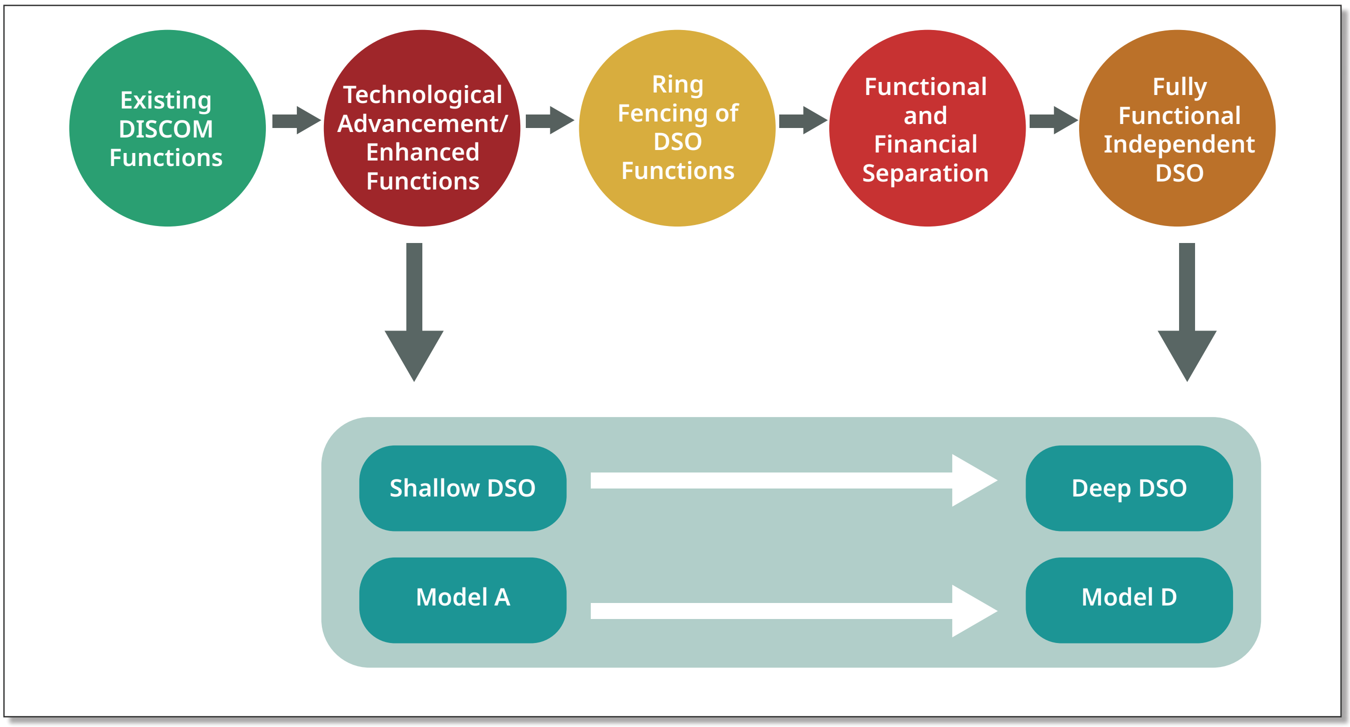


Figure 3.3 Possible evolution of DSOs in India

While adopting a suitable DSO option, each State Government would have to identify the key objective of introducing DSOs, depending upon the current electricity scenario in their respective States. The prevailing power system structure within a State would also serve as the main criteria for adopting a suitable DSO model. For example, states like Maharashtra have private distribution licenses in urban areas, like in Mumbai. They also have ALDC at Ambazari near Nagpur. Looking at the large geographical area and existing entities, Maharashtra may adopt more than one DSO option that suits its area requirements. Using existing infrastructure such as Sub-SLDC/ALDC could save the investment and reduce disturbance in the existing setup.

Institution building takes time, and it should be gradual. The corresponding evolution of DSOs in India is shown in Fig. 3.3. Capacity building and strengthening existing entities, such as SLDCs/ALDCs, Distribution Control Centers, etc., is the prerequisite for introducing DSOs. We have proposed four models for introducing DSOs in India based on these requirements. The various functions that anticipated DSO needs to perform are listed in Chapter 2. In the existing setup, these functions are carried out by some other entities or wholly missing, and this varies state by state. Thus, ring-fencing of DSO functions must be carried out based on the model adopted. Once done, functional and financial separation of the existing entities and DSO should be carried out. Ultimately, over some time and experience, we will have a completely independent and neutral entity as DSO.

It eventually covers the journey of DSO from its shallow to deep form. One of the main driving forces for embracing DSOs would be an improvement in the operational and financial performance of the distribution sector. In the country's eastern region, the current levels of AT&C losses are high. Thus, introducing DSOs either as repackaging existing and new entities (Option A) or a separate non-profit entity (Option D) would ensure integrated operation with other intra-state entities for maximum social welfare/operational efficiency and reduction in losses. Most of the States with Private DISCOMs have lower losses; however, they face challenges due to the high cost of power procurement.

Transitioning from DISCOM to DSO would give them an edge to utilize local resources such as rooftop PV and flexible load, including EVs, more efficiently. It will yield more efficient power procurement and lower retail tariffs.

The entry of DSOs will enable consumers to turn into Prosumers and actively participate in the various markets to earn revenue by providing flexibility/ energy services. The subsequent roll-out plan to accomplish State-specific goals in introducing DSOs would differ. Hence, State regulators should frame State-specific regulations to handle intra-state activities of DSO. However, to ensure security and reliable grid operation at the national level, CERC should prepare and harmonize the rules to ensure smooth TSO-DSO coordination, precisely between DSO and SLDC/RLDC.

4 ELECTRICITY COMMODITY TRADING OPPORTUNITIES UNDER DSO SET-UP

4.1 INTRODUCTION

Traditionally, the electricity is supplied to the end-consumers from the big generating plants located remotely. However, with the increase in installation of DERs in the distribution network, especially, rooftop Solar PV, the consumers are transformed into prosumers. Thus, market participants can be categorized as suppliers, consumers, and prosumers in the new era. The supplier is an entity that generates power that can supply active or reactive power. A consumer consumes electricity in the form of active and reactive powers. A prosumer is an entity that can supply or consume active or reactive power. The flexible loads also come under the category of prosumers since they can consume or reduce their consumption under a demand-side response program. The prosumers can sell power to neighboring consumers or the grid.

With the onset of Open Access (OA) in the Indian wholesale electricity market, it has become possible to purchase electricity for big consumers at a competitive price by participating in the energy exchange. India has three power exchanges, namely, the Indian Energy Exchange (IEX), Power Exchange of India Ltd (PXIL) and Hindustan Power Exchange Ltd. (HPX). The distribution companies or retailers can buy power through the exchange in the WEM and sell it to consumers in the retail market.

In theory, such provision has created a wonderful opportunity for consumers to choose a distribution supplier. However, the Indian distribution system is yet not equipped with the necessary technologies to allow consumers to choose their supplier and option for DERs to trade electricity. The emergence of the DSO in the Indian power sector would facilitate an environment for the electricity market at the local level to cater the requirements of the DERs, prosumers, and consumers. A local level electricity market can provide two diverse types of services, namely, energy and flexibility. Energy is the prime service, whereas flexibility is required to maintain the system's reliability and security. With the proliferation of DERs in the distribution system, flexibility is required for efficient and secure system operation. Local resources could supply such flexibility services more efficiently.

> Democracy is about giving choice to the people.

4.2 INTERNATIONAL EXPERIENCES

Many electricity markets across the globe are trying to efficiently utilize DERs connected to the distribution level network to reduce the investment required for further infrastructure expansion. To efficiently utilize the cheaper resources connected at the distribution level, ideally, all the DERs should be considered by TSOs in the wholesale energy and flexibility scheduling.

However, it isn't easy to consider all the distributed resources due to the system size, complexity, and computation feasibility. Several countries (e.g., North America, United Kingdom, European nations, and Australia) are planning, or a few of them have already implemented pilot projects to introduce DSOs to create a local electricity market platform to utilize DERs and services from prosumers efficiently.

> While it is wise to learn from experience, it is wiser to learn from the experience of others.

4.2.1 DRIVERS FOR THE ELECTRICITY MARKET AT LOCAL LEVEL ACROSS THE GLOBE

The need of the local level electricity market may be for energy trading or flexibility trading. The local level electricity market may be operated by the local market operator in coordination with the wholesale market operator. The local market operator can be a new or an existing entity depending on the distribution system structure and the prevailing regulations. Some of the states in the USA are planning to have DSO as a local level market operator as well as a distribution network operator. The European Union has proposed a separate entity other than DSO to operate the local level market. The driver to establish a local level market in different countries are shown in Table 4.1. The driver to establish a local level market in the USA is to secure the reliability of the power supply by utilizing the energy available locally. In contrast, other countries are introducing a local level market to utilize DERs for flexibility procurement. The Federal Energy Regulatory Commission (FERC) has issued Order no. 2222 to enable the participation of DERs in the wholesale electricity market through DSO and aggregators in 2020 [82].

Table 4.1: Driver for local level electricity market across the globe

Components	USA	UK	European Union	Australia
Driving force	Reliability and energy utilization	Flexibility utilization	Flexibility utilization	Handling grid instability
Creation of DSO	New entity is introduced as DSO	DNO is converted to DSO	In few countries DNO is converted to DSO; whereas, in some countries a new entity is introduced as DSO	New entity is introduced as DSO

4.2.2 CURRENT STATUS OF THE LOCAL LEVEL ELECTRICITY MARKET ACROSS THE GLOBE

Many electricity markets across the globe, such as California (CA) [83], Pennsylvania, New Jersey, and Maryland (PJM), New York (NY) [84], United Kingdom (UK) [37], European Union (EU), and Australia (AU) [85], have started exploring the possibility of utilizing DERs more efficiently either as a flexibility service or an energy service. To attain this, the introduction of market environment at the local level is required, which is in the transitional phase and not matured. In the transitional phase, the functions of the different entities at the local level electricity market in the USA, UK, EU, and AU are presented in Table 4.2. The key factors considered in this regard are ownership of the Distribution Network Infrastructure (DNI), operation of the DNI, provider of coordination services, energy supplier, and aggregation of local resources to offer services in the wholesale market.

Table 4.2: Current status of local level electricity market across the globe

Functions	USA	UK	European Union	Australia
Own, maintain, and operate distribution network	Distribution owner in PJM, Transmission distribution owner (TDO) in CA and NY	Distribution network operator	Distribution system operator	Distribution network service provider (DNSP)
Provide distribution service and coordination for DERs	Distribution system operator, Distribution Service Provider (DSP) in NY	Distribution system operator	Distribution system operator, third parties	Distribution system operator
Provide retail electric energy to end users	Load serving entities (LSE), Retailers	Retailers	Retailers	Financially Responsible Market Participant (FRMP)
Aggregate DER resources to participate in wholesale markets and offer grid services	DER Aggregation (DERA) in CA, DER Coordination Entity (DCE) in NY	Aggregators	Aggregators, VPP	Aggregators

The distribution system is owned and operated by distribution owners in a few states like PJM in the USA. In contrast, the distribution system is owned and operated by a single entity named transmission distribution owner (TDO) in CA and NY. In the UK, the distribution system is owned and operated by a distribution system operator, which previously was a distribution network operator. In AU, a distribution network service provider (DNSP) owns and operates the distribution system. The electricity to end-users is supplied by load-serving entities or retailers in the USA. In the UK and European Union, retailers supply energy to end-users.

Financially Responsible Market Participant (FRMP) provides energy to the end consumers in Australia. The TSO-DSO coordination provides a way to offer DER services in the wholesale electricity market through DSO or aggregators.

Such initiatives have been undertaken for electricity markets in the CA, PJM, NY, UK, EU, AU. The responsible entities for this is presented in the last row of Table 4.2. However, it is in the initial stage of implementation in these markets.

The maturity level of the different markets for the development of TSO-DSO coordination architecture is shown in Fig. 4.1 [44].

The PJM market has the higher participation of DERs in the wholesale market; however, the TSO-DSO coordination architecture is not mature. The CA and NY utilize DERs through DERA and DCE, respectively; however, their interest in the TSO-DSO coordination architecture development is lacking. The UK is ahead of all the markets, and it has moved sufficiently in the direction of DER utilization and TSO-DSO coordination architecture development.

Six different TSO-DSO coordination architectures have been identified by UK Open Network analysis project [37]. There is an active discussion on the different TSO-DSO coordination architecture models in the EU; however, those are only in the discussion stage [86].

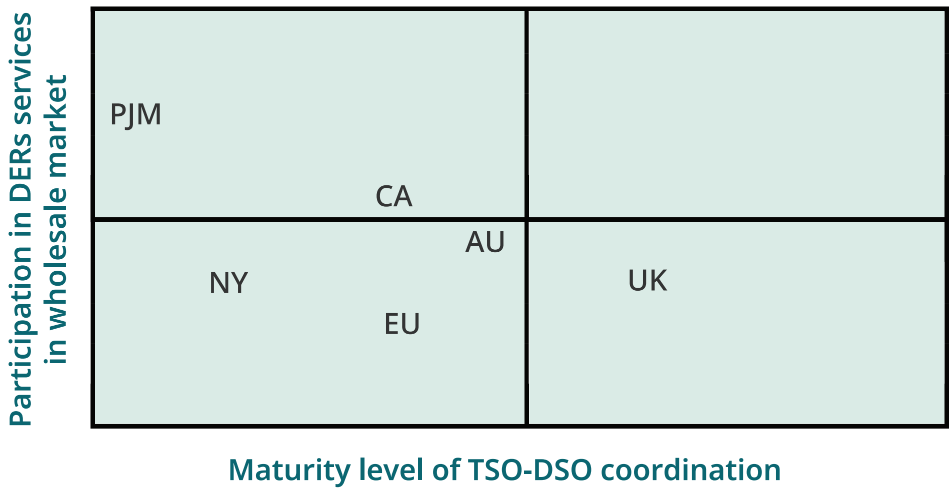


Figure 4.1: Status of the TSO-DSO coordination in different countries [44]

4.3 ROLE OF THE LOCAL LEVEL ELECTRICITY MARKET IN THE INDIAN POWER SYSTEM

The introduction of the Electricity Act 2003 was a game-changer in advancing a competitive environment in the Indian power sector [87]. The key focus of this act was twofold. First, evolution of competitive electricity market in Indian power sector that provides market-driven price signal and option to the consumers.

Secondly, providing the right policy, legal and regulatory platforms to the market participant to exercise their choice. To achieve these two aspects, the act has brought out six key steps as listed below:

- Reorganization of the state-owned vertically integrated electricity boards,
- De-licensing of power generation to enable higher investments,
- Trading and market development,
- Tariff and subsidies,
- Consumer interest, and
- Open Access.

After the introduction of the act, various initiatives have been introduced by central and state regulatory commissions, such as OA for consumers (above 1 MW of load), procurement of power through competitive means, competitions in power distribution franchisee, etc. The de-licensing of generation has attracted significant investment from the private sector. The competitive bidding for the power procurement was introduced by the Ministry of Power which helped in market-based price discovery for generators and consumers. To achieve this, IEX and PXIL were established. This gave an opportunity to distribution companies and open accesses consumers options to purchase power at a competitive price.

Ideally, the Electricity Act has laid the foundation for the competition at the local level through open access provision. Even though all the states have some regulations for the open- access, it has not gained much success because of various issues, such as, lack of regulatory consistency in determining the wheeling charges and cross subsidy, conflict of interest with distribution licensees, lack of consumer awareness, and inadequate distribution infrastructure. One of the major reasons for lack of competition at the local level is the nature of the business model of distribution companies in India, that is, the combined wire and supply business [81]. The wire business is monopolistic, whereas the supply business is conductive to give a choice to consumers in the form of multiple suppliers. The combined business makes it very difficult to have multiple suppliers in the same area. Although, it is possible to introduce a local level electricity market without wire and supply segregation in the Indian power sector.

The wire and supply segregation will create a more favorable condition to introduce the local level electricity market. The retailer can purchase electricity from the wholesale or local level electricity markets at a competitive rate and supply to end-consumer by competing with other retailers in the same area. Further, with the increase in the penetration of DERs, it is high time to introduce a local level electricity market to efficiently utilize DERs and give them options to sell electricity.

> Competition makes us to progress, innovate, and finding better ways

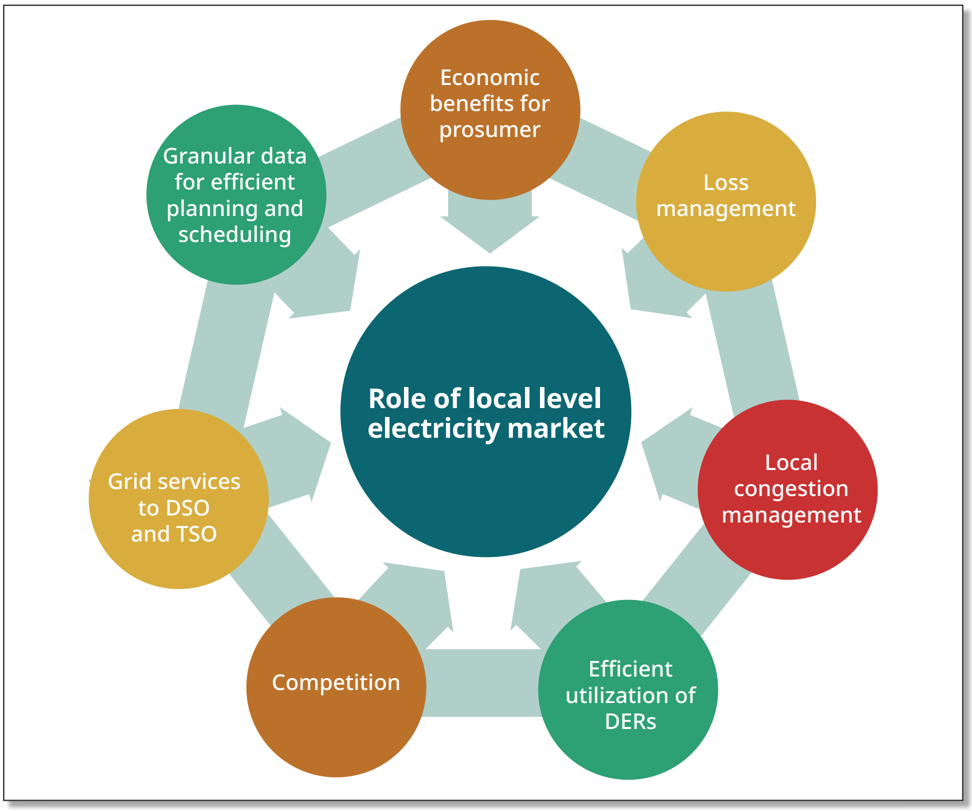


Figure 4.2: Role of the local level market in India

With the introduction of the local level electricity market in the Indian power sector, the consumers and prosumers will be empowered not only in terms of having a choice of supply but would also have the option to sell it (in the form of demand response) either within the local level electricity market or participate in the wholesale electricity market through an aggregator. The consumer can sell electricity through a demand-response program. Similarly, DERs would also have the option in the local level or wholesale electricity markets through an aggregator. A local level electricity market may play numerous roles in the evolving Indian power sector. This will not only enable greater choice of supply but also provide economic benefits for prosumers, efficient utilization of DERs, grid services to TSO and DSO, reduce losses, create granular data for efficient planning and scheduling, etc. as shown in Fig. 4.2

Introducing competition through the local level electricity market will redefine the regulator's role from a price-setter to a monitoring body and arbitrator. In other words, it will establish the rules for the local level electricity market and monitor the market for compliance. Before discussing the local level electricity market design, the important aspect is to define the DERs in the Indian power sector. National Renewable Energy Laboratory (NREL) has defined DERs as "small, modular, energy generation and storage technologies that provide electric capacity or energy where is needed, typically producing less than 10 megawatts (MW) of power". The FERC in Order 2222 defines DERs as "small-scale power generation or storage technologies (typically from 1 kW to 10,000 kW) that can provide an alternative to or an enhancement of the traditional electric power system". A similar type of definition is required for the Indian power sector, which can decide the qualification to participate in the local level and wholesale electricity markets. Following resources can be considered as DERs in India :

- Roof-top solar
- Wind generating units
- Energy storage system (Battery, Flywheel, Hydrogen)
- Biomass generators
- Electric vehicle
- Fuel cells
- Gensets

Further, the prosumers and open access consumers need to be defined in the context of local level electricity market.

4.4 PROPOSALS FOR ENABLING LOCAL LEVEL ELECTRICITY MARKET IN INDIA

Prior to discussing the design of a local level electricity market in the Indian power sector, it is essential to understand how the wholesale level electricity market was designed for the Indian power system. Before introducing the electricity market at the wholesale level, most of the electricity trading was done through long-term contracts or Power Purchase Agreements (PPAs). The electricity was mostly supplied from central or state-owned generators and a few independent power producers. The buyers were State Electricity Boards (SEBs) and DISCOMs. The price of PPAs was decided in two parts, namely, capacity charge and energy charge. The SEBs and DISCOMs were obliged to supply the electricity in their areas. However, the peaks demands were also met through PPAs, which were uneconomical. Further, the DISCOMs did not have the option to sell the short-term surplus. The Electricity Act 2003 envisaged creating an electricity market framework in the Indian power system where sellers and buyers can meet to sell and purchase electricity at a price discovered in the market (in Section 66).

As the first step in this, the CERC has introduced the Open Access Regulations and Inter-State Trading Regulations to facilitate power trading in an organized manner between any two points in India by paying a reasonable Open Access Charge. However, it did not help much because of many issues, such as not much participation, prices of bi-lateral transactions were consistently increasing in subsequent years, pancaking of the wheeling charges, absence of a proper mechanism for energy accounting, etc. In addition, it was a challenging task to handle and despatch a large number of short-term contracts of varying duration to maintain the supply-demand balance for each time interval. This has created a situation to evolve a different entity, named as market operator, to organize electricity trading. In this regard, CERC proposed establishing power exchanges (PXs) in the Indian power system to create a competitive electricity market by considering the following issues [88]:

- National power exchange or many power exchanges
- Mandatory Vs Voluntary participation
- Double side bidding Vs supply side bidding
- Uniform pricing Vs Discriminatory pricing
- Day-ahead exchange Vs same day exchange
- Time block for bidding (hourly/half-hourly etc.)
- Congestion management
- Taking care of operational inflexibilities of generating stations

In a PX, the generation companies submit their offers, and load entities submit demand bids to the market operator. The market operator clears supply offers and demands bids through the intersection of the aggregated demand and supply curves for price discovery on a PX platform. The system operator should validate the market-clearing to avoid congestion in the network. In case of congestion, market- splitting is performed.

The balancing is taken care of by an already established UI mechanism, and PX does not have any role. To avoid any market abuse, uniform price cap and bid cap are introduced. Even though the wholesale electricity market is presently operating, it has very limited access by the DERs. Thus, a local level electricity market should be introduced in the Indian power system, which is envisaged with the introduction of DSOs. The local level electricity market can be designed by taking input from the design of the wholesale electricity market. The important aspect in the design of the local level market is first to decide the definition of the local level, which defines the spatial granularity, i.e., geographical jurisdiction. The geographical jurisdiction of the DSO varies from system to system based on the four options proposed in Chapter 3.

The DSO jurisdiction may include medium voltage (MV), Low voltage (LV), Community level networks, etc. Based on the DSO's jurisdiction, the market level varies. Further, the local level market design should also consider the temporal granularity. The temporal granularity of the market can be Term-ahead (TA), Day-ahead (DA), Intra-day (ID), and Real-time (RT). A DSO may have any of the four, few, or all four markets. A hierarchical market can be designed based on spatial and temporal granularities.

Although several features of the local level electricity market may at the outset sound similar to the wholesale electricity market, there are key differentiators that need to be taken into account on the participation of types of consumers and types of system challenges that arise. The design of the wholesale electricity market is based on the four pillars [89], namely, i) scheduling and despatch, ii) imbalances, iii) congestion management, and iv) ancillary services. The first pillar of WEM is also applicable to the local level market. DSO handles the scheduling and despatch. In the bulk power system at wholesale level, the imbalances, congestion, and uncoordinated activation of ancillary services can create threat to system security.

Hence, explicit consideration is required in market design and they form three different pillars. In local energy markets, the quantum of imbalances is low and there is a default service provider. Hence all three pillars can be combined as a single pillar named flexibility. The important aspect at the local level is the settlement because of the participation of the DERs, prosumers, and active consumers. The settlement also includes metering and billing. The metering and billing can be performed by DSO or a third party. The next important aspect at the local level market is coordination with the transmission system operator for the different aspects of the local market. The definition of the transmission system operator varies as per the four options presented in Chapter 3. From the above discussion, it can be inferred that there should be four essential pillars that play a crucial role in designing the local level electricity market listed as follows and shown in Fig. 4.3.

1 Scheduling and Despatch,

2 Flexibility (Imbalance management and ancillary services, Congestion management),

3 Settlement, and

4 TSO-DSO coordination.

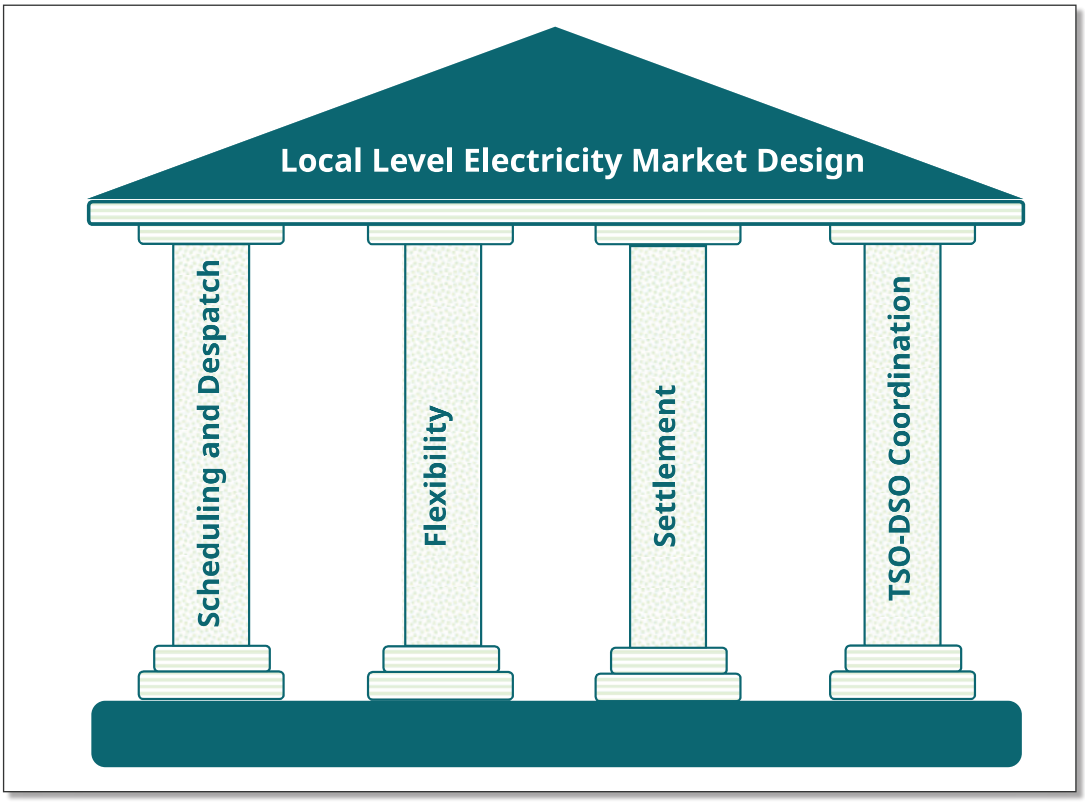


Figure 4.3: Four pillars of the retail/local market design [Adapted from [89]]

4.4.1 SCHEDULING AND DESPATCH

The scheduling and despatch philosophy of the local level electricity market design depends on the ways in which the entities trade electricity; that is, what are the trading avenues in the local level electricity market? Further, it also depends on how the market structure is organized, that is, centralized or distributed market. A typical local level electricity market framework is presented in Fig. 4.4. In a community-level market, the households can sell or purchase electricity with the other households present in the same community. There can be different options to trade electricity with other communities as well. Further, entities in a community can also participate in a common market platform operated by the market operator. The DERs present in the DSO's jurisdiction can sell electricity directly or through the market operator to households or commercial loads. Similarly, commercial loads can purchase electricity directly from DERs or through the market operator. Here, the important concern is that what should be the avenues of the electricity trading in the local market (i.e., TA, DA, ID, or RT). Every entity cannot trade in all the avenues. However, the option should be open for them. Further, the electricity can be traded by making mutual contracts or bidding/offering in a centralized platform.

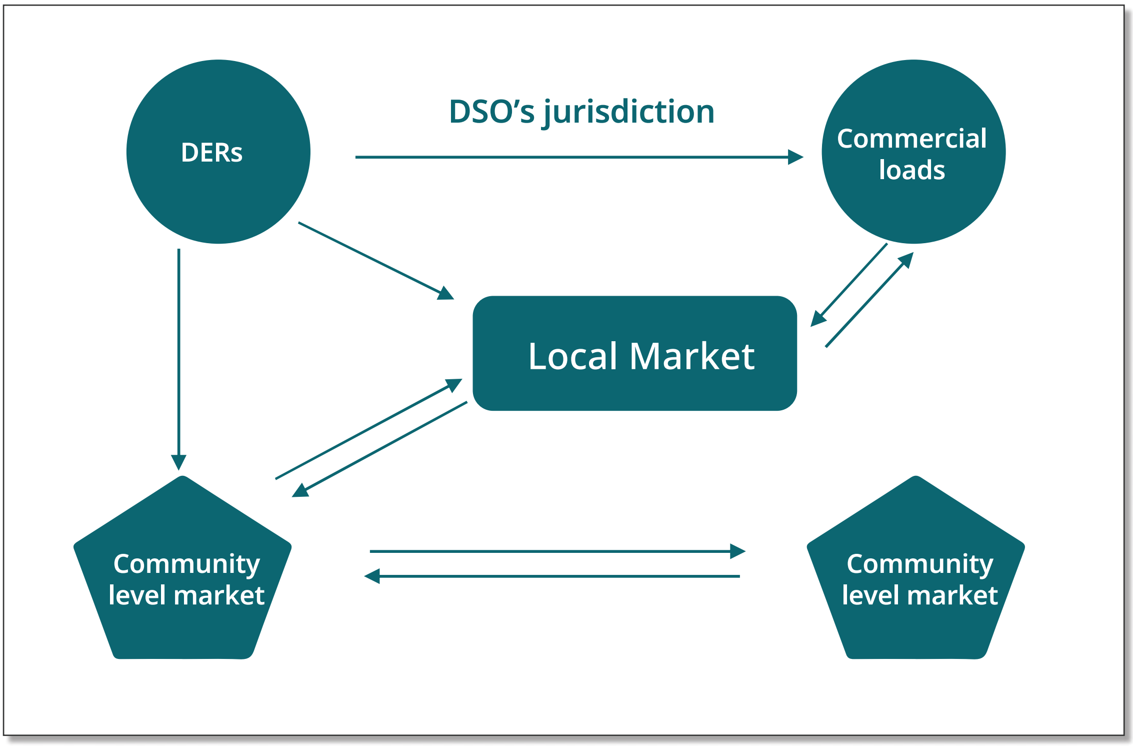


Figure 4.4: Local level electricity market in India

In Mutual contract-based trading, an entity finds its' counterpart and makes a mutual contract for electricity trading. It can have independent financial settlements without any involvement of the market operator or DSO. However, the DSO confirms the physical flow of electricity if the trading takes place between two different predefined communities, or the local network has limited capacity. In addition, the trading price can be decided mutually without considering the current market situation. The contract portfolio includes the contracted amount, contracted price, location, and time. The contracting entities should get permission from the DSO by sharing the contracted amount, location, and time information.

In the bidding/offering based trading, an entity can bid for electricity consumption or offer electricity generation independently to the market operator on a centralized platform. There is no need to have any information about the counterparty (i.e., load for generation and vice versa). The market operator clears the bids and offers on a market platform with predefined objectives. The market operator publishes the market-clearing price and communicates the clearing amount to the respective entity. A generalized bid/offer portfolio should include location, quantity, price, and time. The price-insensitive bid/offer does not include price information, and it acts as a price-taker.

Some services may not be suitable or may not be willing to participate in the market-based trading, for example, demand response and supply response. These services can be traded based on some predefined price signal. A load can reduce or shift its consumption based on the requirement in the demand response program. Similarly, a DER can adjust its output based on the requirement. An example of such a DER is the battery storage system. Both demand response and supply response will be paid based on their quality and quantity of services using a predefined price signal post schedule. The price signal may vary spatially and temporally.

The community-level trading can take place by bidding and offering on a P2P platform. The P2P electricity trading model, basically, forms an online electricity marketplace where seller and buyers can trade electricity, without involvement of any intermediary, at their agreed price. It has similar analogy with the other online markets like “Ola” and “OYO” which are used for cab and hotel booking, respectively, in India. The P2P transaction usually takes place between members of the P2P trading platform which can be obtained by paying a pre-determined monthly/-yearly subscription fee. A prosumer has a flexibility to change its role as seller and buyers as per requirement, thus it creates a win-win situation for the market participants located in the community level. In addition to P2P trading, DERs and prosumers can sell electricity by signing a mutual contract with the commercial loads or different households. Using price signal-based trading, households and commercial loads with battery energy storage systems can participate in the demand-response program.

Network modeling becomes one of the aspects in scheduling and despatch if network has a limited capacity. The network modeling is required for the market-clearing with system constraints, congestion management, contingency analysis, network expansion planning, etc. Further, with the integration of DERs in the distribution network, the bi-directional power flow needs to be modeled. The network for primary and secondary distribution systems are generally modeled as balanced and unbalanced networks, respectively. Thus, it becomes important to consider these aspects before proposing a market-clearing model for a particular system. The network modeling in the market-clearing framework can be broadly categorized as copper-plate, DC, and AC models. Copper-plate and DC models are the AC model's approximated versions and deal only with active power scheduling.

The local market operators in India should use the copper-plate model for the initial phase of the market-clearing due to its simplicity and easy implementation. The system constraints can be insured by DSO separately. Later it should adopt AC network model based linear or convex optimization formulation for market-clearing. The network model adoption also depends on the system attributes. For example, if some system has sufficient network capacity and reactive power support, it can continue with the copper-plate model.

4.4.2 FLEXIBILITY (IMBALANCE MANAGEMENT, ANCILLARY SERVICES, AND CONGESTION MANAGEMENT)

A huge integration of renewable energy sources both at transmission-level as well as distribution-level are taking place in the Indian power system. This Increasing penetration of renewable energy sources has introduced variability and uncertainty in the power system. Consequently, maintaining systems reliability and security are becoming a challenging task. Flexibility is required for the secure and reliable operation of the power system. Conventionally, the NLDC/RLDC procures flexibility services and maintains the system frequency through the resources connected to the transmission network. However, with the increase in the DERs in the distribution network, it is now possible to utilize the flexibility services locally. The NLDC/RLDC can procure flexibility services from different sources, such as generators, storage, solar PV, wind-farms, flexible loads, etc. through DSO to maintain the system frequency. The DSO can procure flexibility services to maintain voltage and congestion of the distribution system directly or through aggregators. The storage can be utilized as a special flexibility resource since it can both increase and decrease its power level quickly. The flexible loads can also decrease their consumption through demand-response programs. With the efficient utilization of flexibility resources, balancing costs can be reduced significantly. Different types of flexibility services may be required depending on the system attributes. Here, a generalized flexibility categorization is presented, and some other services may be included or excluded.

The requirement of flexibility can be divided as frequency regulation and non-frequency regulation services. Frequency regulation services are required to maintain the supply-demand balance and thus the system frequency. Based on the activation time, it can be categorized as Primary regulation, Secondary regulation, and Tertiary regulation.

The Draft Central Electricity Regulatory Commission (Ancillary Services) Regulations, 2021 has mentioned that the DERs and behind-the-meter resources, especially storage and demand response, can also provide the regulation services [90]. A detailed description of the regulation service sources is presented in Table 4.3.

Table 4.3: Frequency regulation services in the local electricity market

Regulatory	Sources	Utilized By
Primary regulation (sub-seconds to seconds)	• Battery energy storage system by charging and discharging • Wind turbine through converter control • PV system through inverter control	RLDC, NLDC
Secondary regulation (1 minutes to 15 minutes)	• Battery energy storage system by charging and discharging • Wind turbine through converter control or changing blade angle • PV system through inverter control • Distributed energy resources • Demand Response and supply response	RLDC, NLDC
Tertiary regulation (more than 15 minutes)	• Battery energy storage system by charging and discharging • Wind turbine through converter control or changing blade angle • PV system through inverter control • Distributed energy resources • Demand Response and supply response	DSO, RLDC, NLDC

Non-frequency regulations are required to maintain the bus voltage and network congestion. The other non-frequency regulation is black-start capacity. The detailed description is presented in Table 4.4.

Table 4.4: Frequency regulation services in the local electricity market

Different Services	Sources	Beneficiaries
Voltage Support (Seconds)	• Battery energy storage system by charging and discharging • Wind turbine through converter control • PV system through inverter control • Distributed energy resources	DSO, SLDC
Reserve (Minutes)	• Battery energy storage system • Distributed energy resources	SLDC, RLDC, NLDC
Black start (Minutes)	• Distributed energy resources • Wind turbine • PV system • Battery energy storage system	NLDC

4.4.2.1 Flexibility Procurement Models

The above-discussed flexibility services can be procured in different ways, namely, market-based and price/incentive-based models.

a) **Market based Flexibility Procurement**
The flexibility services can be procured from a competitive market platform. The flexibility market can be operated by a DSO or a separate market operator exclusively designed for flexibility trading named as flexibility coordinator. When the flexibility market is operated by a DSO, it asks for different resources to submit their offers. The DSO can also ask for flexibility requirement bids from neighboring or connected system operators (similarly, NLDC, RLDC and SLDCs can ask for flexibility bids from different DSOs). The DSO selects the offers based on its requirement and bid submitted by different system operators in a competitive manner. On the other hand, when a flexibility coordinator operates the flexibility market, the different system operators (DSO, SLDC, RLDC, and NLDC) submit their flexibility requirement bids, and different service providers submit their offers to the flexibility coordinator. The flexibility coordinator clears the flexibility market and calculates the clearing services amount and corresponding prices.

b) **Price-signal/Incentive based Flexibility Procurement**
The system operators (DSO, SLDC, RLDC, and NLDC) can procure flexibility services directly themselves or indirectly through a flexibility coordinator by asking for the flexible resources. The system operators can define a price band or some incentive for flexibility procurement. Price-band may vary spatially, temporally, or with system conditions. Incentives can be direct monetary payment, reduction in electricity bill (for demand response), etc.

4.4.3 SETTLEMENT

The scheduling and despatch of the energy and flexibility services is followed by the settlement activity. Electricity as a commodity is completely different from other commodities because there is no conceivable way to map the producer to the consumer in physical way. There are no such green electrons, coal electrons, or nuclear electrons, and they all are the same. Thus, the key task is to identify supply and consumption by metering and contracts in the settlement process. The entities who despatch as per their schedule should be priced accordingly. There should be a clear-cut mechanism to penalize the entities who deviate from their schedule. In the Indian power system, a deviation settlement mechanism at the transmission level takes care of such unscheduled interchanges. To maintain the sanctity of the contract, the deviation pricing and settlement rules should also be in place at the local level electricity market.

The diverse types of services, that would usually come into play while trading various types of commodities in the local level market, will be energy trading facilitation, providing platform and framework for trading flexibility, and pricing and providing network usage in fairly manner. The pricing of the commodities falling under these services can be done either on the competitive basis or by providing pre-defined price signals. The choice between the two needs to be made carefully depending on whether the market for the same has an oligopolistic nature or is leaning towards competitive one.

Apart from this, in certain institutional framework the DSO may offer distribution system operation services. Also, the flexibility services offered by DSO may include services like aggregation of ancillaries, supply and demand response aggregation (including Distribution Energy Resource Management - DERM), under certain institutional framework. In some of the models, metering and billing services would also come under the purview of DSO. In case of DISCOM to DSO transition, the network services provided by the DSO would enjoy natural monopoly and hence pricing for the same need to be regulated by the regulator. Distribution system operation services would remain a monopoly of the DSO in case of rest of available options for creating DSOs, namely Separate Non-profit Entity, ALDC to DSO Transition, and Repackaging of Existing and New Entities.

DSO may offer a variety of services depending upon its role and contractual obligations in the emerging context viz. other stakeholders in the power sector. For instance, DSO is not expected to have any stake in any purchase, sale, intermediation, or trading of electricity in commercial or retail market, but the network charges. In case of DISCOM to DSO transition, being a monopoly/natural monopoly, DSO may collect charges for its services at a regulated price which compensates it for prudent cost and a reasonable return. The DSO would continue for the development, operation, and maintenance of the distribution system.

Understandably, DSO may enjoy a monopoly position for majority of the services it would offer while facing limited competition in others. The distribution ancillary services in all the four proposed models of DSO creation are likely to be oligopolistic in nature if procured through market. Similarly, in all the four possible cases, demand response services would be procured by DSOs and DSOs would have monopsony over this market. Integration of DERs into the distribution system would be supervised by the DERM services, which would act as a monopoly under the umbrella of services offered by DSO. Irrespective of the institutional structure identified for creation of DSO, the variety of services being offered in such a context may evolve as different market structure. The regulators in some European countries in their DSO pricing regulations [91] have proposed to recover their regulated revenue requirement towards facilitating various services in the form of Distribution Use of System (DUoS) charges, i.e., network connection charges paid by stakeholders. Once the DSO is in place in the form of one of the four models proposed, such provision to meet the regulated revenue requirement of DSO needs to be made through charges like DUoS as mentioned above.

4.4.4 TSO-DSO COORDINATION

The significant share of DERs connected in the distribution system has created an opportunity to utilize resources more efficiently to avoid future infrastructural investments. However, it has also created a higher need for flexibility services due to temporal variability. The DERs can be more effectively and efficiently utilized for flexibility services as Distributed Flexibility Resources (DFRs) through proper TSO-DSO coordination. The TSO and DSO can coordinate for energy scheduling, flexibility/ancillary services procurement, demand/generation forecast, network development, load shedding, capacity procurement, etc. Here, the important aspect is to define the TSO for the four options presented in Chapter 3 for the Indian power system. In all the models, the DSO must exist under the jurisdiction of the SLDC only. Hence, in all four models, SLDC act as a TSO.

4.4.4.1.Different Coordination Models

There are many TSO-DSO coordination schemes available in the different proposals and reports. However, the prime focus of them is on the efficient utilization of DERs for flexibility services. TSO-DSO coordination schemes are proposed here from the Indian power system perspective for energy scheduling and flexibility services procurement. The TSO-DSO coordination can be DSO-centric, TSO-centric, or TSO, and DSOs can coordinate through a third party. Details of each model are presented below.

Table 4.5: DSO centric TSO-DSO coordination

Role of SLDC/RLDC	Role of DSO
Balancing the electricity of TN	Balancing the electricity of DN
Organizes and operates the central market for ancillary services	Facilitates a regional flexibility market for flexibility resources connected at DN
Directly procures and activates flexibility resources connected to the TN	Directly procures and activates flexibility resources connected to the DN for T&DN
Commercial relationship with DSO for the procurement of flexibility resources from DN	DSO has a central role in coordinating how DFR are used by the system as a whole

DER	Offer flexibility services directly to the DSO or indirectly via an Aggregator of choice
Aggregator / supplier / local energy system	Offer aggregated output as a flexibility service to the DSO
Customer	Behind-the-meter flexibility resources directly offered to the DSO or indirectly via an Aggregator of choice

a) DSO - Centric Coordination

The role of TSO, DSO, DER, aggregators and customers in this model is presented in the Table 4.5

b) TSO - Centric Coordination

The role of TSO, DSO, DER, aggregators, and customers in this model is presented in the Table 4.6

Table 4.6: TSO centric TSO-DSO coordination

Role of SLDC/RLDC	Role of DSO
Balancing the electricity of TN	Balancing the electricity of DN
Procures and activates flexibility resources connected to the T&DN for T&DN management and energy balancing	Indirectly procures flexibility resources connected to DN for constraint management of the DN via TSO
Commercial relationship directly with DFRs	Commercial relationship with TSO for the procurement of DFR on its behalf

DER	Offer flexibility services directly to the TSO or indirectly via an Aggregator of choice
Aggregator / supplier / local energy system	Offer aggregated output as a flexibility service to the TSO
Customer	Behind-the-meter flexibility resources directly offered to the TSO or indirectly via an Aggregator of choice

c) Third-party Centric (e.g., Flexibility Coordinator)

The role of TSO, DSO, DER, aggregators, and customers in this model is presented in the Table 4.7.

Table 4.7: Third-party centric TSO-DSO coordination

Role of Flexibility Coordinator (FC)	Role of SLDC/RLDC	Role of DSO
Organizes and operates flexibility market for DFRs in a neutral, independent, and transparent way	Balancing the electricity of TN	Balancing the electricity of DN
Procures and despatches DFRs for DN constraint management and TN balancing electricity purposes under whole system optimization platform	Organizes and operates the central market for ancillary services for balancing transmission system	Via FC
Procures and activates flexibility resources connected to the TN and DN by coordinating with TN and DN	Indirectly procures and activates DFRs for TN management and energy balancing via FC	Indirectly procures and activates DFRs for DN constraint management via FCs
Conducts commercial transactions between market participants, TSO and DSO	Via FC	Via FC

DER	Offers flexibility services directly to the FCs or indirectly via an Aggregator of choice, which in turn offers them to TSO and DSO Offers energy to DSO or indirectly via an Aggregator of choice
Aggregator / supplier/ local energy system	Offer aggregated output as a flexibility service to the FCs which in turn offers them to TSO and DSO Offers energy to DSO
Customer	Behind-the-meter flexibility resources that can be offered to FCs or indirectly via an Aggregator of choice

4.4.4.2. Information Exchange between DSO and TSO

Information exchange between TSO and DSOs is a critical issue in TSO-DSO coordination. The first step in this regard is to decide the objective of the coordination, then the responsibility of the TSO and DSO to achieve the particular objective, and then the data need to be defined. The TSO and DSO can exchange the information, namely, i) Price information, ii) Power information, iii) DERs and battery characteristics, iv) Flexible load information, and v) Network information. Based on the different objectives, market model, and policy regulations, few or all of the above information can be shared. However, the important concern is privacy issues. The definition of privacy may vary from system to system. A generalized format of information exchange is presented below.

Table 4.8: Information exchange in TSO-DSO coordination

Coordination objective	DSO to SLDC/ RLDC	SLDC/RLDC to DSO
Energy scheduling	Offer/bid amount Offer/bid amount and price	Clearing amount and price
Flexibility Procurement	DSO Centric: Cleared flexibility amount and price TSO Centric: Flexibility offers and bids	DSO Centric: Flexibility offers and and bids TSO Centric: Cleared flexibility amount and price
Forecasting	DER forecasting Load forecasting	Conventional generation forecasting (connected to TN)
Load shedding	Curtailable load	Load to be curtailed
Capacity Procurement	Available DER Flexible loads	Available conventional generators
Network development	Network Information Requirement of new line Location	Nod if no conflict

4.5 IMPLEMENTATION OF LOCAL LEVEL ELECTRICITY MARKET IN INDIAN POWER SYSTEM

Since the DSOs have to be introduced for the first time in the Indian power system; therefore, the local level electricity market should be implemented in a phase-wise manner. Local level electricity market implementation would require considering the present status of the different states. The status of the penetration of DERs in the different states varies. Based on the DER and OA consumer penetrations, the local level electricity market can be implemented in the three stages, as shown in Fig 4.5. If a system has very limited DER and OA penetration, it may not be beneficial to introduce the local level market. At most, a community-level market can be introduced. In the case of the medium-level DER and OA penetration, a procurement market model can be adopted. In the procurement market model, DERs sells energy to the retailers/consumers and flexibility services to the DSO based on a pre-defined price. The DSOs can procure flexibility services from the DERs, prosumers, and consumers (through demand response) based on a pre-defined price. If a system has high DER and OA penetration, then a fully competitive local level electricity market can be implemented. The competitive market can be operated through a centralized platform like power exchanges at wholesale level. In addition, a community level market can also be operated parallelly at P2P platform.

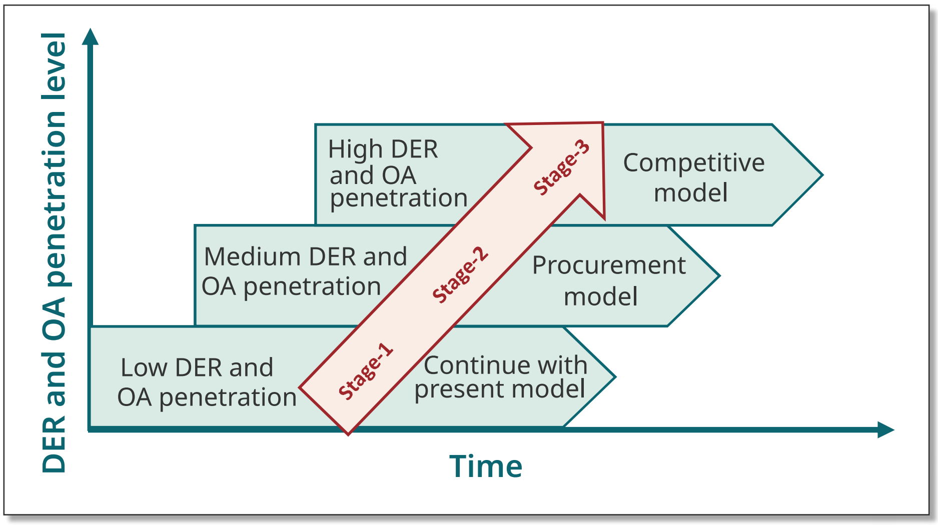


Figure 4.5: Local electricity market implementation based on DER and OA penetration level

The market can be implemented in two different phases based on the maturity level of the DSOs, as shown in Fig. 4.6. In the first phase, a procurement program can be introduced. In the procurement program based local electricity market, the flexibility services can be procured from the DERs. The OA consumers can purchase energy from the local DERs through mutual contracts or by participating in the wholesale electricity market. Once the systems are equipped with the required infrastructure and technologies, a fully competitive market can be introduced in which the energy and flexibility can be traded locally within the community or between different communities through P2P, or on a centralized platform or pool-based market.

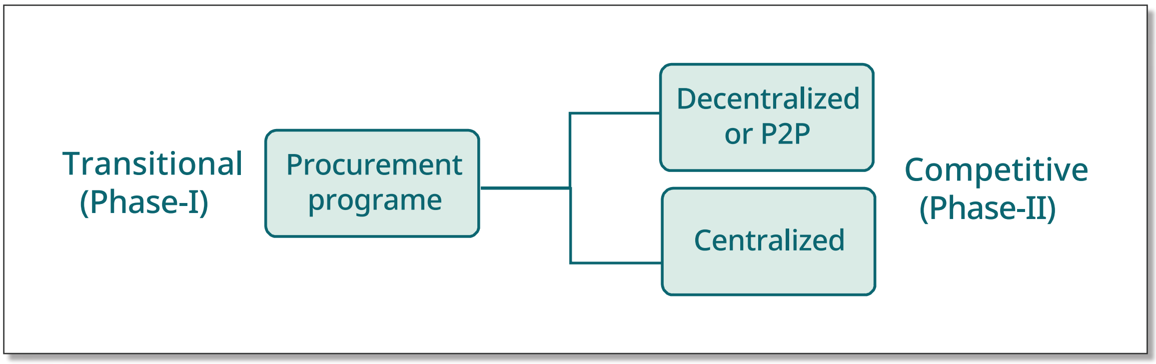


Figure 4.6: Market model implementation based on maturity level of the DSO

The implementation of the local level market would also depend on the regulatory policy for the wire and supply segregation. Different attributes of the local market implementation without wire and supply segregation are presented in Tables 4.9 and 4.10. The common attributes for the four DSO models are shown in Table 4.9, whereas differentiating attributes are shown in Table 4.10. In the transitional phase, that is, Phase I, DISCOM can continue to own the wire business and supply energy to the price-insensitive consumers. DISCOM can procure energy from the wholesale electricity market or from the locally available DERs. DERs can sell energy to DISCOM or in the wholesale electricity market through aggregators in coordination with DSO. DSO can procure flexibility from the DERs and flexible loads. Pay-as-bid is the better way of electricity pricing in the transitional phase. In Phase II, a fully competitive market can be introduced in which all the consumers should be allowed to purchase energy in the local level market. DERs, prosumers, and central resources in the DSOs jurisdiction can sell electricity in the local level market.

Table 4.9: Common attributes of the local electricity market implementation for the four DSO models without wire and supply segregation

Components	Transitional (Phase-I)	Competitive Market (Phase-II)	
	Procurement Program	Decentralized (P2P)	Centralized Platform
Products Traded	Energy and Flexibility	Forward/Spot sales of energy and Grid services	Forward/Spot sales of energy and Grid services
Financial Transactions	Contracts	Two-way subscriptions	Cleared through DSO energy and Grid services
Energy Buyers	DISCOM and OA consumers	Aggregator and Consumers	Aggregator and Consumers
Sellers	DERs and Prosumers	DERs, Prosumer, Central resources	DERs, Prosumers, and Central resources
Market Operator	DSO	Transaction platform Provider (e.g., Blockchain)	DSO/DMO
Pricing Mechanism	Pay as bid or other pricing	Matching buyers with sellers in two-way auction	DLMP or other pricing

The network ownership, network operation, and flexibility buyers for the four different models are shown in Table 4.10. In each model, the network ownership and network operation do not change with the different phases of implementation.

In Phase I, the flexibility is procured by DSO only, whereas, in Phase II, flexibility can be purchased by DSO and TSO (SLDC, RLDC, and NLDC) through the competitive market platform.

Table 4.10: Differentiating attributes of the local electricity market implementation for the four DSO models without wire and supply segregation

Components	Models	Transitional (Phase-I)	Competitive Market (Phase-II)	
		Procurement Program	Decentralized (P2P)	Centralized Platform
Network Ownership	Option A	DISCOM	DISCOM	DISCOM
	Option B	DISCOM	DISCOM	DISCOM
	Option C	DSO	DSO	DSO
	Optiion D	DISCOM	DISCOM	DISCOM
Network Operation	Option A	DSO/DISCOM	DSO/DISCOM	DSO/DISCOM
	Option B	DSO/DISCOM	DSO/DISCOM	DSO/DISCOM
	Option C	DSO	DSO	DSO
	Optiion D	DSO/DISCOM	DSO/DISCOM	DSO/DISCOM
Network Ownership	Option A	DSO	DSO and/or TSO	DSO and/or TSO
	Option B	DSO	DSO and/or TSO	DSO and/or TSO
	Option C	DSO	DSO and/or TSO	DSO and/or TSO
	Optiion D	DSO/DISCOM	DSO/DISCOM and/or TSO	DSO/DISCOM and/or TSO

Different attributes of the local electricity market implementation with wire and supply segregation are presented in Tables 4.11 and 4.12. The common attributes for the four DSO models are shown in Table 4.11, whereas differentiating attributes are shown in Table 4.12. The wire and supply segregation creates an opportunity to introduce a competitive market without any conflict with the DISCOMS. The energy market can be operated by DSO or by a new entity named as a Distribution Market Operator (DMO). The DSO is the buyer of flexibility. There can be a separate market for energy and flexibility trading, or it can be traded on the same platform.

Table 4.11: Common attributes of the local electricity market implementation for the four DSO models with wire and supply segregation

Components	Transitional (Phase-I)	Competitive Market (Phase-II)	
	Procurement Program	Decentralized (P2P)	Centralized Platform
Products Traded	Energy and Flexibility	Forward/Spot sales of energy and Grid services	Forward/Spot sales of energy and Grid services
Financial Transactions	Contracts	Two-way subscriptions	Cleared through DSO/DM
Energy Buyers	Retailer and OA consumers	Retailer/aggregator and Consumers	Retailer/aggregator Consumers
Flexibility Buyers	DSO	DSO and/or TSO	DSO and/or TSO
Sellers	DERs and Prosumers	DERs, Prosumer, Central resources	DERs, Prosumers, and Central resources
Market Operator	DSO/DMO	Transaction platform Provider	DSO/DMO
Pricing Mechanism	Pay as bid or Other pricing	Matching buyers with sellers in two-way auction	DLMP or other pricing

After the wire and supply segregation, the network will be owned by a new entity named as a Distribution Network Company (DNC) for all the models except DISCOM to DSO model. For DISCOM to DSO model, the distribution network will be owned by DSO.

In all four models, the network will be operated by DSO. In Phase I, DSO will be the flexibility buyers, whereas in Phase II, DSO and TSO (SLDC, RLDC, and NLDC) can buy flexibility through the market platform.

Table 4.12: Differentiating attributes of the local electricity market implementation for the four DSO models with wire and supply segregation

Components	Models	Transitional (Phase-I)	Competitive Market (Phase-II)	
		Procurement Program	Decentralized (P2P)	Centralized Platform
Network Ownership	Option A	DNC	DNC	DNC
	Option B	DNC	DNC	DNC
	Option C	DSO	DSO	DSO
	Optiion D	DNC	DNC	DNC
Network Operation	Option A	DSO	DSO	DSO
	Option B	DSO	DSO	DSO
	Option C	DSO	DSO	DSO
	Optiion D	DSO	DSO	DSO
Network Ownership	Option A	DSO	DSO and/or TSO	DSO and/or TSO
	Option B	DSO	DSO and/or TSO	DSO and/or TSO
	Option C	DSO	DSO and/or TSO	DSO and/or TSO
	Optiion D	DSO	DSO and/or TSO	DSO and/or TSO

4.6 IMPACTS OF MARKET MODEL ADOPTION

India is a geographically and politically diverse country. Thus, localized issues will emerge after introducing the DSOs depending upon state, urban, and rural areas. The objectives of the DSOs may be different in different regions, which may not coincide with the national objectives of TSOs. Any political conflict between local and national objectives needs to be very carefully managed.

The adopted model should be compatible with the local objectives, thus needing potentially different models in different regions. The different DSO options presented in Chapter 3 should be suitably chosen for a particular system and accordingly the market model presented in this chapter. The other important aspect is gate closure. In the competitive electricity market, market players submit their bids and offers to the market operator, and the market operator clears the bids and offers.

All the initial bids and offers must be submitted before some pre-specified time of market-clearing, known as 'Initial Gate Closure'. All the final bids and offers must be submitted before the 'Final Gate Closure'. The market players can modify their bids/offers in between Initial and Final Gate Closures. After the final gate closure, no bids or offers are allowed except in exceptional cases. The Gate Closure for different markets, e.g., term-ahead, day-ahead, intra-day, real-time, etc., are different. Similarly, different Gate Closure is used for different services, e.g., energy, frequency regulation, non-frequency regulation, etc. With the introduction of DSOs, the Gate Closure becomes a critical aspect and becomes more important with the TSO-DSO coordination. Gate Closure time for local energy market (i.e., by DSO/DMO), local flexibility market, TSO-DSO coordination, wholesale energy market, and wholesale flexibility market should be synchronously designed.

5 LEGAL AND REGULATORY LANDSCAPE AND CONSIDERATIONS

Power sector in India is governed as per the provisions of the Electricity Act of 2003. While the generation of electricity was delicensed, transmission, distribution and trading are licensed activities. Independent System Operators have been envisaged at National, Regional and State levels. National Load Despatch Centre, Regional Load Despatch Centres and State Load Despatch Centres have been set up. The operation of distribution system in a State/Union Territory is being presently performed by Sub-SLDCs/ALDCs and DISCOMs which have been enumerated in section 3.2.2. With the development and transformation of the power sector, especially at the distribution level, requirement for Independent System Operators at the distribution level has also been felt over a period of time, particularly on account of the rise in distributed generation, electric vehicles, etc., as well as the increasing requirement of demand response. The legal, policy and regulatory landscape (Fig. 5.1) and considerations relevant from the context of management of distribution system is presented in this chapter with a view to understand the organization of core activities and the way they are conducted under various legal/regulations considerations.

LEGAL

- **Electricity Act. 2003**

POLICY

- **National Electricity Policy**
  - Role of SLDC
  - DSO

REGULATORY

- **Indian Electricity Grid Code**
- **State Grid Code**
  - Provisions relate to functions of ALDC, Sub-SLDCs, DCC, DSOCC
- **Distribution Code**
- **Supply Code**
- **Metering Code**
- **Standard of Performance Regulations**
- **Grid Interactive Solar PV System Regulation**
- **Smart Grid Regulation**
- **Micro/Mini Grid Renewable Energy Generation and Supply Regulation**

Figure 5.1: Overview of existing legal, policy and regulatory provisions

5.1 LEGAL/LEGISLATIVE PROVISIONS

Distribution of electricity, as per Section 12 of the Act [87], is a licensed activity. Section 2 (17) of the Act defines the Distribution Licensee as under:

"Distribution licensee means a licensee authorised to operate and maintain a distribution system for supplying electricity to the consumers in his area of supply"

The provisions under various Sections of the Act relevant to system operation and distribution of electricity in a State are presented hereinafter.

Section 14. (Grant of licence): *"The Appropriate Commission may, on an application made to it under section 14, grant a licence to any person –*
(a) to transmit electricity as a transmission licensee; or
(b) to distribute electricity as a distribution licensee; or
(c) to undertake trading in electricity as an electricity trader, in any area as may be specified in the licence
……………………………………………………………………………………

Provided also that in a case where a distribution licensee proposes to undertake distribution of electricity for a specified area within his area of supply through another person, that person shall not be required to obtain any separate licence from the concerned State Commission and such distribution licensee shall be responsible for distribution of electricity in his area of supply".

Section 31. (Constitution of State Load Despatch Centres): *"(2) The State Load Despatch Centre shall be operated by a Government company or any authority or corporation established or constituted by or under any State Act, as may be notified by the State Government:*

....

Provided further that no State Load Despatch Centre shall engage in the business of trading in electricity."

Section 32. (Functions of State Load Despatch Centres):
" (2) The State Load Despatch Centre shall –
(a) be responsible for optimum scheduling and despatch of electricity within a State, in accordance with the contracts entered into with the licensees or the generating companies operating in that State;
(b) monitor grid operations;
(c) keep accounts of the quantity of electricity transmitted through the State grid;
(d) exercise supervision and control over the intra-State transmission system; and
(e) be responsible for carrying out real-time operations for grid control and despatch of electricit within the State through secure and economic operation of the State grid in accordance with the Grid Standards and the State Grid Code.
(3) The State Load Despatch Centre may levy and collect such fee and charges from the generating companies and licensees engaged in intra-State transmission of electricity as may be specified by the State Commission."

Section 42. (Duties of distribution licensee and open access):
"(1) It shall be the duty of a distribution licensee to develop and maintain an efficient, co-ordinated and economical distribution system in his area of supply and to supply electricity in accordance with the provisions contained in this Act."

Section 49. Agreements with respect to Supply or Purchase of electricity

....

Section 50. (The Electricity Supply Code):
"The State Commission shall specify an electricity supply code to provide for recovery of electricity charges, intervals for billing of electricity charges, disconnection of supply of electricity for nonpayment thereof, restoration of supply of electricity; measures for preventing tampering, distress or damage to electrical plant, or electrical line or meter, entry of distribution licensee or any person acting on his behalf for disconnecting supply and removing the meter; entry for replacing, altering or maintaining electric lines or electrical plants or meter and such other matters."

Section 51 (Other businesses of distribution licensees):
"A distribution licensee may, with prior intimation to the Appropriate Commission, engage in any other business for optimum utilisation of its assets:
Provided that a proportion of the revenues derived from such business shall, as may be specified by the concerned State Commission, be utilised for reducing its charges for wheeling.

Provided further that the distribution licensee shall maintain separate accounts for each such business undertaking to ensure that distribution business neither subsidises in any way such business undertaking nor encumbers its distribution assets in any way to support such business.

Provided also that nothing contained in this section shall apply to a local authority engaged, before the commencement of this Act, in the business of distribution of electricity."

Details relevant to other business are defined in State Grid Codes and are discussed in subsequent subsection 5.4.1 (Please refer Table 5.5).

Section 57. (Consumer Protection: Standards of performance of licensee):
"(1) The Appropriate Commission may, after consultation with the licensees and persons likely to be affected, specify standards of performance of a licensee or a class of licensees."

Section 86. (Functions of State Commission):
"(1) The State Commission shall discharge the following functions, namely: -
(d) issue licences to persons seeking to act as transmission licensees, distribution licensees and
electricity traders with respect to their operations within the State;
(e) promote co-generation and generation of electricity from renewable sources of energy by providing suitable measures for connectivity with the grid and sale of electricity to any person, and also specify, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee;
(h) specify State Grid Code consistent with the Grid Code specified under clause (h) of sub-section
(1) of section 79; (i) specify or enforce standards with respect to quality, continuity and reliability of service by licensees"

Section 181. (Powers of State Commissions to make regulations):

"(1) The State Commissions may, by notification, make regulations consistent with this Act and the rules generally to carry out the provisions of this Act.
(2) In particular and without prejudice to the generality of the power contained in sub-section (1), such regulations may provide for all or any of the following matters, namely:
(x) electricity supply code under section 50;
(y) the proportion of revenues from other business to be utilised for reducing wheeling charges under proviso to section 51;
(za) standards of performance of a licensee or a class of licensees under sub-section (1) of section 57;
(zp) any other matter which is to be, or may be, specified."

5.2 POLICY LANDSCAPE AND INITIATIVES

The National Electricity Policy, 2005 notified by the Government of India in compliance with section 3 of the Electricity Act 2003 (EA), provides policy guidelines for accelerated development of the power sector in the States. In addition to the above, Government of India also introduced the Electric Vehicle (EV) Policy to promote EVs in the country, Renewable Energy Policy to accelerate development of RE in the country and Integrated Power Development Scheme (IPDS) to facilitate reform in the distribution sector and to bring in automation through adoption of Information Technology. The draft Indian Electricity Grid Code (IEGC), 2022 details the resource adequacy under planning code. A brief description of the Policy landscape and initiatives as mentioned above is given in the following sub-sections.

5.2.1 NATIONAL ELECTRICITY POLICY

The National Electricity Policy (NEP), 2005 [92] puts emphasis on Independent System Operation through NLDC, RLDCs and SLDCs. Section 5.3.7 states that *"the spirit of the provisions of the Act is to ensure independent system operation through NLDC, RLDCs and SLDCs*"
The NEP recognises that distribution is the most critical segment of the electricity business chain. The real challenge of reforms in the power sector lies in efficient management of the distribution sector (Clause 5.4.1).

The NEP lays emphasis on safeguarding consumer interests and multiple licensees in the same area of supply, restructuring of distribution utilities for achieving efficiency gains, improvements in efficiency parameters in distribution business, reduction in transmission and distribution losses and improving the quality of service to the consumers, creation of network information and customer data base to facilitate management of load, improvement in quality, customer information and prompt and correct billing and collection, etc., SCADA and data management systems are useful for efficient working of Distribution Systems. Relevant extracts from the NEP are reproduced hereunder for ready reference:

"5.4.2 The Act provides for a robust regulatory framework for distribution licensees to safeguard consumer interests. It also creates a competitive framework for the distribution business, offering options to consumers, through the concepts of open access and multiple licensees in the same area of supply."

"5.4.3 For achieving efficiency gains proper restructuring of distribution utilities is essential. Adequate transition financing support would also be necessary for these utilities."

"5.4.10 Modern information technology systems may be implemented by the utilities on a priority basis, after considering cost and benefits, to facilitate creation of network information and customer data base which will help in management of load, improvement in quality, detection of theft and tampering, customer information and prompt and correct billing and collection. Special emphasis should be placed on consumer indexing and mapping in a time bound manner. Support is being provided for information technology-based systems under the Accelerated Power Development and Reforms Programme (APDRP)."

"5.4.12 SCADA and data management systems are useful for efficient working of Distribution Systems. A time bound programme for implementation of SCADA and data management system should be obtained from Distribution Licensees and approved by the SERCs

keeping in view the techno economic considerations. Efforts should be made to install substation automation equipment in a phased manner."

The NEP also provides for protection of consumer interests and quality of supply as under:

"5.13.1 Appropriate Commission should regulate utilities based on pre-determined indices on quality of power supply. Parameters should include, amongst others, frequency and duration of interruption, voltage parameters, harmonics, transformer failure rates, waiting time for restoration of supply, percentage defective meters and waiting list of new connections. The Appropriate Commissions would specify expected standards of performance."

"5.13.2 Reliability Index (RI) of supply of power to consumers should be indicated by the distribution licensee. A road map for declaration of RI for all cities and towns up to the District Headquarter towns as also for rural areas, should be drawn by up SERCs. The data of RI should be compiled and published by CEA."

> It is time for planning and operationalizing DSOs in view of changing paradigm of distribution system operations.

5.2.2 DRAFT NATIONAL ELECTRICITY POLICY, 2021

The Government of India issued the draft National Electricity Policy, 2021 on 27th April 2021 inviting suggestions for framing the Policy [30]. The draft NEP, 2021 proposed introduction of an independent entity called the Distribution System Operator for performing real-time operation of the Distribution System and ensure security and reliability of supply to consumers as well as security of the grid.

It also proposed implementation of Distribution SCADA systems by the utilities as a tool with the DSO, to facilitate creation of network information and customer data base and to help in the management of load, improvement in quality, detection of theft and tampering, customer information and also for prompt and correct billing and collection.

5.2.3 INTEGRATED POWER DEVELOPMENT SCHEME (IPDS)

The Re-structured Accelerated Power Development and Reforms Programme (R-APDRP) was notified by the Government of India (GoI) on 19th September, 2008, emphasising the need for establishment of reliable and automated systems for sustained collection of accurate base line data, and the adoption of Information Technology in the areas of energy accounting. The R-APDRP scheme got subsumed in IPDS scheme in 2014 as a separate component for IT enablement of distribution sector (Part-A IT & SCADA projects under R-APDRP) and strengthening of distribution network (Part-B projects under R-APDRP) in the urban areas.

IPDS extends financial assistance against capital expenditure to address the gaps in sub transmission & distribution network and metering in urban areas to supplement the resources of DISCOMs/Power Department. Projects for strengthening of sub-transmission and distribution system as well as IT and Geographic Information System (GIS) projects have been implemented in DISCOMs as per their requirements. Details in each of the above focused areas of the scheme are presented in Figure 5.2. The states have strengthened their distribution system under this scheme.

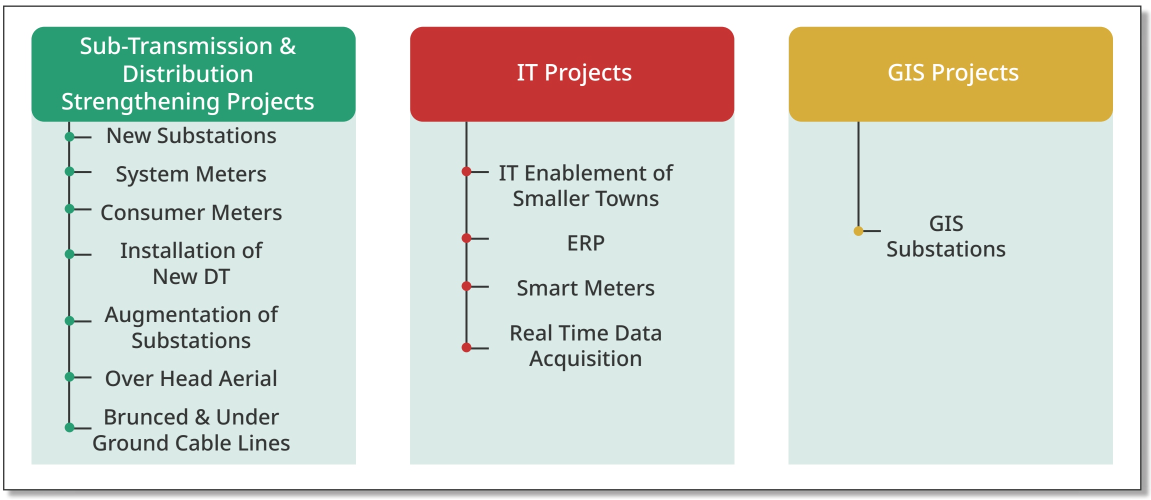


Figure 5.2: Details of works executed under different projects

5.2.4 PROMOTION OF DEVELOPMENT OF ELECTRIC VEHICLES

In order to promote development of electric and hybrid vehicle technology and to ensure sustainable growth of the same, Government of India launched a scheme, namely "Faster Adoption and Manufacturing of Electric Vehicles in India (FAME) Scheme [62] [63], in two phases. Phase-I of the Scheme was effective from 1st April, 2015 to 31st March, 2019 and Phase-II of the Scheme effective from 1st April, 2019 extends up to 31st March, 2024.

Phase-I of the Scheme was implemented through four focus areas namely demand creation, technology platform, pilot project and charging infrastructure. The scheme aims to encourage progressive induction of reliable, affordable and efficient electric and hybrid vehicles (xEV). About 2. 8 lakh electric/hybrid vehicles (xEVs) were supported with a total demand incentive of ~ Rs. 359 Crore for purchase of EVs under this scheme. Also, 465 buses were sanctioned to various States under this Scheme. In addition to above, several projects were approved/sanctioned under technology platform, pilot project and charging infrastructure focus areas of the scheme.

Phase-II of the scheme is being implemented for faster adoption of electric mobility and development of its manufacturing eco-system in the country. Under Phase-II, 2,877 charging stations have been sanctioned in 68 cities across 25 States/UTs and 1576 charging stations along 9 Expressways and 16 Highways. Thirteen states (Andhra Pradesh, Delhi, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Tamil Nadu, Telangana, Uttar Pradesh, Uttarakhand, Meghalaya, Gujarat, West Bengal) have hither to approved/notified dedicated EV policies to promote adoption of electric vehicles.

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5.2.5 POLICIES TO PROMOTE DEVELOPMENT OF RENEWABLE ENERGY SOURCES

To promote development of renewable energy in the country, Government of India introduced various schemes for development of solar projects and solar parks, wind power policy, wind-solar hybrid policy and biofuel policy. Most of the States have notified either the Solar Power Policies or the Renewable Energy Policies.

Net-metering Regulations for solar rooftop systems have also been notified by most of the SERCs. Various policy initiatives are being undertaken so as to promote integration of renewables and EV integration at distribution level as well as strengthening distribution system and protection of consumer interests.

5.2.6 DRAFT INDIAN ELECTRICITY GRID CODE (IEGC) 2022 [93]

To efficiently and effectively integrate various renewable energy resources in power system and demand response from distribution system, draft IEGC provides for integrated resource planning including (i) demand forecasting, (ii) generation resource adequacy planning and (iii) transmission resource adequacy assessment, required for secure grid operation as a part of Resource Planning Code.

5.2.7 DRAFT ELECTRICITY (AMENDMENT) BILL, 2022 [94]

To strengthen the distribution network and consumer choices while enhancing the power system security, certain provisions are proposed in Draft Electricity (Amendment) Bill, 2022. In section 86 of the principal Act, in sub-section (1) after clause (j), the following clauses shall be inserted, namely:—
"(ja) issue directions or guidelines or specify regulations to secure consumer choice and an efficient, coordinated and economical use of the distribution system, where there are more than one distribution licensee in an area of supply;

(jb) review the resource adequacy at intervals of every six months for each of the distribution licensees in accordance with the guidelines issued by the Central Government;"

5.3 REGULATORY PERSPECTIVE

The State Electricity Regulatory Commissions (SERCs) regulate electricity purchase and procurement process of distribution licensees for distribution and supply within the State and facilitate intra-State transmission and wheeling of electricity [Section 86 (1) (b) & (c) of the Act]. The State Grid Code, Distribution Code, Supply Code and Standards of Performance for Distribution Licensee Regulations are the key regulations for supply of electricity at the state level. The Indian Electricity Grid Code specified by the Central Electricity Regulatory Commission (CERC) as part of its obligation to regulate inter-state transmission of electricity [Section 86 (1) (b) & (c) of the Act] is also required to be followed by all the users, which include ISTS, SLDC, RLDC, NLDC, RPC and Power Exchanges.

A few other regulations such as Smart Grid Regulations, Grid Interactive Solar PV System Regulations, Micro/Mini Grid Renewable Energy Generation and Supply Regulations, Demand Side Management Regulations, Load Forecast Regulations and Power Quality Regulations also influence/have a bearing on the operation of distribution system. Mapping of state specific implementation of these codes/regulations is shown in Table 5.1. While States have issued various codes/regulations but there is a large variation in terms of the degree of details covered under each broad parameter. Table-5.2 provides a ready reference of the key entities/terms figuring in these regulations with their definition which are relevant in the context of discharging transmission/distribution functions in a State.

Depending upon the model (discussed in Chapter 3) adopted for setting up of DSO in a state certain changes in terms/entities definitions may be required. For example, in the event of DSO becoming an independent entity, "Aggregator" may have to be registered with DSO (please refer Table 5.2). Framework of the typical codes/regulations along with their objective and broad coverage is given in the following sub-section:

Table 5.1: Main codes/regulations in States

States	Main codes/regulations
Andhra Pradesh	State Grid Code; Distribution Code; Supply Code and related matters; Metering Code; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Arunachal Pradesh	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations
Assam	State Grid Code; Distribution Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Smart Grid Regulations; Grid Interactive Solar PV System Regulations; Micro/Mini Grid Renewable Energy Generation and Supply Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Bihar	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations
Chhattisgarh	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Delhi	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Demand Side Management Regulations
Goa,Chandigarh, Puducherry,Lakshdeep,Andaman And Nikobar,Daman And Diu, Dadra And Nagar Haveli,J&K,Ladakh (JERC)	State Grid Code; Distribution Code; Supply Code and related matters; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations
Gujarat	State Grid Code; Distribution Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Haryana	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Smart Grid Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations; Load Forecast Regulations
Himachal Pradesh	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations
Jharkhand	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Karnataka	State Grid Code; Distribution Code; Supply Code and related matters; Conditions of supply; Smart Grid Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Kerala	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations
Madhya Pradesh	State Grid Code; Distribution Code; Supply Code and related matters; Metering Code; Smart Grid Regulations; Micro/Mini Grid Renewable Energy Generation and Supply Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Maharashtra	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations; Power Quality Regulations
Manipur, Mizoram	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Meghalaya	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations; Power Quality Regulations
Meghalaya	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations; Power Quality Regulations
Nagaland	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations
Odisha	State Grid Code; Distribution Code; Conditions of supply; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Micro/Mini Grid Renewable Energy Generation and Supply Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Punjab	State Grid Code; Supply Code and related matters; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Rajasthan	State Grid Code; Supply Code and related matters; Metering Code; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations; Power System Management Standards
Sikkim	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations; Power Quality Regulations
Tamil Nadu	State Grid Code; Distribution Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations; Load Forecast Regulations
Telangana	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Smart Grid Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Tripura	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Smart Grid Regulations; Grid Interactive Solar PV System Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Uttar Pradesh	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Grid Interactive Solar PV System Regulations; Micro/Mini Grid Renewable Energy Generation and Supply Regulations; Demand Side Management Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Uttarakhand	State Grid Code; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
West Bengal	State Grid Code; Supply Code and related matters; Standard of Performance for Distribution Licensee Regulations; Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations

Legend
State Grid Code
Distribution Code
Supply Code and related matters
Metering Code
Conditions of supply
Standard of Performance for Distribution Licensee Regulations
Smart Grid Regulations
Grid Interactive Solar PV System Regulations
Micro/Mini Grid Renewable Energy Generation and Supply Regulations
Demand Side Management Regulations
Forecasting, Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations
Power System Management Standards
Load Forecast Regulations
Power Quality Regulations

Table 5.2: Entities/Terms defined under various Regulations

Code/Regulation	Entity/Term	Definition
Smart Grid Regulations	Aggregator	Aggregator is an entity registered with the Distribution Licensee to provide aggregation of one or more of the services like demand response services under the demand response mechanism, Distributed Generation, Energy Storage etc. within a control area
Smart Grid Regulations	Cyber Security	Cyber Security means security standards which enable organizations to practice safe security techniques to minimize the cyber security attacks
Smart Grid Regulations	Prosumer	Prosumer means any consumer generating electricity for his own use and/or for selling
Grid Interactive Solar PV System Regulations	Grid Interactive System	Grid Interactive System (GIS) means a system that connects the power generating plant (commonly Solar) in an electricity consumer's premises to an utility grid, so as to supply excess electricity to the distribution company's grid, after meeting the need of consumer and also to draw electricity from the grid to meet the short fall, when sufficient electricity is not produced by the generating plant. Import-export and net energy consumed or injected is measured by net metering
Demand Side Management Regulations	Demand Side Management	Demand Side Management means the actions of a Distribution Licensee, beyond the customer's meter, with the objective of altering the end-use of electricity-whether it is to increase demand, decrease it, shift it between high and low peak periods, or manage it when there are intermittent load demands in the overall interests of reducing Distribution Licensee costs
Demand Side Management Regulations	Energy Services Company	Energy Services Company means a company which is in the busness of providing energy efficient and load management equipment and/or services to end-user customers and is approved by Bureau
Forecasting, Scheduling, Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations	State Entity	State Entity means such person who is in the SLDC control area and whose metering and energy accounting is done at the State level
Forecasting, Scheduling, Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations	Procurer	Procurer means a person, including a Distribution Licensee, Trading Licensee or an Open Access consumer, procuring electricity through a transaction scheduled in accordance with the Regulations governing Open Access
Micro-Grid Renewable Energy Generation and Supply Regulations	Micro-Grid Operator	Micro-Grid Operator (MGO) means a person, a group of persons, local authority, Panchayat Institution, users' association, co-operative societies, non-governmental organizations, a company that constructs, commissions, operates and maintains Miro-Grid Renewable Energy System for generation and supply of electricity in the Micro-Grid areas and has agreed to operate under these Regulations
Forecasting, Scheduling, Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations	Qualified Coordinating Agency	Qualified Coordinating Agency (QCA) means the agency coordinating on behalf of Wind/Solar Generators connected to a pooling station

5.3.1 STATE GRID CODE

In exercise of the powers conferred by Sub-section (zp) of Section 181(2) read with Sub-section (h) of Section 86(1) of the Act, the State Grid Code lays down the information requirements and the procedures governing the relationship between various users of state transmission system as well as the SLDC. These regulations are applicable to the SLDC, transmission licensee in the State and users connected to and/or use the State transmission system. Structure of a typical State Grid Code is shown in Fig. 5.3. In the context of system operation at the distribution level, it includes provisions related to scheduling and despatch, system operation, transmission planning at the state level.

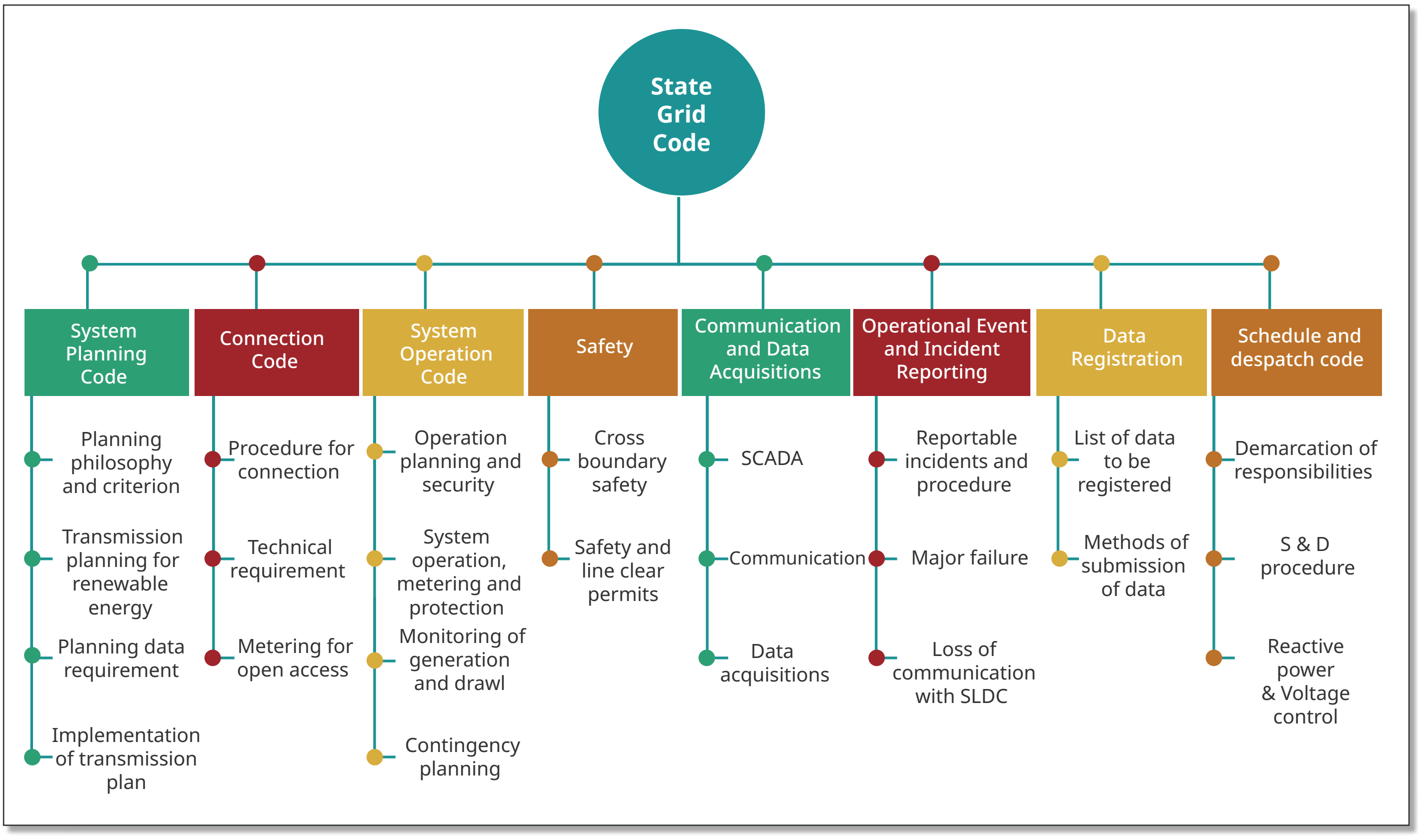


Figure 5.3: Typical structure of State Grid Code

5.3.2 DISTRIBUTION CODE

In exercise of the powers conferred by section 86 (c), (e) and (i) of the EA, the Distribution Code has been specified by the SERCs so as to permit the development, maintenance and operation of an efficient, co-ordinated and economical distribution system. It covers technical aspects related to load 113 forecasting, connections, and the operation and use of the distribution system including the operation of the electrical lines and electrical plant and apparatus. Typical structure of distribution code is given in Fig. 5.4.

Distribution Code					
Distribution Planning Code	**Connectivity Conditions**	**Operation Code**	**Metering & Protection Code**	**Cross Boundary Safety Code**	**Incident/Accident Reporting**
• Load data • Forecast Methodology • Technical and design criteria • Energy audit	• Operational labeling • System performance • Connection point/interface point • Connection agreement	• Demand estimation • Outage planning • Contingency planning • Demand management and load shedding • Interface with small generating units • Communication • Monitoring & control of voltage, frequency & PF • Safety, maintenance & Testing • Training	• Operational metering • Tariff & commercial metering • Measurement of energy import/export • Protection system • Fire protection	• Control persons and their responsibilities • Procedures	• Major incident • Reporting procedure

Figure 5.4: Typical structure of Distribution Code in the states

5.3.3 SUPPLY CODE AND RELATED MATTERS

In exercise of the powers conferred by section 50 and clause (x) of sub-section (2) of section 181 of the EA, the Supply Code covers recovery of electricity charges, intervals for billing of electricity charges, disconnection of supply for non-payment thereof, restoration of supply of electricity, tampering, distress or damage to electrical plant, electric lines or meter, entry of distribution licensees or any person acting on his behalf for disconnecting supply and removing the meter, entry for replacing, altering or maintaining electric lines or electrical plant or meter as shown in Fig. 5.5.

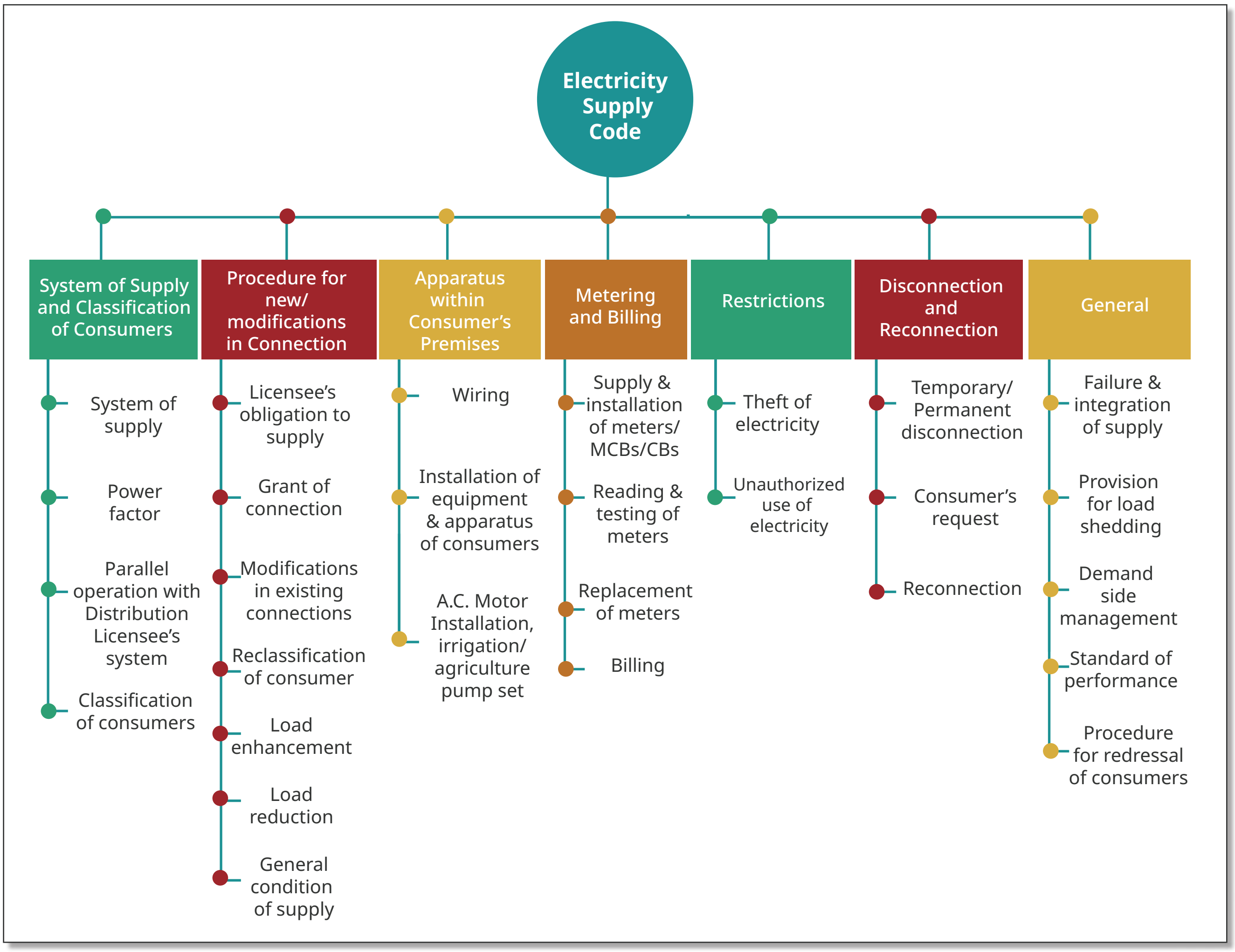


Figure 5.5: Typical structure of Supply Code in the states

5.3.4 SMART GRID REGULATIONS

In exercise of the powers conferred by clause (zp) of sub-section (2) of section 181 of the EA, these regulations (Fig. 5.6) deal with

- *"Tariff design for enabling consumers, prosumers and utilities to derive the benefits of the Smart grid investments*
- *Incentive/dis-incentive design for consumers, prosumers and utilities to ensure maximization of the efficiency gain from the Smart grid investments*
- *Protection of consumer privacy and maintaining integrity of data*
- *Network and interoperability standards and codes*
- *Security of network operations, particularly with respect of cyber security*
- *Enabling effective integration of Renewable Energy/Distributed Generation."*

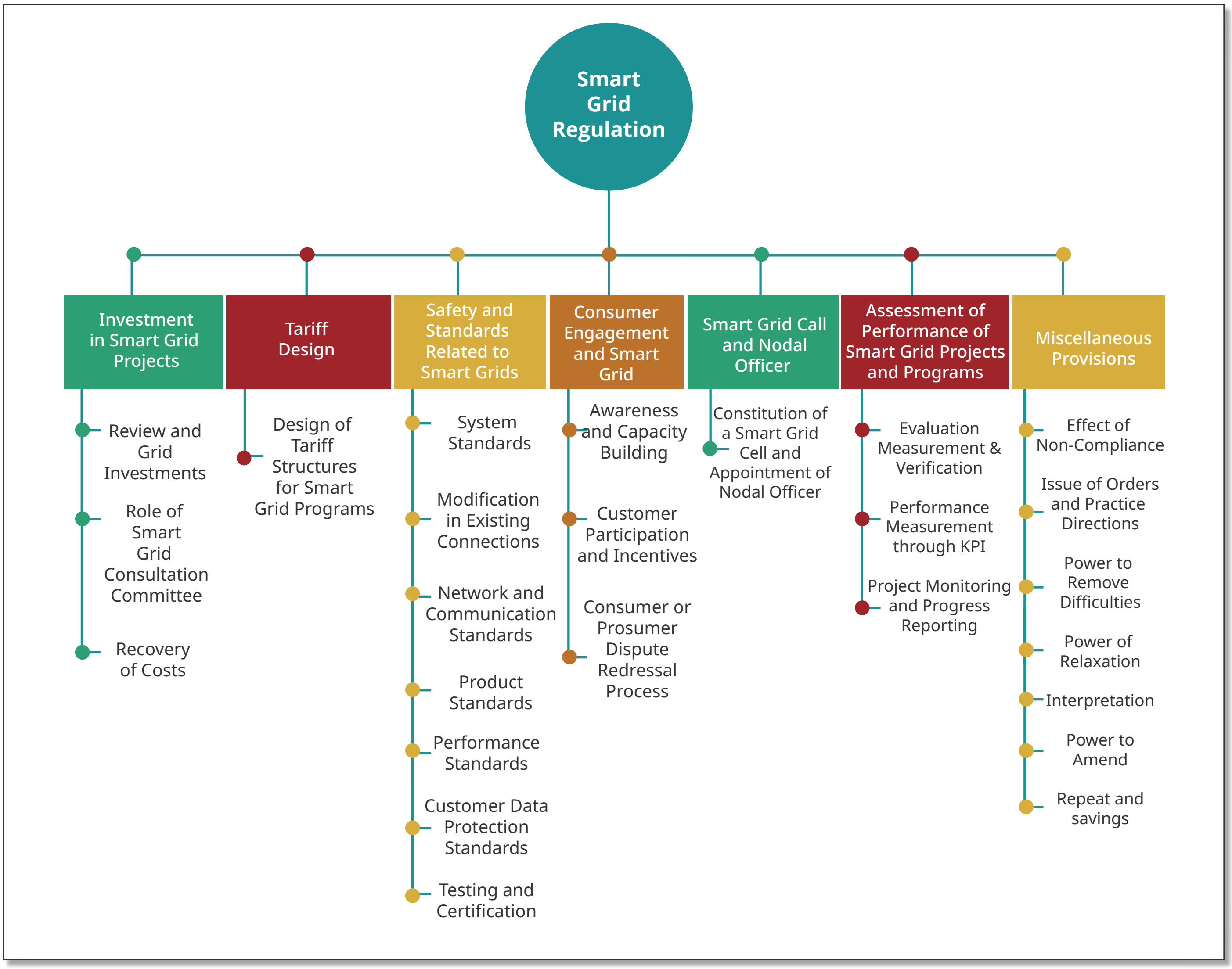


Figure 5.6: Typical structure of Smart Grid Regulations in the state

5.3.5 GRID INTERACTIVE SOLAR PV SYSTEM REGULATIONS

In exercise of the powers conferred under sections 61, 66, 86(1)(e) and 181 of EA, these regulations are applicable to the distribution licensee and consumers of electricity of distribution licensee having a Solar Grid. It covers provisions related to grid specifications, standards and safety requirements for interconnection, solar RPO, metering, protective devices, etc. Fig. 5.7 presents an overview of these regulations.

Grid Interactive Solar PV Systems	Capacity Targets for Distribution Licensee
	Eligible Consumer, Individual Project Capacity and Interconnection Voltage
	Interconnection with the Grid Specifications, Standards and Safety Requirements
	Energy Accounting and Settlement
	Solar Renewable Purchase Obligation (Rpo)
	Eligibility to Participate under Renewable Energy Certificate Mechanism
	Wheeling and Open Access
	Metering Arrangement
	Connection of Meters and Protective Devices
	Agreement
	Overriding Effect
	Power to Remove Difficulties
	Issue of Orders and Directions
	Power to Relax
	Power to Amend

Figure 5.7: Typical structure of grid interactive solar PV System Regulations in the states

5.3.6 DEMAND SIDE MANAGEMENT (DSM) REGULATIONS

In exercise of the powers conferred by clause (zp) of sub-section (2) of Section 181 of EA, these regulations are applicable to Licensees to formulate DSM objectives to implement cost-effective DSM initiatives in the state. The objectives include power shortage mitigation, seasonal peak reduction, cost effective energy savings, lowering the cost of electricity, reduction in emissions of greenhouse gases etc. Typical outline of DSM regulations is shown in Fig. 5.8.

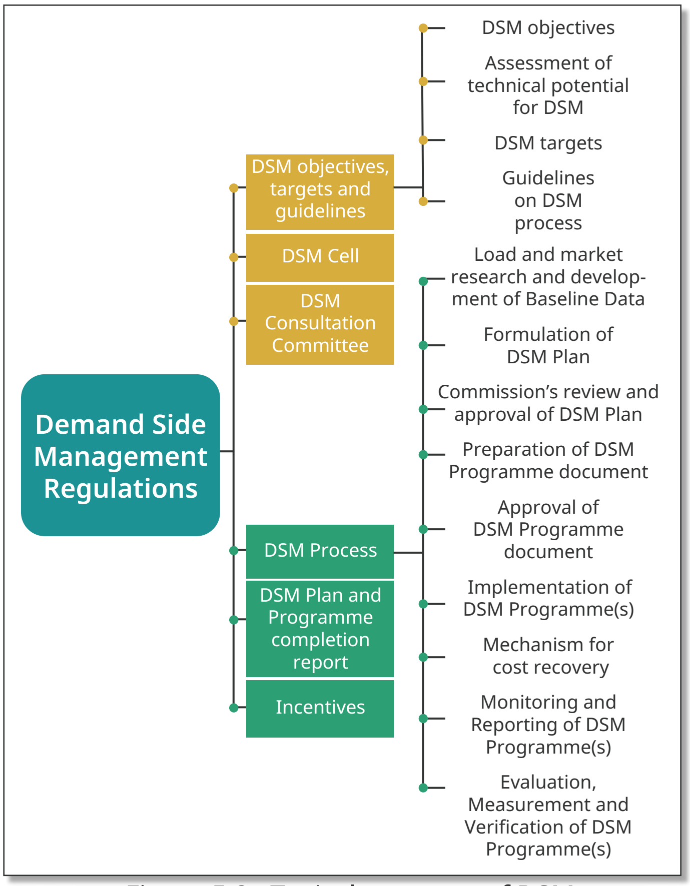


Figure 5.8: Typical structure of DSM Regulations in the states

5.3.7 STANDARDS OF PERFORMANCE FOR DISTRIBUTION LICENSEE REGULATIONS

In exercise of the powers conferred under Section 181(1) and 181(2) (za) and (zb) read with Sections 57, 58, 59 and 86 (1) (i) of EA, these standards provide guidelines for Distribution Licensee to maintain distribution system parameters within the permissible limits for an efficient, reliable, coordinated and economical system of electricity distribution and retail supply (Fig. 5.9). The objectives of these performance standards are:

- To ensure that the Distribution System performance meets a minimum standard which is essential for the Users' installation to function properly.
- To enable the Users to design their systems and equipment to suit the electrical environment that they operate in.
- To enhance the quality of standards of the Distribution System and services to meet acceptable standards in the short term and gradually moving towards improved standards in the long term.

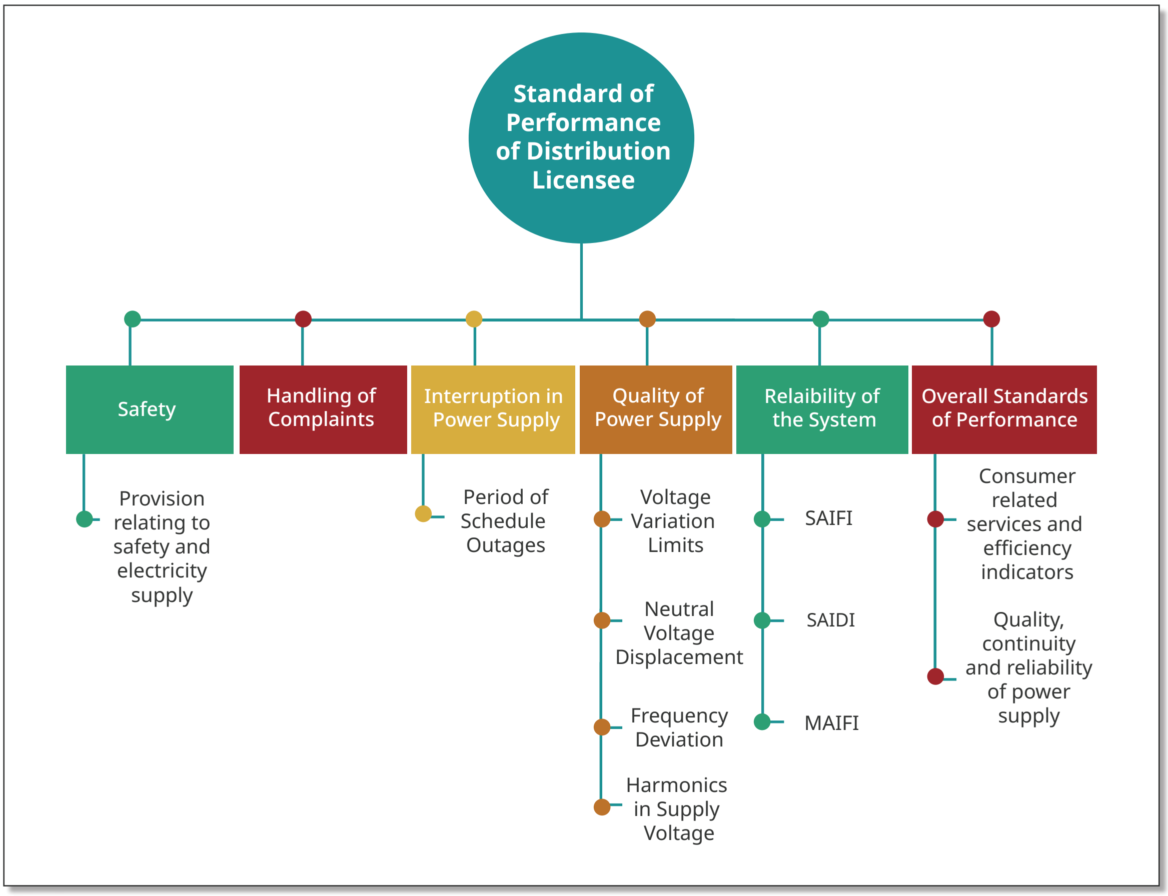


Figure 5.9 Typical structure of DSM Regulations in the states

5.3.8 FORECASTING, SCHEDULING, DEVIATION SETTLEMENT AND RELATED MATTERS OF SOLAR AND WIND GENERATION SOURCES, REGULATIONS

In exercise of the powers conferred by sub-section (1) of section 181, of the EA, and all other powers enabling it in this behalf SERCs have made these regulations for the respective States. One of the objectives of these regulations is to facilitate large-scale grid integration of solar and wind generating stations while maintaining grid stability and security as envisaged under the grid code, through forecasting, scheduling and commercial mechanism for deviation settlement of these generators (Fig. 5.10).

The SLDC uses the flexibility provided by the conventional generating units and the capacity of inter-grid tie-lines to accommodate wind and solar energy generation subject to grid security. Qualified Coordinating Agency (QCA) is specified for the following purposes:

- Provide schedules with periodic revisions as per these regulations on behalf of all the Wind/Solar Generators connected to the pooling station(s)
- Responsible for metering, data collection/transmission, communication, coordination with DISCOMs, SLDC and other agencies
- Undertake commercial settlement of all charges on behalf of the generators, including payments to the State UI pool accounts through the concerned SLDC
- Undertake de-pooling of payments received on behalf of the generators from the State UI Pool account and settling them with the individual generators
- Undertake commercial settlement of any other charges on behalf of the generators as may be mandated from time to time.

Forecasting, Scheduling, Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations

- Forecasting and Scheduling Code
- Principles of appointment of QCA
- Deviation Settlement for Intra-State Transactions
- Deviation Settlement for Inter-State Transactions
- Implementation Procedure : Metering and Energy Accounting
- Communication between QCA and SLDC
- Deviation Accounting
- Payment Mechanism for Deviation Settlement
- De-Pooing of Deviation Charges
- Intimation of Curtailment
- Energy Accounting

Figure 5.10 Typical structure of Forecasting, Scheduling, Deviation Settlement and Related Matters of Solar and Wind Generation Sources, Regulations in the states

5.3.9 MICRO-GRID RENEWABLE ENERGY GENERATION AND SUPPLY REGULATIONS

In exercise of powers conferred by Section 181 read with Sections 13, 14, sub-section (h) of section 61, 66, clause (e) and (k) of sub-section (1) of section 86 of the EA, the Micro-Grid projects with installed capacity of 10kW or more are governed by these Regulations. These regulations exist in few states, namely, Madhya Pradesh, Odisha, Assam and Uttar Pradesh. These Regulations are applicable to new & existing Micro-Grid projects for generation and supply of electricity to consumers or selling electricity to Distribution Licensee.

5.3.10 POWER QUALITY REGULATIONS

In exercise of the powers conferred under section 181 of the EA read with section 61, section 57 and section 59, the objective of standards specified in these regulations is to ensure the quality and reliability of electricity supplied by the distribution licensee to the end consumers and by the designated customers.

Any failure by the distribution licensee or designated customer to achieve and maintain the power quality parameters specified in these regulations are liable to payment of compensation under the EA to an affected entity.

5.3.11 CONSIDERATIONS

Implementation of provisions of the Act and policies through various regulations necessitated on account of needs emerging from time to time and changing scenario of distribution system described in preceding sub-sections has yielded benefits. Some of these regulations are, however, yet to be framed by the SERCs in certain states. The expected transformation of distribution system due to increased penetration of large number of variable and inherently non-despatchable DERs will require pro-active management of the distribution system by DSOs including flexibility services, and management of large amount of data from consumers, prosumers, electric vehicles, storage, etc. The role and functions envisaged for DSO are discussed in detail in Chapter 2.

Table- 5.3 presents mapping of the functions of DSO, the entities performing these functions and the related codes/regulations. The paradigm shift in the distribution system operation calls for detailed examination of existing regulations and codes to identify the provisions which need to be changed in this backdrop.

> "The starting point for energy security today as it has always been is diversification of supplies and sources
> – Daniel Yergin"

The new functions proposed to be performed by the DSO presented in Table 5.3 also call for necessary amendments in some of the existing regulations or framing new regulations.

Table 5.3: Mapping of DSO function with Codes and Regulations

Existing Functions of DSO	Presently performed by	Codes/Regulations
Network Operation and Control	At distribution Level-DISCOM	Distribution Code/Supply Code/Load Forecast Regulations/Power Quality regulations/Standard of Performance for Distribution Licensee Regulations
	At state transmission level-SLDC/Sub-SLDC	State Grid Code/ Forecasting, Scheduling, Deviation Settlement and Related Matters of Solar and wind Generation Sources
System Coordination	DISCOM	Distribution Code/Supply Code
Integrated Network Planning	At distribution Level-DISCOM	Distribution Code
	At state transmission level-SLDC	State Grid Code
Forecasting	At distribution level-DISCOM	Distribution Code
	At state transmission level-SLDC	State Grid Code/Forecasting Scheduling Deviation Settlement and Related Matters of Solar and Wind Generation Sources
Scheduling and despatch	At state transmission level-SLDC	State Grid Code
Metering	DISCOM	Distribution Code and Suplly Code
	For Open Access at state transmission level-SLDC	State Grid Code
Billing and Collection	DISCOM	Distribution Code/Supply Code
Detection of Theft and Tamppering	DISCOM	Supply Code
Contingency planning	At distribution Level-DISCOM	Distribution Code
	At state transmission level-SLDC	State Grid Code
Cyber- Security	SLDC/DISCOM	State Grid Code/CEA guidelines/Smart Grid Regulations
New Functions	**Presently performed by**	**Codes/Regulations**
Forecasting (DER)	Only load forecasting at distribution level by DISCOM	Distribution Code
Market Facilitation	None	New regulations to be framed
Ancillary/Flexibility Services	None	New regulations to be framed
Resource Adequacy	Demand Estimation by DISCOMs, STU/CTU/Generating companies	New Regulations to be framed

5.4 INSTITUTIONAL FRAMEWORK FOR SYSTEM OPERATION AT THE STATE/DISCOM LEVEL

SLDC is the apex body for ensuring integrated operations of the state grid. ALDCs/Sub-SLDCs/DSOCCs/DCCs have been set up in a number of states drawing power from the State Grid Code. The functions related to operation of distribution system are being carried out accordingly. The SLDC deals with the operation of entire state grid spanning from 400kV/200kV/132kV (max voltage in the state) to the LV distribution grid, generally 33/11kV. SLDCs in many states have established Sub-SLDC(s) for providing assistance in performing functions efficiently/effectively. Currently, low voltage distribution networks (below 33/11 kV) are operated by DISCOMs which require active management generally limited to overload control, voltage control, network maintenance, reinforcement, etc. Furthermore, the management of low voltage network information is limited to providing technical data about network operational parameters by DISCOMs to SLDC. In many states, distribution licensee has established an ALDC under provision of "Other business of distribution licensee" and "State Grid Codes" to perform the following functions:

- monitoring and control of distribution system in its area of supply
- receive and carryout the instructions of SLDC on behalf of the distribution licensee
- co-ordinate with Distribution System Operation & Control Centre (DSOCC)/Distribution Control Centre (DCC) and SLDC to streamline the operation and enhance operational efficiency.

The DSOCC(s)/DCC(s) have also been established by distribution licensees at strategic locations preferably near the geographical centre and load centre to take timely action in response to grid warnings. Table 5.4 provides a snapshot of the despatch/control centres in some of the states.

Table 5.4: Provisions related to DSOCC/DCC/ALDC in State Grid Code

State	Provisions relating to operational of Distribution System
Haryana	Area Load Despatch Centre (ALDC) : "The Area Load Despatch Centre to be established by the distribution licensees." Distribution System Operation & Control Centre (DSOCC) : "The Distribution System Operation and Control Centre as established by the distribution licensee to carry out the functions as per the Haryana Grid Code."
Punjab	Area Load Despatch Centre (ALDC) : "Area Load Despatch Centre means a computerized load despatch centre of Punjab State Transmission Corporation Limited (PSTCL) which reports to SLDC." Distribution Control Centre (DCC) : "The office & associated facilities established by the Distribution Licensee to coordinate with SLDC and carry out the functions as laid down in the State Grid Code."
Karnataka	Area Load Despatch Centre (ALDC) : "Area Load Despatch Centre as established by each Distribution Licensee to carry out the instructions of SLDC and perform all the duties assigned to it in the Grid Code and Distribution Code." Distribution System Operation & Control Centre (DSOCC) : "The Distribution System Operation and Control Centre as established by the distrubution Licensee to carry out the functions specified in the GRID CODE and Distribution Code."
Odisha	Sub-LDC (Sub-Load Despatch Centre) : "The Area-wise Load Despatch Centre, as established by SLDC to carry out the instructions of SLDC and perform all the duties assigned to it in the Odisha Grid Code and Distribution Code." Distribution System Operation & Control Centre (DSOCC) : "The Distribution System Operation and Control Centre as established by the Distribution Licensee to carry out the functions as directed by the Odisha Grid Code and Distribution (Planning and Operation Code."

Table 5.4 brings out that the operation of distribution system is either being performed by a Centre established by the Distribution Licensee or by a Centre established by the SLDC. The options given in the succeeding sub-sections could, therefore, be considered for distribution system operations:

5.4.1 Distribution System Operation under Distribution Licensee

A "Licensed Business" means the functions and activities, which the licensee is required to undertake in terms of the licence granted by the Commission or being a deemed licensee. At present, distribution licensees are performing system operation functions (Table 5.5) drawing power from Section 51 of the EA 2003 in terms of provisions made in the respective state code. System Operation is performed by distribution licensee by establishing ALDC/DCC/DSOCC to coordinate/communicate with SLDCs and load management unit for secure and reliable system operation. Distribution system operation could, therefore, continue to be a licensed activity. Given the transformation in the distribution system, distribution licensee may continue to perform many of the functions of distribution system operator. However, there may be a need for reassignment of some of the functions depending on the model of the DSO adopted by the State as detailed in Sub-section 3.2.3 of Chapter 3.

Table 5.5: A snapshot from the codes of the states

State	Other business of distribution licensee
Haryana (HGC Regulations 2009)	2.6.2 Distribution licensee shall also in addition perform the following functions : "(1) to establish asn Area Load Despatch Centre to carry out the following functions: (a) to help in focused monitoring and control of distribution system in its area of supply; (b) to receive and carryout the instructions of SLDC on behalf of the distribution licensee (c) to co-ordinate with DSOCC and SLDC to streamline the operation and enhance operational efficiency. (2) to establish DSOCC(s) at strategic loactions preferably near the geographical centre and load centre of the distribution licensee's area of supply, having adequate communication facilities. The DSOCC(s) shall be manned round the clock with the required staff. It shall take timely action in response to grid warnings as per standard instructions laid down by the distribution licensee and if necessary, issue suitable instructions in addition, if a particular situation so warrants. The SLDC shall intimate the distrution licensee through ALDC, regarding significant deviations in final schedules of State generators and Central Generating Station (CGS) on overall merit order. The ALDC shall undertake suitable load management and curtailment."
Punjab (SGC Regulations 2013)	2.3.4. The functions of Distribution Licensee shall be as stated in Section 42 of the Act. With reference to SGC, some of the functions of distribution licensee shall be as under: "(a) to develop and maintain an efficient, coordinated and economical distribution system in its area of supply (b) to provide non-discriminatory open access to its distribution system for use by- (i) any licensee or generating company on payment of the distribution charges; or (ii) any consumer as and when such open access is provided by the Commission under section-42(2) of the Act, on payment of charges for wheeling and a surcharge thereon, as may be specified by the Commission; (c) in order to facilitate load control, scheduling & despatch, and open access operation etc. under the ABT mechanism within the state, each Distribution Licensee shall establish a Distribution Control Center (DCC) within its Area of Supply, having adequate communication facilities with round the cloud manning. It shall take appropriate action in response to any Event in the grid in coordination with the SLDC;
Karnataka (KEGC 2005)	As part of the functions, Distribution Licensee is required to- "3.6 Establish an Area Load Despatch Centre to carry out the following functions: 1) The ALDC shall help in focused monitoring and control of Distribution System in its Area of Supply. 2) Receive and carry out the instructions of SLDC on behalf of the Distribution Licensee 3) Co-ordinate with DSOCC and SLDC to stream line the operation and enhance ease of operation efficiency. 3.7 Establish DSOCC at a strategic location near the geographical centre and load centre of the licensees' Area of Supply, having adequate comminication facilities. The DSOCC shall be manned round the clock with the required staff during emergency periods. It shall take timely action in response to Grid warnings as per standard instructions laid down by the Distribution licensee in this regard and if necessary issue appropriate instructions in addition, if a particular situation warrants. The SLDC shall intimate the Distribution licensee through ALDC, regarding significant deviations of final schedules of State generators and CGS on overall merit order. The ALDC shall undertake suitable Load Managment and curtailment."

Odisha (OGC Regulations 2006)	2.5 As part of the functions, Distribution Licensee is required to- "Establish DSOCC at a strategic location near the geographical centre and load centre of the Distribution Licensees" Area of Supply, having adequate communication facilities. The DSOCC shall be manned round the clock with the required staff during emergency periods. It shall take appropriate action in response to grid warnings as decided by the Distribution Licensee and convey suitable instructions to the operating staff. It shall take timely action in response to grid warnings as per standard instructions laid down by the Distribution Licensee in this regard and if necessary, issue appropriate instructions in addition, if a particular situation warrants. The SLDC / Sub-LDC shall intimate the Distribution Licensee through DSOCC, regarding significant deviations of final schedules of State generators and CGS on overall merit order. The DSOCC shall undertake suitable load management and curtailment."

5.4.2 Distribution System Operation under Sub-SLDC

The SLDC in India is the apex body to ensure integrated operation of the power system in a State. In a few states like Gujarat, Maharashtra, Himachal Pradesh and Odisha, the Sub-SLDC has also been established with main functions of data acquisition & transfer to SLDC, supervisory control of load in their respective area, as well to assist SLDC for (a) ensuring integrated operation of the power system in the state, (b) monitoring grid operations, and (c) supervision and control over the intra-state transmission system within their area.

The second option in regard to creation of DSO could be assigning function of distribution system operation to Sub-SLDC which would work in close coordination with SLDC. SLDC will continue to be the apex body to ensure integrated operation of the power system at state level and will have overall control over the security and reliability of the state grid. Different functions with respect to DSO are discussed in detail in Sub-section 3.2.2 of Chapter 3. However, there may be a need for reassignment of functions depending on the model of the DSO adopted by the State as detailed in Sub-section 3.2.2 of Chapter 3.

5.4.3 Distribution System Operation through Statutory Provision

The National Electricity Policy, 2005 specifies that *"the spirit of the provisions of the Act is to ensure independent system operation through NLDC, RLDCs and SLDCs"* (Section 5.3.7). In order to make the Distribution System Operator also to be independent in accordance with the aforementioned spirit of the Act, distribution system operator should eventually be a neutral and independent entity/body; similar to SLDC in states; under the jurisdiction of SERC.

DSO Fees and Charges Regulations would then have to be framed in line with SLDC/RLDC fees and charges regulations. Other related codes and regulations would also need to be amended as is the case in other two options described under Section 5.4.1 and 5.4.2
.

5.5 WAY FORWARD

Creating a fully functional DSO that can perform functions outlined in Chapter 2 could take time in India. While this transformation is expected to happen over a medium-to-longer term horizon, DSO need to embrace the digitalisation and innovation in the operation, maintenance and designing of distribution system. While the infrastructure and corresponding functions of DSO would continue to evolve, consumers will still seek a safe, reliable, and affordable supply of energy, this chapter highlighted the opportunities in legal and regulatory amendments/provisions matching with the alternatives for creating DSO as described in section 3.2. Creation of DSO may help in accelerating energy transition by wider ambit. Appropriate policy provisions and facilitating Regulations/Codes may help in the introduction of DSO in states.

6 RECOMMENDATIONS

Setting up of DSO in India has been under discussion for the last few years. The FoR has recognized the need for DSOs in the Indian power system and capacity building in this regard. The FoR, in its SAMAST report, underlined the difficulties likely to be faced by SLDCs/RLDCs/NLDC in operation and financial settlement because of the increasing number of Short-Term Open Access (STOA) customers, prosumers, EVs, battery storage, and DERs (specially Rooftop solar) within the distribution control area.

The Technical Committee on implementation of framework on renewables at the State level acknowledged the need for a robust institution as a system operator which should be neutral, independent, transparent, non-discriminatory, and equipped with a skilled workforce. The concept of DSO on the by-lines of SLDC was also elaborated. Similarly, in the CABIL report, establishing DSOs in each state has been recommended.

The DSOs are recommended to ensure safe and secure operation of distribution system in coordination with SLDCs. The main functions performed by DSO as mentioned as Table 5.1 are: Network Operation and Control, System Coordination, Integrated Network Planning, Forecasting, Scheduling and despatch, Metering, Billing and Collection, Detection of Theft and Tampering, Contingency planning and Cyber – Security.

Certain new functions proposed to be performed by DSO include Forecasting (DER), Market Facilitation, Resource Adequacy and Ancillary/Flexibility Services. Based on the review of existing national and international learning and studies presented in the preceding chapters, recommendations on technical, regulatory, institutional manpower & skill requirement aspects, cost-benefit analysis and implementation plan are presented in the following sub-sections.

6.1 TECHNICAL RECOMMENDATIONS

A DSO control centre will require a state-of-art SCADA system and software for data acquisition, monitoring, supervision, and control. As there has been a growing demand of real-time visualization, monitoring, and control of the power system network at control centre, two-way strong and redundant communication network between SCADA and fast responding intelligent devices, such as IEDs, PMUs, and IoT devices, is needed. Seamless data interoperability among - these devices, using different protocols, is also needed to be ensured. Further, some of legacy devices, such as old energy meters communicating over old communication technologies, need to be modified/ replaced to make them communicable using latest communication technology. This will ensure better security of the data from legacy devices. Following recommendations are made for the control centre.

6.1.1 ADMS ARCHITECTURE

The proposed Advanced Distribution Management System (ADMS) should be flexible and adopt plug and play architecture, keeping in mind the future addition of new functions. It is suggested that the ADMS should be based on open standard, such as IEC Common Information Model (CIM) [IEC 61968], so that future modifications are seamless. Data exchange should be via Enterprise Service Bus (middleware) so that the data exchange among applications and devices is standardised. The ADMS algorithms should be built using open-source languages, such as Python, so that future modifications, expansion, and conversion are easy and cost effective; proprietary software applications should be avoided. This will ensure easy, fast, and cost-effective changes in the applications. The efforts should be made to develop ADMS solutions in India. The ADMS architecture should have various data analytics capabilities with predictive capability and should be able to suggest the course of actions against any event, rather than just being a data display engine.

6.1.2 INFORMATION AND COMMUNICATIONS TECHNOLOGY (ICT)

It is recommended that the ICT functions which have hitherto been part of the managing the SCADA/EMS at DSO must be made a full-fledged functional vertical so as to manage the challenges which are likely to be faced in future. High obsolescence rates, cyber security, third party software versus in-house capability, besides vendor development may be factored by the ICT team. The ICT architecture might be built in such a way that any future technology upgradation is easy and cost effective. The critical components of ICT architecture may have redundancy with fallback capability, service continuity, and no data loss.

6.1.3 ADVANCED METERING INFRASTRUCTURE (AMI)

Headend and Meter Data Management System (MDMS) may have flexible Service-Oriented Architecture (SOA) and may be configurable for exchanging data over CIM/Enterprise Service Bus (ESB). This will enable the AMI system for easy sharing of data/information over multiple protocols with different applications. Smart meters may be developed with the capability of data reporting rate as low as 30 seconds to ensure near real-time data acquisition for better analytics, monitoring, and control.

6.1.4 CYBER SECURITY

The following standards that address the concerns about cyber intrusions into power systems are recommended in the context of DSO:

- IS:16335 Power Control System : Security Requirement
- IEC/ISO:27001 International standard on information security management
- IEC:62351 A specific standard related to data and communication security in power systems and other related systems such as EMS, SCADA, distribution automation & protection.
- IEC 62443 Secure industrial automation and control system

Along with the aforementioned standards, it is recommended to leverage the fundamental understanding of distribution systems when designing the security tools. As a result, securing the DSO might necessarily involve a multi-layered approach that incorporates cyber security and system theory.

Some of the recommendations for DSO security are listed below.

a) Security Monitoring and Attack Detection

Field measurements, control input, and other variables may be used to monitor the grid, enabling the DSO to distinguish between observed behaviour during an attack and expected behaviour during normal operation. Both active and passive methods of attack detection may be used, where passive detection entails validating the statistical properties of the measurements, while the active detection entails approach such as benchmarking and moving targets.

b) Attack Resilient Algorithms

Algorithms that govern distribution system operations need to be resilient to cyber-physical attacks, allowing the DSO to take corrective action in the event of an attack while still ensuring that the grid meets the critical performance objectives.

c) Forensic/Vulnerability Audit

Impact assessment of various module failures on the DSO need be assessed on a regular basis, to identify vulnerable links in the overall security framework. For scenarios in which a group of malicious sensors is isolated, the trade-off between performance and security of DSO need to be audited. Audits should be conducted to determine how changing the security properties of individual cyber and physical subsystems affect the entire connected cyber physical power system.

d) Firewalls

Appropriate deployment and configuration of different types of firewalls need to be ensured. Various firewalls which can be deployed in DSO could be a) Boundary firewalls or packet filters, b) host Firewalls, c) Application-level firewalls, d) SCADA hardware firewalls.

e) Role/Patch/Version Management

The roles assigned to various users is recommended to be updated on a regular basis, as are the passwords and access levels. Security patches need to be applied on a regular basis to the DSO's various cyber and physical components. Firmware and software used by various stakeholders need to be updated on a regular basis to the latest available version.

f) Adoption of the proposed ICT architecture

The ICT architecture proposed in Section 2.3.2 is recommended for integration of various OT and IT services between the high-speed service bus and the enterprise bus via the Common Information Model (CIM).

6.1.5 POWER QUALITY

Issues pertaining to power quality and the need for greater regulatory intervention in ensuring quality of power supply was highlighted in FoR Report on “Power Quality of Electricity Supply to the Consumers” [95]. For management of active distribution system by DSO, appropriate regulations are recommended taking note of FoR Report on Power Quality. Regarding continuity of supply, reliability indices - SAIDI, SAIFI, MAIFI and CAIFI are recommended. The incentive/disincentive mechanism is also outlined in For report and the same is recommended to be implemented in a phased manner. For key performance indicators voltage index such as System Average Voltage Fluctuation Index (SAVFI), System Average Voltage Magnitude Violation Index (SAVMVI), System Average Voltage Unbalance Index (SAVUI), System Control Device Operation Index (SCDOI), System Energy Loss Index (SELI) and System Reactive Power Demand Index (SRPDI) could also be used [96].

6.2 REGULATORY RECOMMENDATIONS

Functions of Distribution system operation are presently performed by DISCOMs/Sub-SLDCs and have been discussed in Chapter 5. Codes such as State Grid Code, Distribution Code/Supply Code are being followed for distribution system operations. In addition, SLDCs, RLDCs, NLDC are required to comply with the provisions of the Indian Electricity Grid Code (IEGC). The integration of large number of small-scale distributed resources will require a functional evolution of the current operation and control of distribution system with investments in metering and instrumentation in the distribution network for capturing requisite data and transmitting the same to the control centre, hardware, software and communication system at the distribution control centre, etc.

DSOs are proposed to be regulated entities under the jurisdiction of SERC/JERC. Therefore, regulations need to spell out the role and responsibilities of DSOs and other entities having role in/bearing on distribution system operation. Regulations need to be framed taking note of emerging trends in end-use (prosumers, EV charging/support) demand response requirements, and cyber security from such a distribution system.

> A powerful process automatically takes care of progress, productivity and profits.

Existing codes/regulations will need modifications/additions to address new functions and to perform the existing functions in the manner or to the extent they need to be performed. Moving from the current distribution/state regulatory model to the new scenario where DERs and digitalization would be integrated in distribution network, following recommendations are made:

a) Forecasting
The Distribution code and supply code consider load forecasting, where "Load" means an entity or electrical equipment that consumes electrical energy. However, granular behind the meter forecasting with segregation of load and DER generation, which is a crucial aspect for system operation is becoming essential. Regulations are required to take into consideration behind-the-meter forecast of DERs such as Electric Vehicle to Grid, roof-top solar Solar PV, etc., to maintain distribution network security and reliability as well as planning as envisaged under the Distribution/Supply Code. Data and tools required for forecasting need to form a part of the Regulations.

b) System Coordination
Roles and responsibilities of the entities such as prosumers, aggregators, retailers, and active consumers, etc., who have a bearing on distribution system operation need to be defined depending on the DSO model to be adopted by any State. Regulations/codes on connection point, boundaries, etc., with assigned responsibilities for co-ordinated action between the DSO, other entities and the transmission system operator need to be updated as required. Co-ordination and communication protocols among all the participants in the system is required for complete clarity on the part of all the entities.

c) Market Facilitation
Increasing emergence of prosumers, grid to vehicle (G2V) and vehicle to grid (V2G) end uses, P2P trading among prosumers and ancillary service support are expected to assume increasingly important role with the passage of time. Regulations for the distribution market to ensure that the market design is bringing the adequacy, flexibility and ancillary services needed for secure operation of the system with requisite DSO-TSO coordination.

d) Cyber Security
Interconnection of distribution system to a large number of devices and systems spread across the distribution system increases the cyber risk. The regulations related to Indian Computer Emergency Response Team (CERT-In) for distribution may encompass all the related entities to devise way forward for handling these on regular basis. Regulations for Data Management and Data Protection are recommended.

e) Resource Adequacy
Assessment of resource adequacy (RA) is recommended for operational planning, at the distribution level, in consultation with the distribution licensees periodically, at least on annual basis [97]. The guidelines and model regulations to review the operational resource adequacy would be extremely helpful for fast tracking the RA assessment by the DSOs.

f) Integrated Network Planning
The distribution network, planning has hither to been carried out based on conventional methodologies. For lower voltages/distribution level planning will also become complex especially with penetration of DERs, prosumers, P2P transactions, V2G & G2V, demand response, electronics load, etc. it is recommended that distribution System Planning Code Regulations be revisited; role and responsibilities of various entities to carry out planning efficiently and effectively may be explicitly included. Adequacy of distribution system needs to be anticipated for next 5 years so as to avoid overloading of system which has the potential of impairing continuity, reliability and quality of supply.

g) Scheduling and Despatch

To perform day-ahead scheduling of DERs' generation & load demand and for handling network contingencies, unplanned generator/feeder outages, system faults, etc., review of regulations for scheduling & despatch is recommended. These regulations shall consider various entities such as distribution network company, SLDC, STU, DERs with their roles and responsibilities in preparing and issuing generation/supply schedule.

6.3 INSTITUTIONAL RECOMMENDATIONS

The system operation and control in India has over the years witnessed a shift leading it to be a neutral and independent entity. The Regional Load Despatch Centres (RLDC) which were owned and operated by CEA were transferred to the Power Grid Corporation of India Ltd. (POWERGRID) in mid 1990s. The ring fencing of RLDCs from other functions of CTU was under discussion for quite a few years. Power System Operation Corporation Limited (POSOCO) was incorporated in 2009 as a 100% subsidiary of POWERGRID with the objective of ring-fencing operation of power system. In 2017, POSOCO got separated from its parent Company - POWERGRID and started functioning as an independent Government Company with responsibility for operating NLDC and RLDCs [98]. System operation was thus entrusted to a Public Sector Undertaking to perform statutory roles assigned under EA 2003 and functions assigned by CERC from time-to-time. The SLDCs have also been envisioned as entity to ensure independent system operation in the state having statutory role/functions. In the same vein, the DSO should also be an independent and neutral entity so as to enable it to function effectively for discharging its responsibilities without the influence of the power sector organisations in the state. The neutrality and independence of DSO is all the more important in view of the fact that the DSOs are responsible for maintaining continuity, reliability and quality of supply to end consumers which have a bearing on recovery of dues – an extremely important aspect in view of poor financial health of DISCOMs.

A Separate Non-profit Entity

The mapping of DSO functions in Chapter 3, shows that some functions are not being undertaken by any institution currently and few functions requires separate attention, it may be possible to create separate entity (under the appropriate statute) with specific responsibility to execute some or all of those activities. Such an entity will be a new independent entity without any past baggage. As a result, the entity will be able to focus on the activities envisaged for it. Given the nature of activities it is expected to perform i.e., integrated network planning, scheduling and despatch, behind-the-meter DER forecasting, advance active network, etc., it is desirable that such an entity need to be well defined regulated entity. Further, the ownership of existing infrastructure (assets and tools), capacity building and funding of such an entity could be an issue.

Sub-SLDC / ALDC to DSO Transition

The Sub-SLDC/ALDCs are established by Distribution Licensee or SLDC to carry out the instructions of SLDC and perform all the duties assigned to it in the State Grid Code and Distribution Code. The second option that has been explored with respect to creation of DSO is setting its functionality to Sub-SLDC/ALDCs which work with SLDC. Single entity (SLDC) will remain to be the apex body to ensure system operation of the power system at state level and will have overall control over the security and reliability of the process. States where ALDC are established under DISCOMs, this option may require transfer of some of the assets, skills and manpower from DISCOMs to Sub-SLDC.

DISCOM to DSO Transition

The third option that has been explored is creating Distribution System Operator Cell as a part of DISCOMs (Distribution Utility). The onus of executing various activities/functions under DSO essentially lays coordination with Distribution Utilities. Some of the activities at present are being undertaken by DISCOMs in many States. One of the issues that need to be addressed in this option is to bring accountability of the DISCOMs to undertake these functions. This can be done through appropriate regulatory mechanism.

Repackaging of Existing and New Entities

The distribution network was restructured post-enactment of the EA based on the scenario (passive network) existing at that time, and the emergence of DERs was not envisaged. To address the emerging requirement for connecting DERs and ensure efficient distribution network operation, there is a need to redefine the existing entity and add provisions for new entities. Exploring the segregation or combination of various functions carried out by an individual or multiple entities may be worthwhile to mitigate the emerging challenges and ensure reliable and efficient distribution system operation. A few possible options related to repackaging existing and new entities are suggested in Chapter 3. These options need thorough investigation, and their adoption favorably relies upon the state's geographical, economic and regulatory setup.

The key players in design and implementation of DSO are SERCs and distribution licensees. Though, DISCOMs/Sub-SLDCs carry out distribution system operations, active distribution network management with DERs is a new dimension which is going to assume increasing importance. In Chapter 2, various functions and related tasks of DSO are discussed. It is necessary to identify entity/ body which can undertake these functions. The four proposed options for DSO have been discussed in Chapter 3. To start with, a State may adopt any model as they deem fit. However, they should in due course make the DSO a neutral and independent body which is one of the options and is recommended for eventual option. The transition from the initial to eventual model (independent body) should be planned in a systematic manner by each State depending on the option which they deem fit duly keeping in view the existing mode of distribution system operation in the State (DSOCC/DCC/ALDC/-Sub-SLDC), degree of penetration of DERs and the applications planned to be rolled out.

6.4 HUMAN RESOURCE AND SKILL REQUIREMENT

While the distribution system operation is being managed with the human resource available with the distribution licensee/Sub-SLDC/ALDC, an effort has been made to revisit human resource requirement from the perspective of the need for round – the – clock monitoring, supervision and control of the active distribution network which is likely to change the functioning of distribution system operation. Appropriate skills required to effectively perform the functional responsibilities will play a key role in the changing scenario of distribution system. Considering the key functional areas, current [99] & envisaged activities for distribution system operations, a typical organogram for a DSO is given in Fig. 6.1.

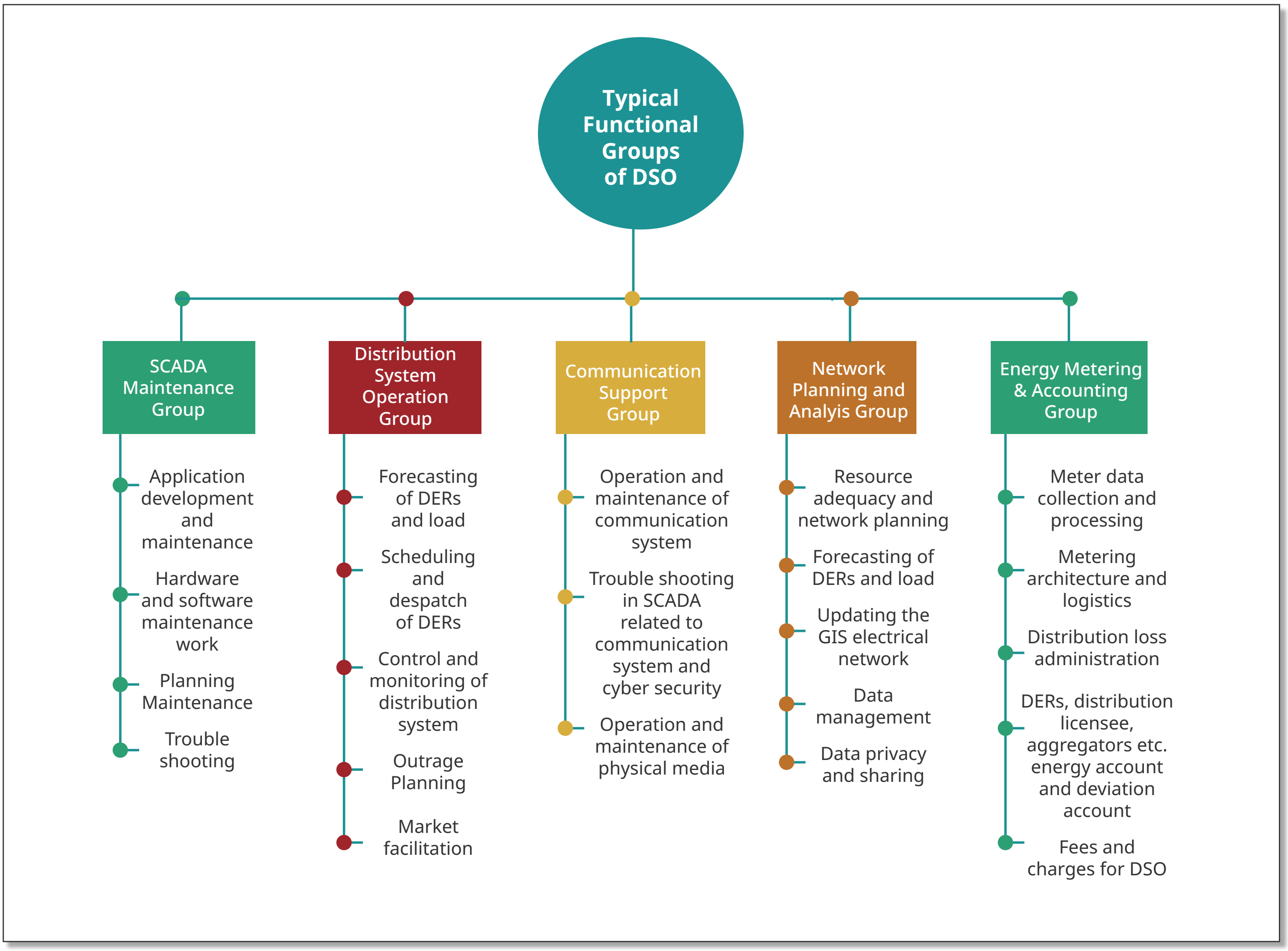


Figure 6.1 A typical organogram for establishing DSO with key responsibilities

The human resource requirement of 40 persons for each DSO is grouped into five major heads namely, SCADA Management Group (SMG), Distribution System Operation Group (DSOG), Communication Support Group (CSG), Network Planning and Analysis Group (NPAG) and Energy Metering & Accounting Group (EMAG). Table 6.1 details the responsibilities & personnel in each group along with the skill requirements. In addition to engineering and IT Skills, Power Market Analyst, Data Analyst, System Analyst (Power, Communication, Cyber) are also required. The conventional functions related to the HR management, finance and account, etc., will in any case be required to make the DSO a self-sufficient entity in-charge of monitoring, supervision and control of distribution system. Capacity building of DER owners is also recommended to increase the level of awareness regarding their roles, functions, data sharing and the need for cyber resilience across distribution network.

Table 6.1: Typical functional groups of the DSO, their responsibilities and skill requirement

Group	Responsibilities	Skill Requirement
SCADA Maintenance Group (SMG)	a) Database engineering and development; application development and maintenance b) Day-to-day hardware and software maintenance work and trouble shooting c) Maintenance planning and updating annual maintenance contracts d) Attending all system related troubles like system hang, software bugs, and errors	• Electrical/Electronics Engineers with IT experience related to database administration/ maintenance and software apllication development. • Eight (8) Executives considering control room 24x7 operations*.
Distribution System Operation Group (DSOG)	a) Forecasting of DERs and Load b) Scheduling and despatch of DERs c) Day-to-day operation including control and monitoring of distribution system d) Coordination with field staff to attend to planned, unplanned, and emergency outages e) Issuing safety permits f) Generation of Management Information Systems and other reports g) Market facilitation	Electrical Engineers with basic knowledge of forecasting, network and distribution system. • Four (4) Engineers to operate SCADA system in each shift. • One (1) Manager level person in-charge of SCADA operations in day shift. • Total 17 executives for 24x7 operations*, considering 4 operation engineers per shift for manning SCADA terminals.
Communication Support Group (CSG)	a) Operation and maintenance of communication system which will include terminal equipment, communication system for distribution automation system and trouble shooting in SCADA related to communication system and cyber security b) Operation and maintenance of physical media that is OPGW, OFC and radio link c) Provide all future communication requirements for sub-station and RMU and their linking with SCADA system d) Coordination with the local area network (LAN) networking group.	CSG in charge with a team of four executives with electronics and communication and IT background.
Network Planning and Analysis Group (NPAG)	a) Resource Adequacy and Network Planning • Short-term and long-term planning of 66/33/ 11 kV and 415 V system in view of addition of new grid stations, power transformers, new sources from Transco and new connections/ disconnections, etc. • Forecasting and Preparation of resource adequacy planning (daily, monthly, yearly) • Preparation of yearly CAPEX plan for network augmentation/improvement schemes, etc. • Periodic review of the network load growth pattern; Identification of automation points for enhancing reliability; and Improvement of power quality indices • Coordination with SCADA system to get parameters for load flow analysis	Planning group with Five (5) Electrical engineers with two of them having GIS knowledge.

Group	Responsibilities	Skill Requirement
	b) Commercial Interface • Analysis by NPAG of all commercial connections of large industrial power (LIP) and small industrial power (SIP) before giving sanction by commercial group for their potential impact and load planning on network. Low tension (LT) connections below a certain limit (say 15 kW) be sent to NPAG for network updating in GIS after field deployment. c) GIS Interface and user registration • Updating the GIS electrical network for all new connections/disconnection and other new schemes. d) Data-Management • Data sharing with third-party • Data privacy	
Energy Metering & Accounting Group (EMAG)	a) Meter data collection and processing (in case not automated) b) Metering architecture and logistics Distribution loss administration c) DERs, distribution licensee, aggregators etc. energy account and deviation account d) Fees & Charges for DSO	Team of Six (6) having two Executive from electrical domain and 3 with administration and logistics.

*3 shifts + 1 reliever shift
(Source: Proposition developed based on [94])

6.5 COST-BENEFIT ANALYSIS

Implementation of DSO will require smart technologies to perform the designated functions. To perform the DSO functions along with existing infrastructure of DISCOMs' DCC/SCADA system, new investments are required in future oriented grid solutions to accommodate various DERs, grid flexibility, demand response and RA, etc. To provide the service with specified reliability and quality standards, DSOs incur capital expenditures (CAPEX) and operational expenditures (OPEX). CAPEX consists of mainly investments in the distribution system primarily catering to (i) network reinforcements to accommodate new demand and DERs, (ii) improving the reliability and flexibility of the system, and (iii) replacement of old assets. On the other hand, OPEX consists of operation and maintenance (O&M) cost of distribution system SCADA, network installations and costs associated to withcommercial services., The DISCOMs submit their CAPEX plan along with the Annual Revenue Requirements (ARR) and tariff revision proposal to the Regulatory Commissions for in-principle approval for financial investment, which are trued-up subsequently. During ARR and tariff determination process, the impact of only the approved capital investment is taken into consideration.

> The energy transition demands a clear vision of the steps that need to be taken and a stable, meaningful regulatory framework. It appears important to us to awaken public opinion to the fact that this transition will necessarily come at a cost and will, at least in the short term, involve a price increase"
> - Christophe de Margerie

Two case studies are provided below which gives a fair idea of the benefits of SCADA for Distribution System Operator.

a. Case study of TP Western Odisha Distribution Ltd. (TPWODL)

The DPR submitted by TP Western Odisha Distribution Ltd. (TPWODL) – joint venture of Tata Power (51%) and Odisha Government (49%) for CAPEX provided the objective of ensuring reliable power supply and ensuring best customer services to the end consumers with a capital investment plan in five major heads viz. statutory and safety, reliability, loss reduction, load growth and infrastructure and technology adoption. The total capital proposed amounted to Rs.1663 crore staggered across 5 years. For FY2021-22, the CAPEX planned is Rs.462.42 crore including implementation of GIS and SCADA (1st phase) towards Rs.34.19 crore.

TPWODL emphasized the need to setup a Centralized Power System Control Centre along with Area Power System Control Centre to coordinate the network operations in real-time by implementing state-of-the-art technologies available in the market for distribution network. Functional requirements proposed to be met through the CAPEX by TPWODL as well as benefits are given in Annexure – 1 for ready reference.

b. Case study of BSES Rajdhani Power Limited (BRPL)

Capital Investment Plan for FY2007-2011 of BRPL, proposed capital investments for strengthening of its existing system, automation, reduction of AT&C loss and routine up-gradation for development of distribution network with the aim to maintain a reliable and quality power supply to its consumers, after taking over DVB in July 2002.

For SCADA system for the Delhi Distribution network, the Plan envisioned for centralized control and monitoring of the network for optimum and synergized usage of resources. The Plan mentioned that SCADA & Distribution Management System will be used as enterprise-wide management of the BRPL networks. It will provide for efficient operations, enhance operational outputs and translate into economic benefits. Installing SCADA system is seen to be a major initiative to improve quality and reliability of power supply to the consumers. The applications in SCADA & DMS for BRPL system are given at Annexure 2 for further reading.

Regarding implementation of SCADA, the Plan mentioned that SCADA has been completed. BRPL proposed expenditure of Rs. 50.39 crores SCADA/ADMS/GIS for the period FY 2007-08 to 2010-11 in MYT order dated 23rd February, 2008. Approval of Delhi Electricity Regulatory Commission (DERC) for the subsequent years is not available in the public domain. The DERC Tariff Order for BRPL for the FY2005-06 and FY2006-07 provides the actual expenditure incurred by BRPL towards SCADA/GIS in the CAPEX as given in Table 6.2.

Table 6.2 CAPEX details of BRPL

	Total CAPEX*	Installation of SCADA & GIS
FY2004-05	Rs.923 Crore	Rs.9 Crore (~1% of total CAPEX)
FY2005-06	Rs.476 Crore	Rs.27 Crore (~5.7% of total CAPEX)

*CAPEX includes: HVDS based electrification projects, EHV Schemes, Distribution Schemes and LTMP, Installation of Capacitor Banks, SCADA/GIS, Meters & AMR, Test equipment, tools & tackles, Service Cable, Distribution Automation, IT & Communication, Vehicles, Land & Building & Misc.

The data and assumptions considered for calculating the levelized expenditure for SCADA/ GIS are given below in Table 6.3.

Table 6.3 Data and assumptions considered for calculating the levelized expenditure for SCADA/ GIS

Cost of SCADA including GIS	Rs. 36 crore
Debt-Equity ratio	70 : 30
ROE	16%
Interest on Loan	9%
Loan tenure	15 years
Depreciation rate	6%
Discount rate	7.7%
Sales escaltion	4%

Based on the above details, the levelized expenditure for SCADA/GIS works out as 0.33 paisa/kWh.

Perceived Tangible Benefits

ii) AT&C Loss reduction

The AT&C loss reduction since FY2004-05 till FY2018-19 is shown below.

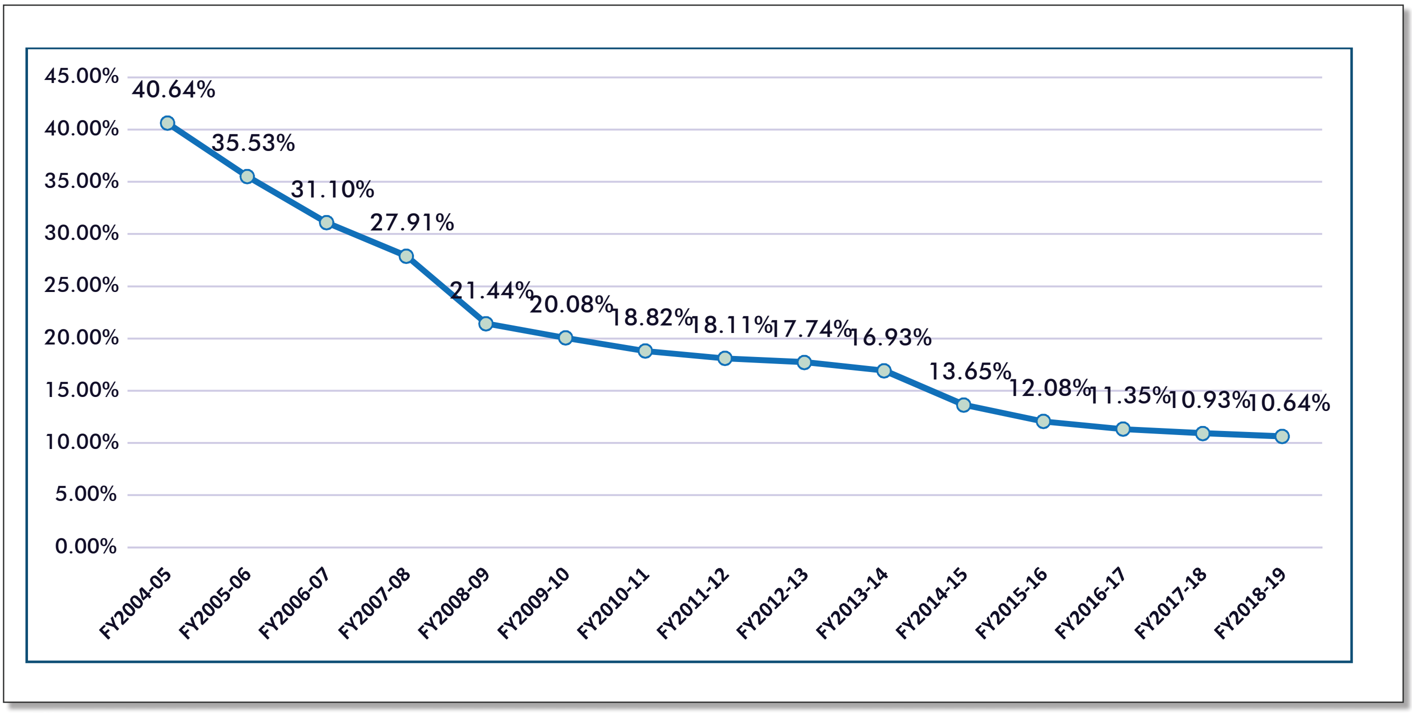
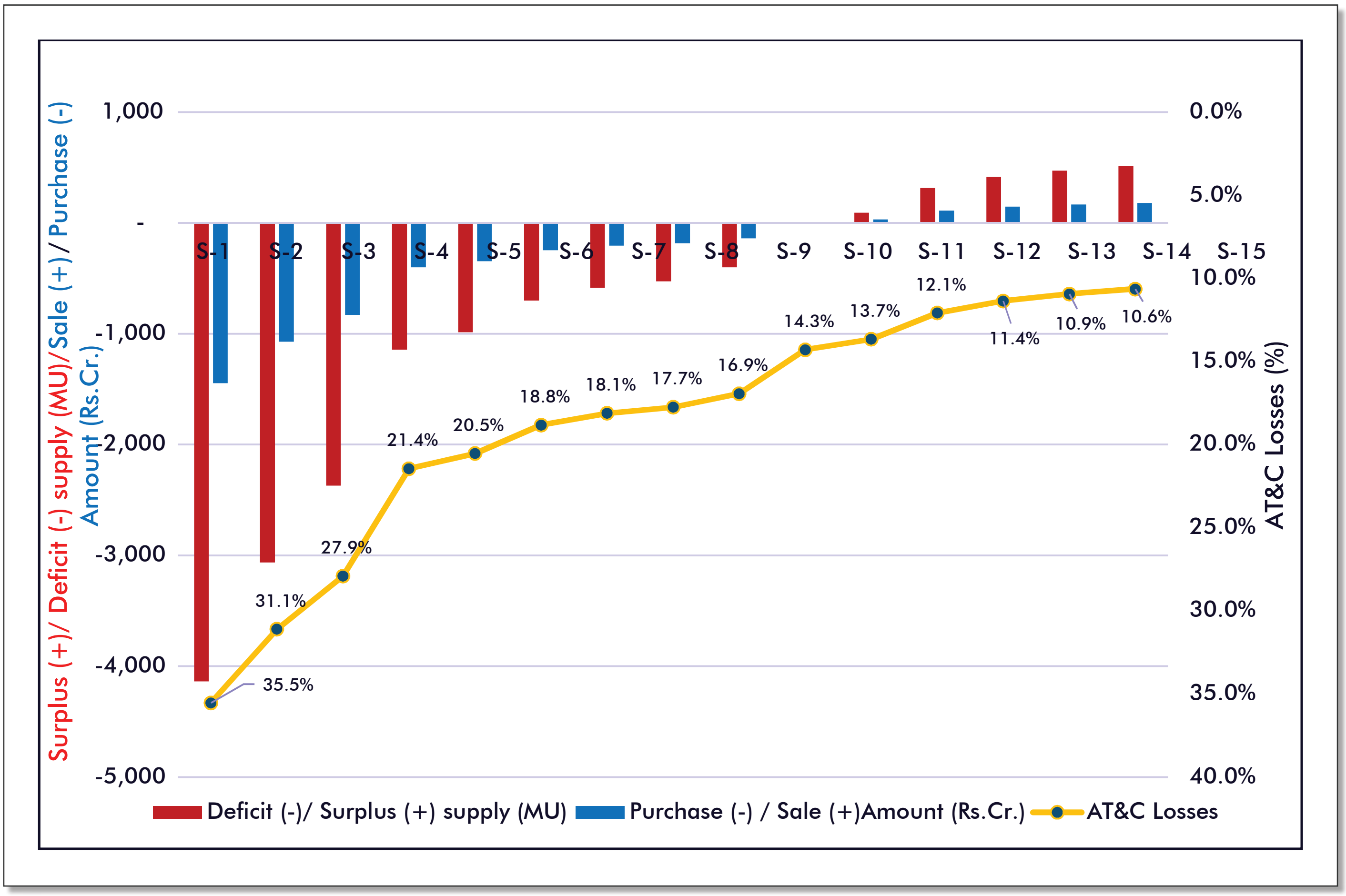


Figure 6.2: AT&C loss trajectory of BRPL (Source: DERC Tariff Orders for BRPL)

The reduction in AT&C losses is attributable to a number of factors, including network upgradation, reduction in theft, improved metering, billing and collection, automation, better monitoring supervision and control, etc. It may be observed from Fig. 6.3 that progressive reduction in AT&C losses resulted in reduction in short-term power purchase by the DISCOM.

A number of scenarios have been developed to analyze the impact of reduction in loss on the short-term power purchase and the financial outflow on account of such purchases considering APPC rate of Rs.3.85/kWh for 2021-22 (CERC Order dated 31.03.2021) as purchase rate and sale rate of Rs.3.50/kWh (BRPL Tariff Order for FY 2021-22). The Fig 6.3 shows the scenarios corresponding to losses.

Figure 6.3: Stylized Scenarios (Source: TERI compilation)



BRPL in its presentation on "BRPL a journey of Operational Excellence Year 2002-2017" have indicated their savings on various accounts including AT&C Loss reduction. Savings due to AT&C Loss reduction achieved over past 15 years have been shown as Rs.21,835 Cr.

Reduction in AT&C Losses results in decreased purchase of short-term power to meet BRPL's requirement and reduced Annual Revenue Requirement. Reduced power purchase costs will also have a direct bearing on the customer tariffs which will ultimately benefit the consumers.

ii) Standards of Performance (SoP)

The SoP of BRPL covering SAIFI, SAIDI, MAIFI and CAIDI for the period from 2008-09 till 2018-19 is shown below in Table 6.4. The SoP for earlier years i.e. 2006-07 and 2007-08 are not available.

The terms SAIDI, SAIFI, MAIFI and CAIDI are explained in Annexure – 3.
Improvements in these parameters have a direct bearing on the availability of power supply as well as improved quality of supply to its consumers.

Table 6.4 SoP of BRPL

	SAIFI	SAIDI	MAIFI	CAIDI
FY2008-09	3.10	4.68	0.04	
FY2009-10	3.01	3.84	0.05	
FY2010-11	3.105	3.887	0.041	
FY2011-12	3.843	3.891	0.046	
FY2012-13	2.48	3.18	0.04	
FY2013-14	2.23	3.22	0.02	
FY2014-15	2.35	3.24	0.08	
FY2015-16	1.7	2.11	0.02	
FY2016-17	1.235	1.604	0.017	
Apr. '17-Aug.'17	0.74	0.93	0.00	
Sep. '17-Mar.'18	0.3	0.4		10.8
FY2018-19	1.63	1.45		10.27

Benefits

The technical infrastructure required by DSO such as SCADA/ADMS implementation have tangible as well as intangible benefits. The Tangible benefits include direct and indirect benefits as given below:

a) Direct Benefits: Some of the direct benefits which translate into increase in the revenue of various entities are:

1. Improvements in power supply and power quality
   - Reduction in loss of revenue due to improvement in SAIDI/SAIFI
   - Cost savings by optimal scheduling due to continuous monitoring of the distribution system
2. Reduction in Operation and Maintenance Costs
   - Restoration cost savings due to real-time monitoring of distribution transformer for internal fault analysis and stress build-up
3. Deferred Capital Investment
   - Deferment in the investment requirements for capacity augmentation due to better performance of the distribution system

The possible direct benefits that can be reaped by DISCOMs are presented in Fig. 6.4.

b) Indirect Benefits: One of the indirect benefits is availability of the relevant data which may provide additional revenue to various entities through

- Potential savings due to better demand forecasting using historical data
- Savings on implementing demand response by understanding the consumer behavior
- Improvement in billing and collection efficiency

REDUCED O&M COSTS

- Better Economic Power Generation/Intechange
- Improved Load Management
- Network Loss Reduction
- Efficient Crew Dispatching
- Reduction of Engineering Analysis labor
- Reduced Training Cost

INCREASED REVENUES

- Increased Interchange capability
- Reduction of Forced outages
- Faster System Restoration

AVOIDED COSTS OF OUTAGES

- Reduction of Forced outages
- Faster System Restoration

Figure 6.4: Potential direct benefits to DISCOMs

The intangible benefits (longer term) which have impact on the consumers and the service provider itself i.e., DISCOM could be

- Renewable integration to reduce carbon-emissions
- Reduced wide scale blackouts
- Improved image of the DISCOM due to better continuity, reliability and quality of power supply
- Improved skills and personnel safety of the employees of the DISCOM
- Consumer satisfaction leading to willingness to pay

> It's important to have a sound idea, but the really important thing is the implementation.

6.6 IMPLEMENTATION PLAN

The electricity distribution system in India has traditionally been operating with unidirectional flow of power sourced from large power plants over the upstream transmission system to the consumers. The penetration of DERs such as rooftop solar PV installations, micro wind turbines, battery energy storage systems, plug-in electric vehicles and smart home appliances are however expected to transform the distribution system from passive to active with reverse power flows. The total installed capacity of solar roof-top installation in India was 6645.70 MW (as on 31.03.2022), grid-interactive renewable power was 108327.73 MW (as on 31.03.2022), total number of operational EVs (2-wheelers, 3-wheelers, 4-wheelers, goods, others) was 10,51,202 (as on 22.03.2022), number of operational public charging stations was 2826 (as on 04.08.2022) and sanctioned public charging stations under Fame- II are 4453. The states have different level of deployment of these systems/stations/meters. The states have been grouped into four categories in respect of each of the aforementioned attributes and the grouping is shown in Fig. 6.5 to Fig 6.10.

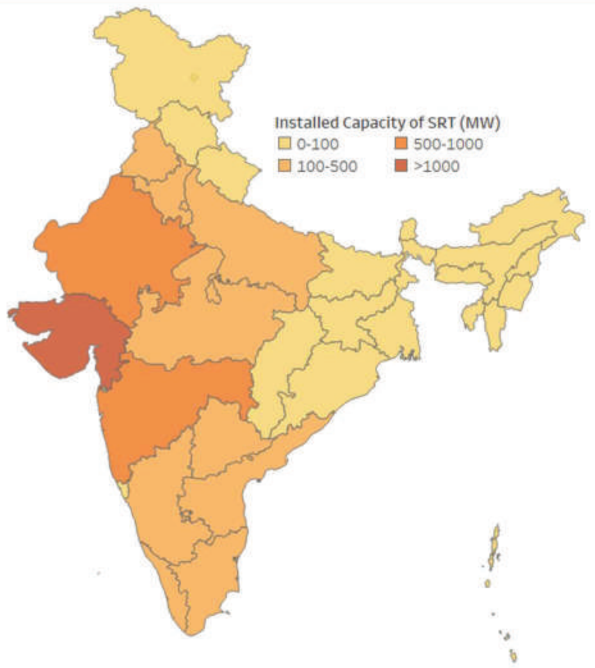


Figure 6.5: Clustering of states based on Installed Capacity of Solar Roof Top Plants

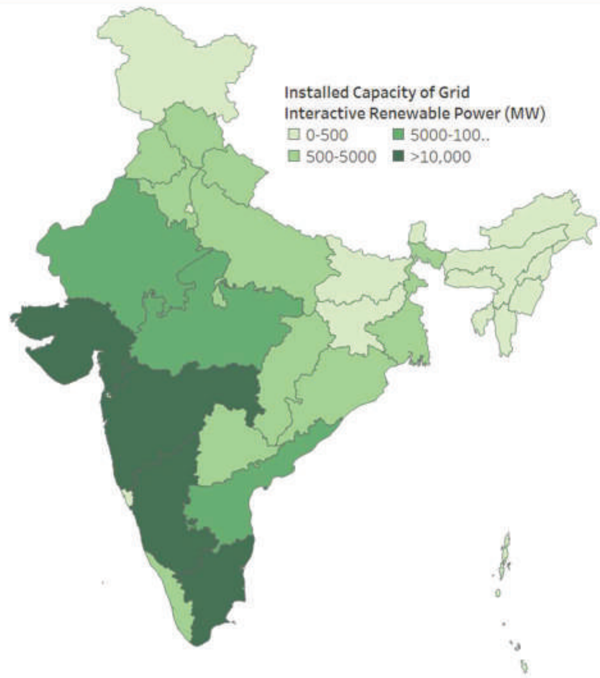


Figure 6.6: Clustering of states based on Installed Capacity of Grid Interactive Renewable Power

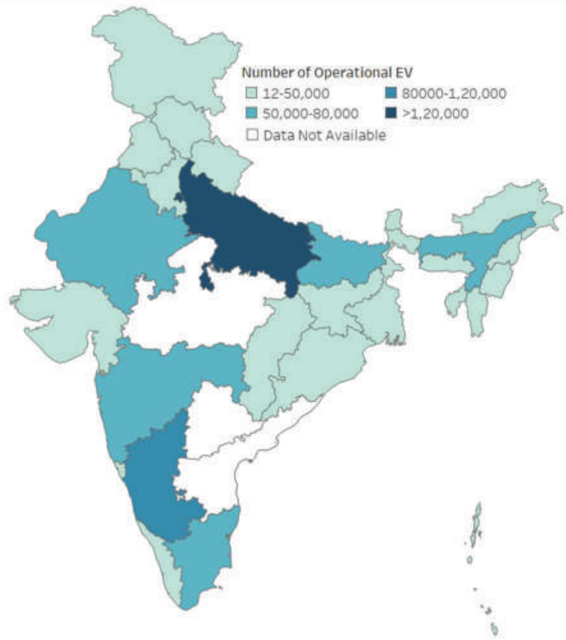


Figure 6.7: Clustering of states based on number of operational EVs

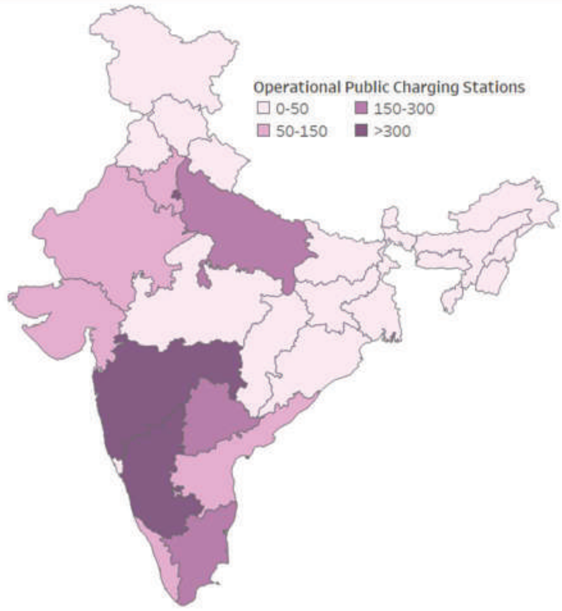


Figure 6.8 Clustering of states based on number of operational public charging stations

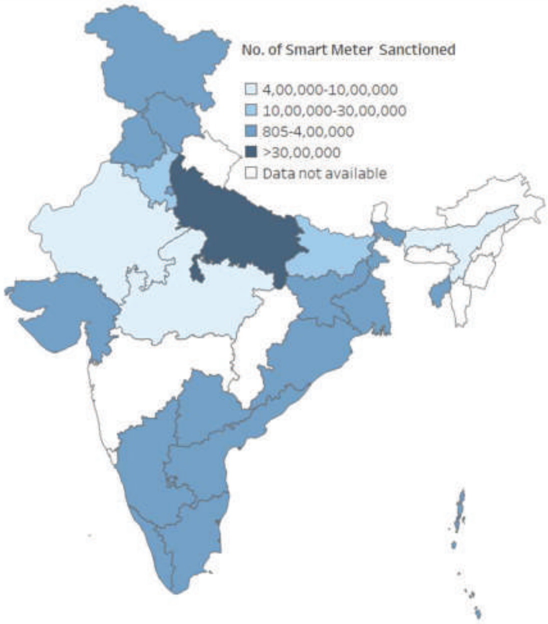


Figure 6.9: Clustering of states based on sanctioned smart meters

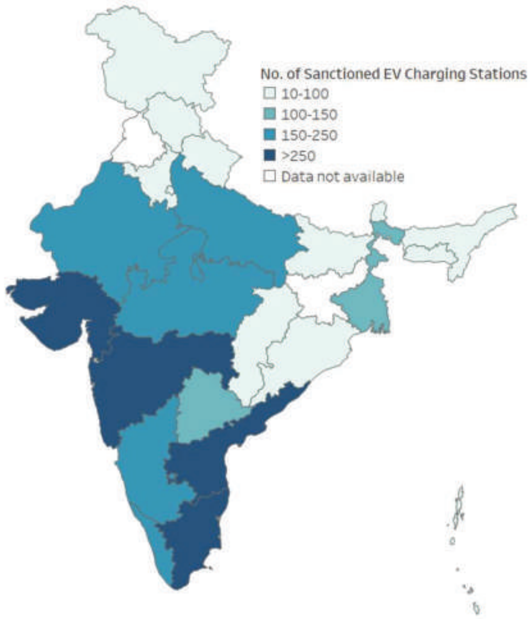


Figure 6.10: Clustering of states based on sanctioned public Charging Stations under Fame II

The emergence of DERs such as rooftop solar and EVs along with existing technology such as smart metering [13] [100] and ALDC/DCC/DSOCC equipped with SCADA/DMS in various states of India can help in understanding the potential challenges on in distribution system operation and prepare them for the adoption of DSO. The variation in the deployment and projection in various states could be due to factors- such as the number, type and density of customers, geographical location, topography, historical factors and the existence of regulations. Some states already have basic infrastructure for ADMS and some are in transition to acquire facilities which act as foundation block for DSO.

DSOs need to be introduced in states in a phased manner keeping in view (a) the degree of variable RE generation in their generation mix, (b) their plans/targets to add variable RE generation in their system, (c) their plan to introduce E-mobility, etc. The states may accordingly plan their transition to DSO as they deem appropriate. Fig. 6.5 to Fig. 6.10, help us to group the states in four clusters as shown in Fig. 6 .11. The states under Cluster-1, could graduate to perform DSO functions as they have decent amount of solar roof top, EVs and technology upgradation (SCADA, DMS, Smart meters, etc.). These states could be the early movers towards the DSO. The states in other clusters, could plan the timing of transition to one of the options [101] for DSO depending on the growth in the DERs, EVs as well as deployment of infrastructure for ADMS. Understanding various possible future trends related to DERs helps a DSO in making investment decisions and long-term planning of the grid they operate.

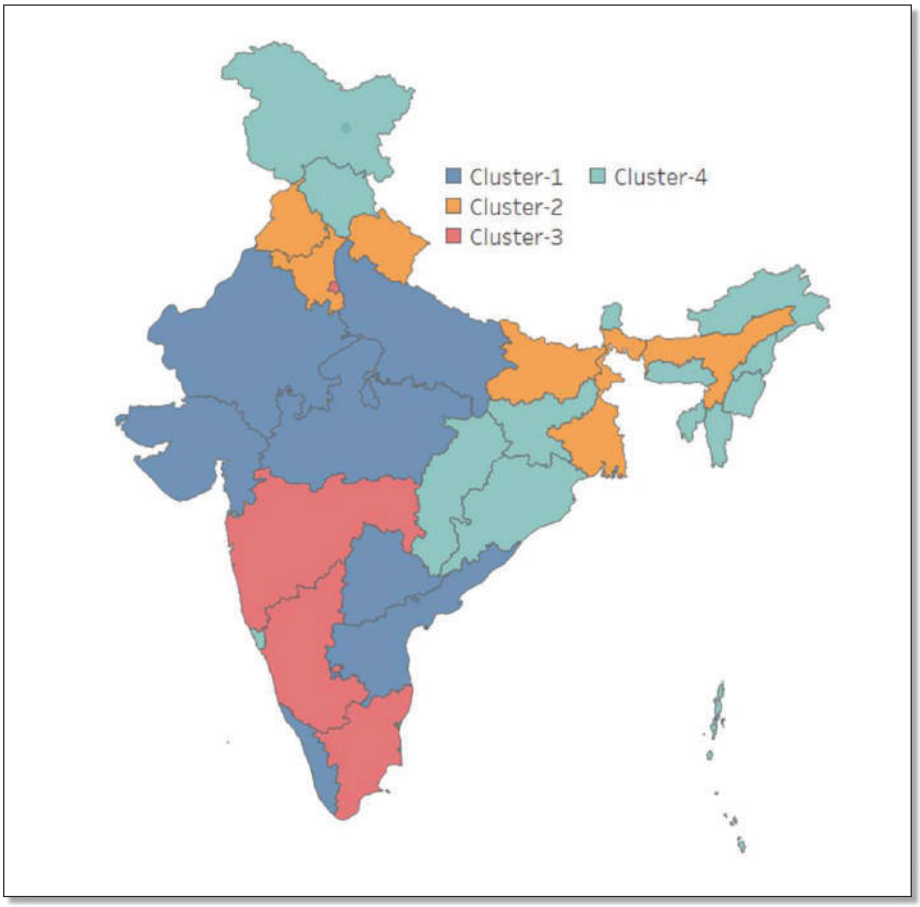


Figure 6.11: Cluster of States

Roadmap for DSO to implement is shown in Fig. 6.12. The distribution system needs to be equipped with the advanced measurement infrastructure which act as building blocks for DSO. Some states are equipped with SACDA and automation systems on distribution system. However, with high increase of DERs, new solutions are necessary on the distribution system to deal with interconnected grid connections and market operations. Carefully designed implementation plan and collective efforts will be needed to meet the needs of all the participants and stakeholders.

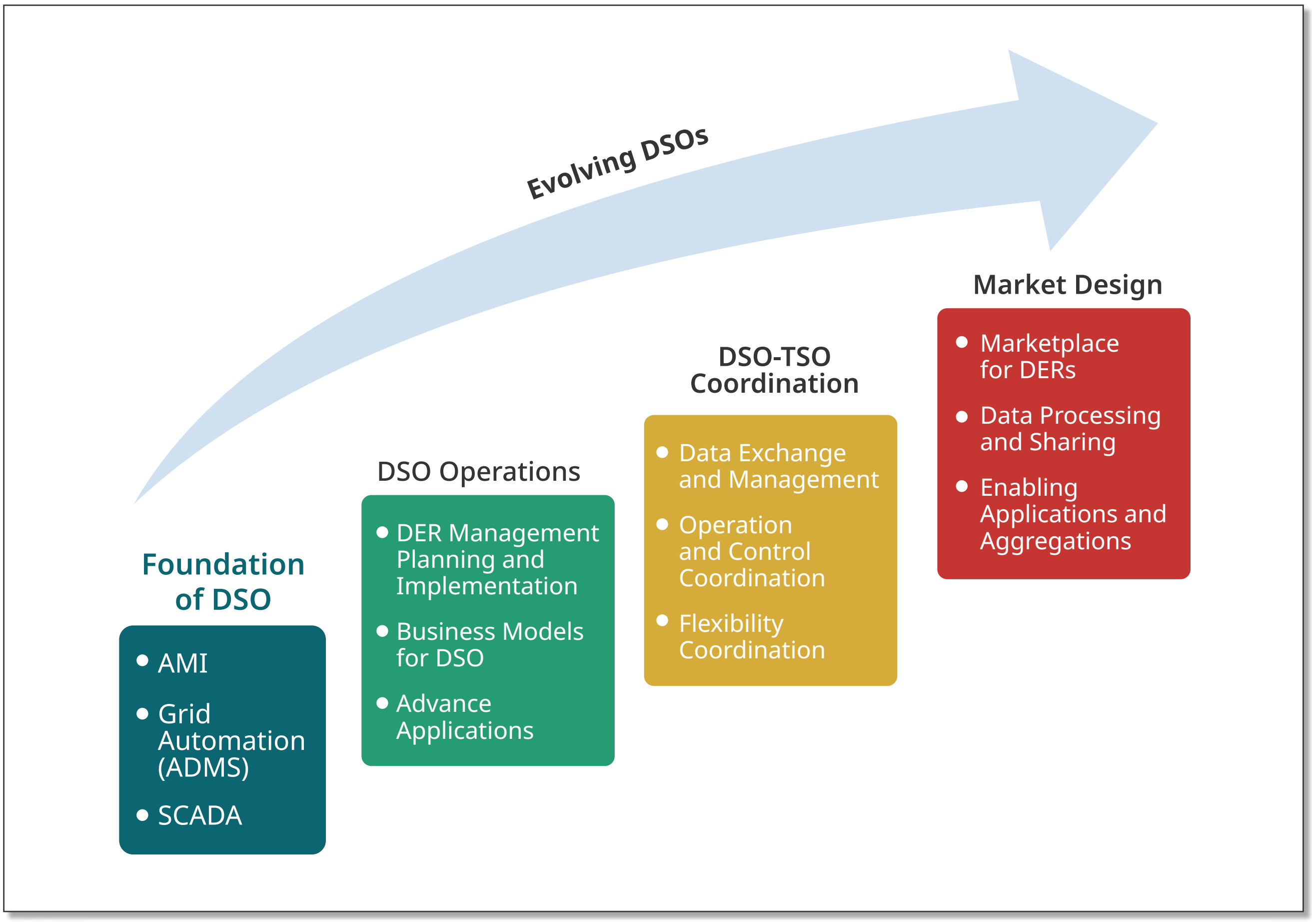


Figure 6.12: Roadmap for DSO implementation

6.7 CONCLUSIONS AND WAY FORWARD

The Indian distribution sector is transitioning to a dynamic, decentralized, and distributed energy paradigm with DERs leading to bi-directional power flow and issues related to power quality. For distribution grid's emerging role and functionalities, DSO is becoming a foreseeable necessity to ensure efficient and reliable operation of the distribution system. The SAMAST and CABIL reports have recognized the need for an entity like DSO in the Indian power system. The draft National Electricity Policy, 2021 also emphasised the need to introduce DSO for real-time operation of the Distribution System. The key functions of DSO are detailed in Chapter 2.

The institutional framework, electricity trading opportunities, policy and regulatory landscapes and considerations which are instrumental in driving the transition of distribution system operation in India to meet the emerging requirement and challenges are presented in Chapter 3, 4 and 5 respectively.

DSO's expertise, structural frameworks, and new technological investments are required to drive India's distribution system transition. However, the distribution systems are diverse and large for a one-size-fits-all approach. To start with, four DSO options and trading opportunities for DERs under DSO are proposed in Chapter 3 and 4 respectively. Considering the role and responsibilities that a DSO would have and the benefits that would accrue, States may adopt any of the four options suiting their requirements with minimum changes in their institutional framework and regulations.

However, it is recommended that states should eventually make the DSO a neutral and independent body. Well-designed state specific research and policy/regulations development is necessary for DSO to plan for effectively transitioning to a full-fledged DSO.

ANNEXURE – 1 FUNCTIONAL REQUIREMENTS PROPOSED TO BE MET THROUGH THE CAPEX BY TPWODL AS WELL AS BENEFITS

Excerpts from the DPR submitted by TPWODL are presented below, mentioning the functional requirements proposed to be met through CAPEX as well as benefits:

With the objective of ensuring reliable power supply and ensuring best customer services to the end consumers, TPWODL proposed the capital investment addressing the following major functional requirement:

i. Centralized System for visibility of the entire distribution network.

ii. Enables standardized Data Acquisition and Reporting.

iii. Perform all critical system operations including routine and emergency operations with enhanced operational availability of distribution network and reliable power supply to customers.

iv. Predictive and Analytical tools for efficient management and decision making for the entire distribution network.

v. System supporting Cyber Securities management through Centralized Account Management, domain controller, IPS & IDS, User Authentications, Network Segmentation, Access Control, Route and Traffic Control, Implementation of Trust Boundaries, OS up gradation, patch management of application and OS, monitoring of real-time alert of compromise and potential compromise

vi. The Centralized System will provide common training platform for systems and maintenance of assets.

vii. Enhanced Operational safety.

viii. Implementation of adequate Network Management and Cyber Security measures.

TPWODL proposed for a Capital Expenditure in five-year plan in phased manner as given under:

i. Deployment of New SCADA System with the concept of MCC & BCC s.

ii. Monitoring and Control of 315 nos. of Sub-stations with proposed SCADA System.

iii. Integration of 33/11 KV SCADA compatible switch gear of ODSSP 33/11KV S/Stn.

iv. RTU installation, Commissioning & Testing to monitor As-Is condition of old type Sub-station

v. Deployment of New Communication system for coordinate the entire substation.

.

The Benefits proposed as per CAPEX Plan of TPWODL is given below:

Refurbishment of substations and feeders will benefit TPWODL through

i. Improvement of voltage profile.
ii. Reduction in number of outages
iii. Increase in vertical clearances
iv. Reduction in equipment downtime
v. Reduction in unserved energy
vi. Enhanced reliability of power supply
vii. Reduction in number of accidents.
viii. Ease of Operation and Operational flexibility

.

ANNEXURE – 2 APPLICATIONS IN SCADA & DMS AND IN GIS FOR BRPL SYSTEM

Excerpts from Capital Investment Plan for FY2007-2011 of BRPL mentioning the applications in SCADA & DMS and in GIS is given below:

Applications in SCADA & DMS

- Supervisory Control: This function normally includes remote device control and local device tagging. Activities normally start with device selection and complete with feedback of status.
- Improved Visibility: All the Indications like Fault Condition, Breaker Status, etc. and measured Values like Load Current, Voltage, Active and Reactive Power etc. are available on the same screen providing all the required information to carry out remote operation.
- Data Acquisition: SCADA accumulates data from the chain of field devices (IEDS, substation data and protective devices, via RTUs or substation controllers). Operators get the data in scan groups, so that polling and updating can be used for maximum efficiency
- SCADA Events: Event in SCADA is any spontaneous change in system. All the events are logged and historically preserved.
- SCADA Alarms: Using different knowledge-based parameters, alarms are generated or suppressed on a need-to-know basis, confident that all events (alarms being a subset of events) will be logged and historically preserved
- SCADA Tagging: SCADA allows tagging of Isolators and Switches. A comment line is assigned to each tag, which shows the date & time and also provides space to assign comments.

As per the BRPL Plan, the GIS which was to contain details of all assets of the Distribution Network and shall be used for asset management and with integration of GIS with other enterprise systems like ERP, SCADA, AMR, and Trouble Call Management will provide a strong base as well as user friendly tool for management of assets, outages, crew management, etc.

Applications in GIS

- Provides common Spatial Data Format
- Promotes Data Sharing
- Enhances Communication and Facilitates Decision Making
- Getting Geographical locations and other details of various Facilities of the organization
- Equipment Failure Analysis
- Load Forecasting
- Optimal Substation load allocation and transformer Sizing
- Power Flow route tracing
- Outage Management in conjunction with IVR System
- Determination of Location wiseLocation wise Load Density
- Automatic reconfiguration of the Network and updating the inventory in the database when equipment is added or removed

ANNEXURE – 3: SAIDI, SAIFI, MAIFI, CAIDI

System Average Interruption Duration Index (SAIDI)

System Average Interruption Duration Index (SAIDI) is commonly used as a reliability indicator for electric power utilities. SAIDI is the average outage duration for each customer served, and in 11 kV feeder system in the town level, SAIDI may be calculated as follows,

$$SAIDI = \frac{\sum U_i N_i}{N_T}$$

Where U_i is the duration of interruption of the ith feeder and N_i is the number of customers in that feeder. N_T is the total number of customers served in all feeders of the town. SAIDI is measured in units of time, in minutes or hours.

System Average Interruption Frequency Index (SAIFI)

SAIFI= (Total No of customers interrupted)/(Total No. of customers served). Assuming all customers connected with the feeder gets interrupted for each feeder failure,

$$SAIFI = \frac{\sum \lambda_i N_i}{N_T}$$

Where λ_i is the no. of failure in the ith feeder and N_i is the number of customers in that feeder. N_T is the total number of customers served in all feeders of the town.

SAIFI is measured in units of no of interruptions per customer.

Momentary Average Interruption Frequency Index (MAIFI)

MAIFI is the average number of momentary (less than 5 minutes) interruptions per consumer during the year. It is the ratio of the annual number of momentary interruptions to the number of consumers.

MAIFI = (Total number of momentary interruptions in a year) / (Total number of consumers)

Consumer Average Interruption Duration Index (CAIDI)

CAIDI is the average duration of an interruption, calculated based on the total number of sustained interruptions in a year. It is the ratio of the total duration of interruptions to the total number of interruptions during the year.

CAIDI = (Total duration of sustained interruptions in a year) / (Total number of interruptions).

ANNEXURE – 4: LIST OF SYSTEM OPERATORS

S. No.	Level	State	Website
1	National Level	NLDC	https://posoco.in/
2	Regional Level	NRLDC	https://nrldc.in/about-us/
3		NERLDC	https://www.nerldc.org/about-us/
4		WRLDC	http://www.wrldc.in/
5		SRLDC	http://www.srldc.in/
6		ERLDC	https://erldc.in/
7	State Level	Andhra Pradesh	https://aptransco.co.in/
8		Assam	https://www.sldcassam.in/
9		Bihar	https://sldc.bsptcl.co.in/
10		Chhattisgarh	https://www.sldccg.com/
11		Delhi	https://www.delhisldc.org/
12		Gujarat	https://www.sldcguj.com/
13		Haryana	https://haryanasldc.org.in
14		Himachal Pradesh	https://hpsldc.com/
15		Jharkhand	https://www.jusnl.in/sdlc.php
16		Karnataka	https://kptclsldc.in/
17		Kerala	https://sldckerala.com/
18		Madhya Pradesh	https://www.sldcmpindia.com/
19		Maharashtra	https://mahasldc.in/home.php/
20		Meghalaya	https://meeclsldc.nic.in/
21		Mizoram	https://sldc.mizoram.gov.in/
22		Manipur	https://sldcmanipur.com/
23		Odisha	https://www.sldcorissa.org.in/
24		Punjab	https://www.punjabsldc.org/
25		Rajasthan	https://sldc.rajasthan.gov.in
26		Sikkim	https://sikkim.gov.in/
27		Tamil Nadu	https://tnebsldc.org/
28		Tripura	http://www.tsecl.nic.in/
29		Uttarakhand	https://uksldc.in/
30		Uttar Pradesh	https://www.upsldc.org/real-time-data
31		West Bengal	http://www.wbsldc.in/

ANNEXURE – 5: LIST OF PROJECT MONITORING COMMITTEE (PMC) MEMBERS, SPEAKERS/EXPERTS

Current UI-ASSIST Project Monitoring Committee (PMC) Members	
Prof. Vijayamohanan K. Pillai (Chairman)	Ex-Director, CSIR-CECRI, Karaikudi
Shri Arun Kumar Mishra	Director, NSGM, Gurugram
Dr. A.K. Tripathy	Former DG CPRI, Chief Technical Adviser PRDC
Prof. H.P. Khincha	Retd. Professor, IISc. Bangalore
Dr. Rajendra Prasad	Andhra University, Visakhapatnam
Dr. SP Gon Chaudhari	Chairman, Tripura State Solar Power Committee, Tripura
Dr. S. Aravamuthan	Ex-ISRO, Bengaluru
Shri S.K. Soonee	Former and Founder CEO, Power System Operation Corporation (POSOCO), New Delhi

Previous UI-ASSIST Project Monitoring Committee (PMC) Members	
Dr. Mylavarapu Ramamoorty (Chairman)	Former Chancellor, K L University Vijayawada Andhra Pradesh, Ex DG, CPRI Bangalore and Director, ERDA
Dr. S. Aravamuthan	Rtd. Deputy Director, VSSC ISRO
Dr. A. K. Tripathy	Former DG CPRI, Chief Technical Adviser PRDC
Smt. Anjuli Chandra	Member, Punjab State Electricity Regulatory Commission, and Ex Chief Engineer, CEA
Shri Arun Kumar Mishra	Director, NSGM, Gurugram
Shri Meenu Singhal	Vice President & Head Industry Business, Schneider Electric India
Prof. Sanjay Kumar Bose	Professor, Department of Electronics and Electrical Engineering, IIT Guwahati
Prof. H.P. Khincha (Chairman in absence of Dr. Ramamoorty)	Retd. Professor, IISc. Bangalore
Shri S.K. Soonee	Former and Founder CEO, Power System Operation Corporation (POSOCO), New Delhi

Webinar : Distribution System Operator (DSO) : Emerging need, roles and responsibilities
Date : Saturday, 24th October, 2020 Time : 2:30 p.m. to 4:30 p.m (IST)

Speakers/Experts	
Shri B. B Mehta	Director [SLDC, IT & Telecom] Odisha Power Transmission Corporation Ltd
Shri A S Bakshi	Ex-Member, CERC
Shri Anand Kumar	Chairman, GERC
Shri Abhishek Ranjan	Vice President (System Operations) and Head-Renewable, BRPL, Delhi
Shri Arun Kumar Mishra	Director, NSGM, Gurugram
Shri B. J. Umesha	CEE-North, Banglore Electricity Supply Co. Ltd.
Shri Bibhu Prasad Mahapatra	Director (Finance), UPPTCL
Shri Rajib Das	Deputy GM (Planning), GESC, Kolkata
Shri S K Soonee	Former and Founder CEO, Power System Operation Corporation (POSOCO), New Delhi
Dr. JBV Reddy	Scientist F at DST, Govt. of India
Shri Bibhu Prasad Mohapatra	Senior Advisor at UP GENCO & TRANSCO
Shri K Ramanathan	Distinguished Fellow, TERI
Prof. Abhijit R Abhyankar	IIT Delhi
Shri Ajay K Saxena	TERI, New Delhi
Prof. Suresh C Srivastava	IIT Kanpur
Prof. Anoop Singh	IIT Kanpur
Ms Jyoti Sharma	TERI, New Delhi
Dr. Ashok M Jadhav	IIT Delhi

Expert Roundtable : Distribution System Operations : Key Functions - Present and Potential Challenges
Date : Thursday, 28th October, 2021 Time : 10:30 to 12:30 hrs (IST)

Speakers/Experts	
Shri S. R. Narasimhan	Director (SO), POSOCO
Shri D. R. Parmar	Director (Tariff, A & A), GERC
Shri B. B. Mehta	Director (SLDC, IT & Telecom), OPTC
Shri Kanti J. Bhuva	Deputy Director
Shri Abhishek Ranjan	Vice President (System Operations) and Head - Renewable, BRPL, Delhi
Shri Anup K. Dutta	Director (Engg.), WBERC
Shri S. B. Chandrashekaraiah	EE-SCADA (D), SLDC, KPTCL
Smt. Anjuli Chandra	Member, Punjab State Electricity Regulatory Commission, and Ex Chief Engineer, CEA
Shri S. K. Soonee	Former and Founder CEO, Power System Operation Corporation (POSO-CO), New Delhi
Prof. Abhijit R Abhyankar	IIT Delhi
Shri Ajay K Saxena	TERI, New Delhi
Shri JBV Reddy	Scientist F at DST, Govt. of India
Shri Robin Mazumdar	TERI, New Delhi
Prof. Suresh C Srivastava	IIT Kanpur
Prof. Abheejeet Mohapatra	IIT Kanpur
Prof. Ankush Sharma	IIT Kanpur
Prof. Anoop Singh	IIT Kanpur

JCERDC-UIASSIST Interactive Feedback Session on DSO (Distribution System Operators) :
Date : April 19, 2022 Time : 10 a.m. to 1:00 p.m. (IST)

Speakers/Experts	
Dr. Anita Gupta	Advisor/Scientist G at DST, Govt. of India
Dr. Nandini Kannan	Executive Director of the Indo-U.S. Science & Technology Forum (IUSSTF)
Shri S. K. Soonee	Former and Founder CEO, Power System Operation Corporation (POSOCO), New Delhi
Shri Samir Chandra Saxena	Chief General Manager at Power System Operation Corporation Ltd
Shri Vivek Pandey	General Manager at Power System Operation Corporation Ltd
Shri Arshad Jamal Siddique	SE, UPSLDC
Shri Arun Kumar Mishra	Director, NSGM, Gurugram
Shri Kanti J. Bhuva	Deputy Director (Technical), GERC
Shri Prafulla Varhade	Director (EE) at Maharashtra Electricity Regulatory Commission, Mumbai
Smt. Anjuli Chandra	Member, Punjab State Electricity Regulatory Commission, and Ex Chief Engineer, CEA
Shri A. K. Rajput	Chief Engineer, CEA
Mr. Rajesh Kumar	Powergrid Corporation of India Ltd
Smt. Kumud Wadhwa	Powergrid Corporation of India Ltd
Dr. A. K. Tripathy	Former DG CPRI, Chief Technical Adviser PRDC
Shri Ajay K Saxena	Teri, New Delhi
Dr. JBV Reddy	Scientist F at DST, Govt. of India
Dr. Chaitali Bhattacharya	Principal Science Officer at Indo-US Science & Technology Forum
Prof. Abhijit R Abhyankar	IIT Delhi
Prof. Suresh C Srivastava	IIT Kanpur
Prof. Anoop Singh	IIT Kanpur

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