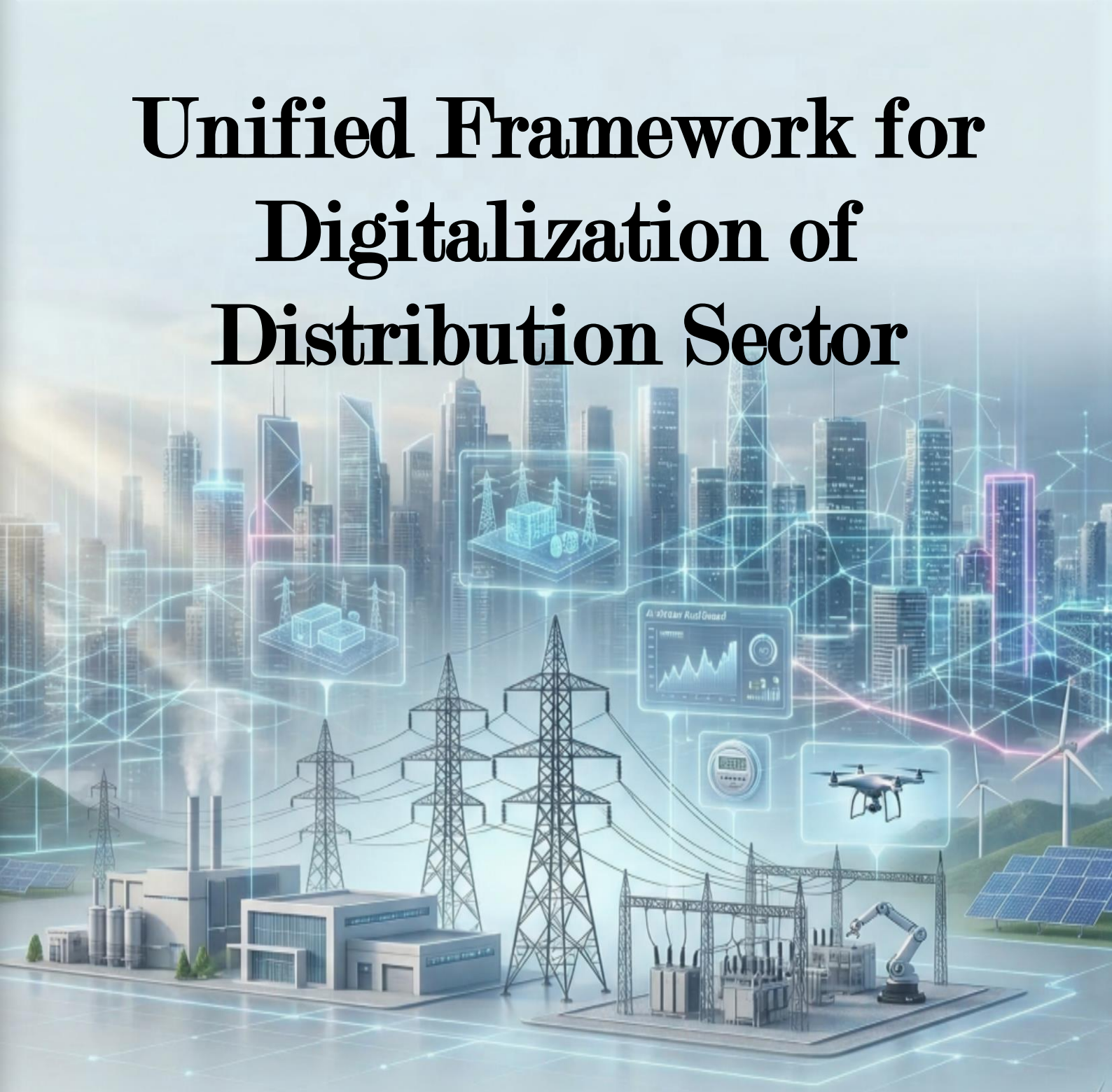
Unified Framework for Digitalization of Distribution Sector



सत्यमेव जयते

Central Electricity Authority
October 2026

पंकज अग्रवाल, भा.प्र.से.
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MESSAGE

India's electricity distribution sector is central to the country's economic growth and the delivery of reliable and quality power to consumers. With rising electricity demand, increasing distributed renewable energy penetration and growing consumer expectations, distribution utilities must increasingly operate networks that are complex, dynamic and data-intensive.

Government of India, through the Revamped Distribution Sector Scheme (RDSS), is supporting states to improve the operational and financial efficiency of distribution utilities, including though development of secure, scalable, interoperable digital systems capable of supporting the evolving needs of the sector.

The Unified Framework for Digitalisation of the Distribution Sector, prepared by Central Electricity Authority, provides a common strategic direction for this transformation. It brings together key digital capabilities including smart metering, SCADA/DMS, GIS, outage management, distributed energy resource management and AI-enabled analytics, etc.

The Framework rightly adopts a maturity- and need-based approach rather than prescribing a uniform technology solution. Utilities should adopt digital capabilities based on their requirements, network conditions, investment priorities and demonstrable business benefits. Open standards, interoperability, technology-neutral architectures and strong cybersecurity should remain fundamental principles to ensure resilience. Ultimately, digital transformation is not only about technology, its success will depend on institutional capacity, skilled manpower, effective data governance and cybersecurity.

I am confident that this Framework will serve as an important reference for Distribution Utilities, State Governments, Regulators and other stakeholders in building a more intelligent, resilient and consumer-centric distribution sector. I congratulate the Central Electricity Authority and all stakeholders who have contributed to preparation of this Framework and look forward to its effective implementation across the country

Pare

(Pankaj Agarwal)

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FOREWORD

The electricity distribution sector is undergoing a profound transformation driven by increasing consumer expectations, rapid growth of renewable and distributed energy resources along with electrification of transport and other sectors, pushing for greater reliability, efficiency and financial sustainability. At the same time, distribution utilities are required to manage increasingly complex networks, bidirectional power flows, emerging flexibility requirements and rapidly growing volumes of operational and consumer data.

In this evolving environment, digitalisation has emerged as an important enabler for transforming distribution utilities into more visible, responsive, data-driven and intelligent organisations. Digital technologies can enable Distribution Utilities to improve network visibility, strengthen asset and consumer data management, enhance outage management and restoration, improve operational efficiency, reduce losses, facilitate renewable and distributed energy integration, and provide better services to consumers.

The "Unified Framework for Digitisation of the Distribution Sector" document has been developed with the objective of providing a common strategic direction for Distribution Utilities in India. The Framework brings together the key digital capabilities required across the distribution value chain, including Advanced Metering Infrastructure, Meter Data Management, Geographic Information Systems, SCADA/RT-DAS, Outage Management Systems, Advanced Distribution Management Systems, Distributed Energy Resource Management, asset and workforce management, data analytics, Artificial Intelligence and other emerging digital technologies.

An important principle underlying this Framework is that digitalisation should be driven by utility requirements and measurable outcomes rather than by technology adoption alone. The transformation of a Distribution Utility should progressively move from visibility and data quality to integration, controllability, automation and optimisation, with selective adoption of autonomous capabilities where adequate safeguards and system maturity exist. Digital technologies should complement, and not substitute, the necessary physical strengthening and modernisation of distribution networks.

The Framework also recognises the significant diversity among Indian Distribution Utilities in terms of network characteristics, consumer mix, geographical spread, digital maturity, financial capability and existing technology platforms. Accordingly, the Framework provides a maturity- and need-based approach, enabling each Distribution Utility to determine its priorities and implementation sequence based on its specific requirements, business case, regulatory framework and system dependencies. Not every emerging technology will be appropriate for every utility or at every stage of digital maturity.

Interoperability, data quality, cybersecurity and data governance are fundamental to successful digital transformation. Digital systems should therefore be developed as an integrated ecosystem, with appropriate standards, open interfaces, reliable communication infrastructure, secure architecture and clearly defined ownership and stewardship of data. Cybersecurity and resilience must be considered throughout the lifecycle of digital assets—from planning and procurement through implementation, operation, upgrade and eventual decommissioning.

The Framework further emphasises that major digital investments should be supported by a clear business case and assessed on the basis of total cost of ownership, measurable benefits, scalability, interoperability and long-term sustainability. Capacity building and organisational change are equally important, as digital transformation is ultimately as much about transforming processes, skills and institutional practices as it is about deploying technology.

The Central Electricity Authority has been supporting the evolution of the Indian power sector through technical standards, planning frameworks, technology guidance and initiatives aimed at strengthening the distribution system. This Framework builds upon these continuing efforts and seeks to provide Distribution Utilities with a practical reference for planning and implementing their digital transformation journeys.

I am confident that the Unified Framework for Digitisation of the Distribution Sector will provide a useful common direction for Distribution Utilities, policymakers, regulators, technology providers and other stakeholders. Its successful implementation will require sustained collaboration among all stakeholders, continuous capacity building and periodic updating in line with technological, regulatory and operational developments.

The ultimate objective of digitalisation must remain firmly centred on the consumer and the power system—a more reliable, efficient, resilient, secure, responsive and sustainable electricity distribution sector capable of supporting India's rapidly evolving energy transition.

(Ghanshyam Prasad)

New Delhi
28 Sept 2026

ACKNOWLEDGEMENT

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We place a special appreciation for **Power Finance Corporation Limited (PFC)** for its valuable support in finalizing and drafting the report, and for **All India Discoms Association (AIDA)** for providing valuable technical inputs that enriched the framework. The contributions of all participating organizations and experts have helped to shape a practical, forward-looking and implementation-oriented framework for accelerating the digital transformation of India's electricity distribution sector.

CEA gratefully acknowledges the collective efforts and cooperation of all concerned stakeholders in this important endeavor.

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KEY TERMINOLOGIES

The key terminologies used across in this document are:

- **Advanced Metering Infrastructure (AMI):** End-to-end smart metering ecosystem including meters, communications, Head End System, and Meter Data Management.
- **Application Programming Interface (API):** Standardized methods for systems to exchange data and commands programmatically.
- **Asset Management System (Enterprise Asset Management – EAM/CMMS):** Tools for asset registers, maintenance, work orders, spares, and lifecycle planning.
- **Common Information Model (CIM – IEC 61968/61970):** Standardized data model enabling interoperability among utility IT-OT systems.
- **Customer Information System (CIS):** Core application for customer records, billing, collections, tariffs, and service workflows.
- **Cybersecurity for Industrial Control Systems (IEC 62443):** International standards for securing OT/industrial automation environments.
- **Data Lake / Data Warehouse:** Central repositories for structured and unstructured data used for reporting and analytics.
- **DDRA-** Discom Digital Readiness Assessment
- **Demilitarized Zone (DMZ):** Controlled network zone separating IT and OT, used to securely broker data flows.
- **DERMS-** Distributed Energy Resource Management System
- **Distribution Management System (DMS):** Operational applications (often with SCADA) for monitoring, analysis, and switching of distribution networks.
- **DLMS/COSEM:** Open metering standards for data models and communication with electricity meters.
- **EAM-** Enterprise Asset Management
- **Enterprise Service Bus (ESB) / Message Broker:** Middleware enabling reliable, decoupled integration between IT-OT applications.
- **ERP-** Enterprise Resource Planning
- **Field Workforce Management (FFM):** Mobile tools and platforms for dispatch, routing, digital workflows, and proof-of-work for field crews.
- **Geographic Information System (GIS):** Geospatial database of network assets and connectivity for planning and operations.
- **Head End System (HES):** AMI platform that communicates with smart meters, manages firmware, and forwards validated data.
- **Historian:** Time-series database capturing high-frequency OT data (e.g., SCADA/IED measurements).
- **Human–Machine Interface (HMI):** Operator screens and consoles used to visualize and control OT systems.
- **Identity and Access Management (IAM):** Processes and tools governing user/device identities and access privileges.
- **Industrial Protocols (IEC 61850, IEC 60870-5-104, DNP3):** Interoperable standards for utility protection, control, and telemetry.
- **Intelligent Electronic Device (IED):** Digital protection and control device (e.g., relays, meters, controllers) communicating over OT protocols.
- **Meter Data Management System (MDMS):** Central system that validates, estimates, edits, stores, and publishes meter interval data.

- **Network Segmentation:** Architectural practice of isolating network zones to limit attack surface and enforce least privilege.
- **Outage Management System (OMS):** System to detect, predict, manage, and communicate outages, including crew dispatch and restoration updates.
- **Power Quality (PQ):** Characteristics of voltage/current (harmonics, flicker, sags/swells) affecting equipment performance.
- **Programmable Logic Controller (PLC – controller):** Industrial controller used for automation logic in substations and field equipment.
- **Reliability Indices (SAIDI, SAIFI, CAIDI, MAIFI):** Standard measures of outage duration and frequency for service quality monitoring.
- **Remote Terminal Unit (RTU/FRTU):** Field device collecting telemetry and executing control commands for substations/feeders.
- **Role-Based Access Control (RBAC):** Access control model granting permissions based on defined user roles.
- **Security Information and Event Management (SIEM):** Platform aggregating logs/events to detect and respond to cybersecurity threats.
- **Security Operations Center (SOC):** Central team and tools monitoring security posture, threats, and incidents.
- **Smart Grid:** A digitally enabled electricity network that uses interoperable two-way communications, advanced sensing, automation, and analytics to monitor, control, and optimize distribution operations and customer services—enhancing reliability, efficiency, resilience, safety, and customer participation - without prescribing specific technologies or vendors.
- **SOE-** Sequence of Events
- **Substation Automation System (SAS):** Integrated protection, control, and monitoring in substations using IEDs and standardized protocols.
- **Supervisory Control and Data Acquisition (SCADA):** Real-time OT system for monitoring and remote control of substations and feeders.
- **Topology Processor / Network Model:** Logical representation of network connectivity used by DMS/OMS for analysis and switching.
- **Utility Communication Networks (WAN/FAN):** Wide- and field-area networks connecting control centers and field devices.
- **Virtual Private Network (VPN):** Encrypted tunnel enabling secure remote access to utility systems and data.
- **VVO-** Voltage Var Optimization
- **WFM-** Work Force Management
- **Work Management System (WMS):** Platform to plan, dispatch, and track field orders and crews; typically integrated with GIS and CIS.

1 DIGITALIZATION IN POWER SECTOR – GLOBAL TREND

Power systems worldwide are undergoing a profound structural transformation driven by rapid digitalization. Traditional electricity networks - historically designed for centralized generation, one-way power flows, and manual control - are being replaced by increasingly complex, data-driven systems. These modern systems must accommodate bidirectional energy flows, high penetration of variable renewable energy, distributed energy resources, electric mobility, and active consumer participation.

Digital technologies have become deeply embedded across the power sector value chain, particularly in the distribution segment where operational complexity is the highest. Advanced sensing, communication networks, cloud platforms, data analytics, and automation are now integral to how grids are planned, operated, and monitored. This shift reflects a global recognition that reliable, resilient, and efficient power systems can no longer be managed through conventional, manual, or siloed approaches.

As electricity systems scale to meet decarbonization and electrification goals, digitalization is emerging not as an optional enhancement, but as a foundational requirement for modern power system functioning.

1.1 DIGITALIZATION AS A GLOBAL TREND

Globally, utilities are moving toward continuous, data-driven operations. Real-time monitoring, automated control, and predictive analytics are becoming standard features of modern power systems. Distribution networks, in particular, are transitioning from passive infrastructure to actively managed platforms capable of sensing conditions across assets, forecasting system behavior, and responding dynamically to changing demand and supply patterns.

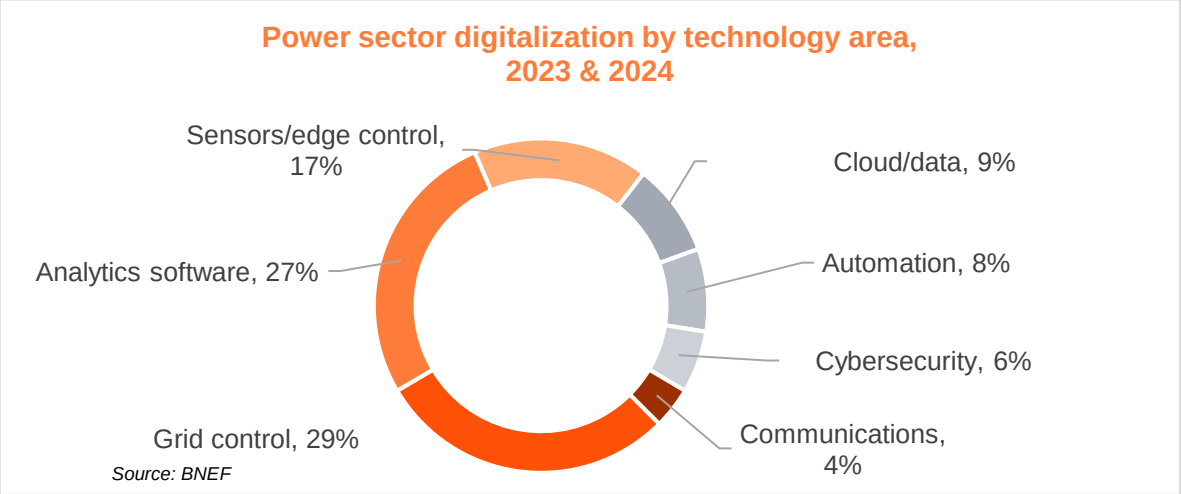
Investment patterns reflect this shift. A growing share of grid expenditure is directed toward digital capabilities such as grid control systems, analytics platforms, sensors, automation, and secure data infrastructure. Grid control and analytical tools dominate this landscape, indicating a global emphasis on operational intelligence, automation, and optimization rather than standalone digitization of individual processes.

IEA notes[1] that digital investment now accounts for 19% of total grid investment, with distribution utilities driving 75%+ of all digital spend.

Overall, grid control accounted for almost 1/3rd of the total digitalization[2] activities in power sector, with key enablers being adoption of DERMS, virtual power plants, advanced distribution management systems, vehicle-to-grid, demand response and digital substations.

[1] *https://www.iea.org/energy-system/electricity/smart-grids*

[2] *https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Oct/IRENA_INN_Digitalisation_AI_for_power-systems_2025.pdf*



1.2 Global Digitalization Initiatives

In response to these structural shifts, many countries have initiated formal digitalization strategies, action plans, and coordinated programs for the power sector.

- Europe[3] has adopted a coordinated approach through the European Union's Action Plan for Digitalizing the Energy System.
- The United Kingdom[4] has advanced the concept of a national "Digital Spine" for the energy sector.
- In the United States[5], the Department of Energy's Grid Modernization Strategy places digital technologies at the core of future grid development.
- The G7 presidency[6], in collaboration with international agencies, has explicitly linked digitalization to global climate goals.

Global Digitization Initiatives

Europe

EU's 2022 Action Plan for Digitalizing the Energy System mandates:

- Interoperability standards
- Consumer empowerment
- Cybersecure digital energy data exchanges
- Coordinated smart grid investments

United Kingdom

- Launched the "Digital Spine" feasibility study — a national-level digital backbone for unified data exchange across utilities.

[3] *https://energy.ec.europa.eu/topics/eus-energy-system/digitalisation-energy-system_en*
[4] *https://www.gov.uk/government/publications/digital-spine-feasibility-study-exploring-a-data-sharing-infrastructure-for-the-energy-system*
[5] *https://www.energy.gov/sites/default/files/2024-12/Grid%20Modernization%20Strategy%202024.pdf*
[6] *https://www.irena.org/Digital-Report/Digitalisation-and-AI-for-power-system-transformation-Perspectives-for-the-G7*

US

DOE 2024 introduced strategy for Grid Modernization, the strategy focuses on 6 pillars that will help achieve the grid of the future.

- The pillars are Devices and Integrated Systems; Operations; Planning; Markets, Policies, and Regulations; Resilient and Secure Systems; and Flexible Generation and Load.

G7 Presidency

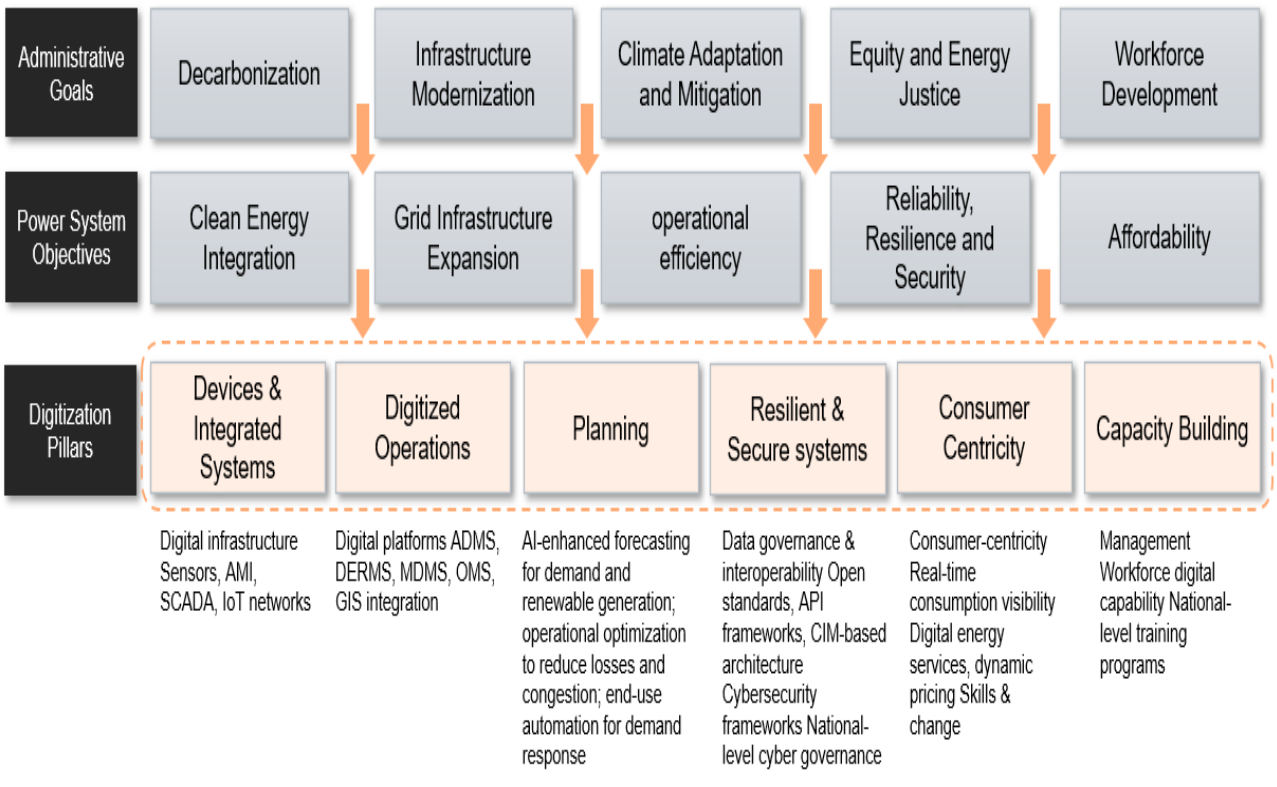
Recognizes that - COP28 goal of tripling renewable energy capacity by 2030 can be "catalyzed by digitalization “

- G7 in collaboration with IRENA –direction-setting for digital power system transformation, prioritizing across 5 areas.
  - Monitoring through smart sensors and meters.
  - AI-enhanced forecasting for demand and renewable generation.
  - Operational optimization to reduce losses and congestion.
  - end-use automation for demand response; and
  - transparency through digital platforms

1.3 Key Levers for Digitalization from Global Policies and Initiatives

Direction of global policymaking is clear: countries are moving from isolated pilots to national, integrated frameworks that combine infrastructure, platforms, data, security, consumers, and skills.

Key Levers for Digitalization from Global Policies and Initiatives



2 DIGITALIZATION IN INDIAN DISTRIBUTION SECTOR

India's power distribution sector is entering a phase of structural transformation, marked by fundamental changes in demand patterns, supply configurations, and governance priorities. Rapid demand growth driven by urbanization, industrial expansion, rising cooling requirements, and the acceleration of electric mobility is placing unprecedented pressure on distribution networks. These shifts are altering both the scale and the operational complexity of the sector, requiring distribution utilities to manage higher loads, greater variability, and more dynamic consumption behavior.

At the same time, the sector is witnessing fast penetration of distributed energy resources such as rooftop solar, energy storage systems, and electric vehicles, which are reshaping the traditional one-way flow of electricity. This transition is unfolding alongside government-led reform programs aimed at improving financial sustainability, enhancing reliability, and strengthening consumer empowerment.

In view of this, we can see that India's power distribution sector is at the **convergence of three disruptive forces:**

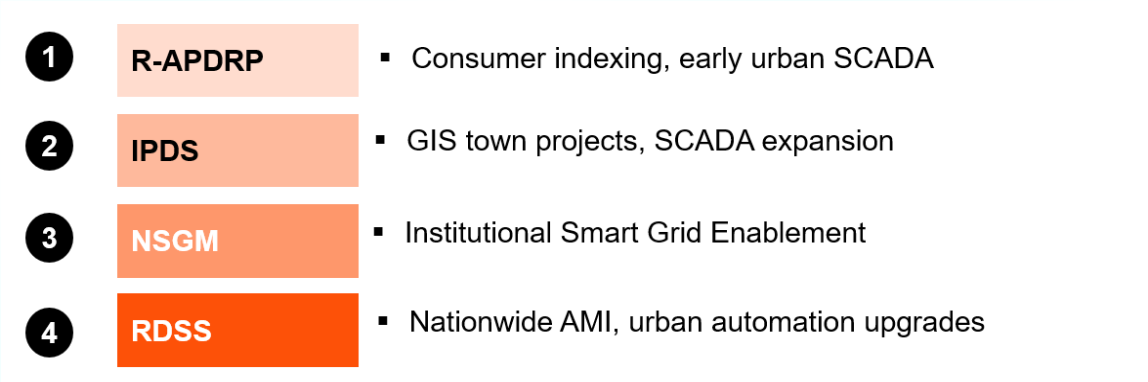
- Rapid demand growth driven by urbanization, industrial expansion, cooling load, & electric mobility.
- Fast penetration of distributed energy resources (DERs) rooftop solar, storage, EVs.
- Government-led reform programs that target financial sustainability, reliability, and consumer empowerment.

Together, these converging forces are redefining the role of distribution utilities and necessitating new approaches to planning, operations, and system management.

2.1 DIGITALIZATION LED BY VARIOUS SCHEMES AND INITIATIVES

Over the years, India's power distribution sector has witnessed progressive digitalization driven through multiple sector-specific initiatives, each addressing distinct operational and institutional gaps at different points in time. These programs were designed to introduce digital systems incrementally starting with consumer indexing and basic monitoring, expanding to GIS-based asset mapping and network automation, enabling smart grid capabilities, and more recently scaling advanced metering and urban automation.

Digitization initiatives were driven via multiple initiatives namely:



- **Integrated Power Development Scheme (IPDS)**
  Launched in 2014 to strengthen sub-transmission, distribution networks, and metering in urban areas. The scheme carried forward the IT enablement and distribution network strengthening components of the earlier R-APDRP program (subsumed later in IPDS). It also sanctioned smart grid pilot projects to demonstrate functionalities such as smart metering and advanced communication technologies (GPRS, RF, PLC). These pilots provided valuable lessons on procurement, product standardization, capacity building, and regulatory support, laying the groundwork for large-scale digitization.

- **National Smart Grid Mission (NSGM)**
  Launched by the Ministry of Power in 2015, NSGM was designed to promote digitization at the distribution level. It coordinated smart grid activities across the country and supported pilot projects, capacity building, and adoption of smart metering systems and IT-enabled consumer services. NSGM also provided the institutional framework for scaling up digitization efforts nationwide.

- **Revamped Distribution Sector Scheme (RDSS)**
  Launched in 2021 to accelerate reforms in the distribution sector, RDSS has significantly advanced digitization through the rollout of prepaid smart meters at the consumer level and communicable meters at transformer and feeder levels. This is creating the backbone for automated energy accounting and real-time monitoring. The scheme has further institutionalized Advanced Metering Infrastructure (AMI), enabling two-way communication to support remote operations, demand-side management, and improved billing efficiency.

With the installation of smart meters, utilities are now able to efficiently manage cash flows, reduce AT&C losses, and strengthen energy accounting. Data gathered through AMI supports improved load forecasting, enabling optimized power procurement and reduced cost of supply. In parallel, several Discoms have implemented SCADA/RT-DAS, GIS mapping, and Distribution Management Systems (DMS), while some private utilities have adopted advanced platforms such as Outage Management Systems (OMS) and integrated Distribution Management Systems, marking a significant step forward in digitization.

Next phase of Digitization reforms

Building on the initial rollout of smart metering and AMI, the next phase of reforms shall transition from foundational infrastructure to advanced digital applications across operations. The emphasis will shift from system deployment to effective utilization, ensuring that data and platforms deliver measurable improvements in efficiency, reliability, and consumer service. Key focus areas include:

- Advanced ICT Integration: Leveraging Artificial Intelligence, Machine Learning, and Blockchain to convert operational data into actionable insights for loss reduction, demand forecasting, asset management, renewable energy integration, and tariff design.
- Smart Metering Data Utilization: Harnessing the two-way communication capability of prepaid smart meters to strengthen energy accounting, improve billing efficiency, enhance cash flow management, and support optimized power procurement.
- Expansion of Digital Systems: Scaling up SCADA, RT-DAS, DMS, and GIS mapping, while advancing towards integrated distribution management and outage

management platforms for real-time monitoring, predictive maintenance, and consumer-centric service delivery.

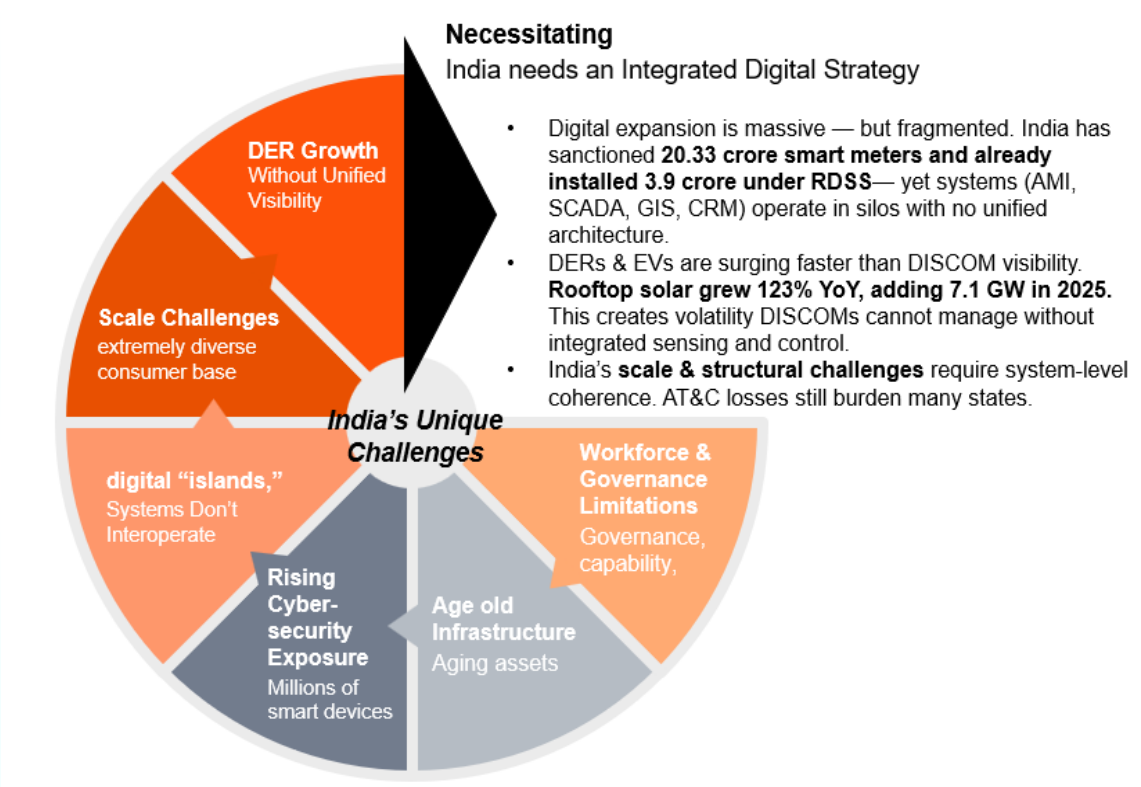
- Alignment with initiatives planned under India Energy Stack (IES) to establish a national digital infrastructure that provides a standardized, modular, and secure digital framework to manage, monitor, and innovate across the energy ecosystem.

2.2 India's Unique Challenges & Need for an Integrated/ Unified Digital Strategy

As digitalization efforts scale across India's power distribution sector, a set of structural & systemic challenges has become increasingly evident. These challenges span technology, infrastructure, institutions, and people, and together they constrain the ability of DISCOMs to fully realize the benefits of ongoing digital investments.

- DER Growth without Unified Visibility - Rapid growth of rooftop solar, storage, and EVs is occurring without integrated, real-time visibility at the DISCOM level, limiting the ability to forecast load, manage voltage, and maintain grid stability.
- Scale Challenges (Extremely Diverse Consumer Base) - India's distribution sector serves a vast and heterogeneous consumer base across urban, semi-urban, and rural areas, making uniform digital deployment, service quality, and operational standardization inherently complex.
- Digital "Islands" - Multiple digital systems such as AMI, SCADA, GIS, billing, and CRM have been implemented through different programs but largely operate in silos, preventing end-to-end process integration and data-driven decision-making.

India's Unique Challenges



- Rising Cybersecurity Exposure - The increasing deployment of millions of smart meters, sensors, and connected devices has expanded the cyber-attack surface, while cybersecurity capabilities and governance frameworks remain uneven across utilities.
- Age-Old Infrastructure (Aging Assets) - Large parts of the distribution network continue to rely on aging physical infrastructure, limiting the effectiveness of digital systems and increasing failure rates, losses, and maintenance challenges.
- Workforce & Governance Limitations - Digital transformation is constrained by gaps in institutional governance, limited digital skills within the workforce, and insufficient alignment of roles, processes, and accountability with new digital systems.

Together, these challenges highlight that incremental and fragmented digitalization is no longer sufficient for India's distribution sector. Addressing issues of scale, system silos, DER visibility, cybersecurity risk, aging infrastructure, and institutional capacity requires a coordinated, end-to-end digital approach. Further, with the focus on roll-out of a national level digital public infrastructure for energy (IES), with focus on defining common identifiers, interoperability standards, trusted data exchange mechanisms, and open APIs – it is an imperative that an integrated unified digitalization framework is in place. This unified framework must align technology deployments with common architectures, governance frameworks, data interoperability, cybersecurity, and workforce capability-ensuring sustained operational, financial, and consumer-centric outcomes.

3 MAJOR SMART DISTRIBUTION TECHNOLOGIES IN PRACTICE

The current landscape includes systems such as Supervisory Control and Data Acquisition (SCADA), Geographic Information Systems (GIS), Distribution Management Systems (DMS), Outage Management Systems (OMS), smart metering with Advanced Metering Infrastructure (AMI), and Remote Terminal Units (RTUs), among others. Each of these technologies addresses specific operational challenges while contributing to the broader objective of building resilient, consumer-centric distribution networks.

This chapter outlines the key digital and smart distribution technologies presently in use, examining their role, functionality, and impact on Discom operations. Together, they illustrate how digitalization is reshaping the distribution sector and laying the foundation for future advancements

3.1 ADVANCED METERING INFRASTRUCTURE (AMI)

Advanced Metering Infrastructure is a foundational Smart Grid technology enabling two-way communication between customer premises and the utility's data center. AMI includes smart meters, communication networks, HES, Meter Data Management Systems (MDMS), etc. Unlike traditional AMR systems, AMI provides real-time or near-real-time data, remote connect/disconnect functionality, and support for prepaid, post-paid, and net-metering setups. AMI is essential for dynamic pricing, demand response, accurate energy auditing, and improved cash flow management.

It is an architecture for automated, two-way communication between a smart utility meter (using an IP address/RF mesh/PLC / DCU/access points etc) and a utility system (HES-MDM). The goal of an AMI is to provide utilities with near real-time data about power consumption and allow customers to make informed choices about energy usage based on the price at the time of use.

Building Blocks of AMI: AMI is comprised of various hardware and software components, all of which play a role in measuring energy consumption and transmitting information about energy to utility companies and customers. The overarching technological components of AMI include:

a) ***Smart Meters:*** Advanced meter devices have the capacity to collect information about energy usage at various intervals and transmitting the data through fixed communication networks to utility, as well as receiving information like pricing signals from utilities and conveying it to consumer.
b) ***Communication Network:*** Advanced communication networks which supports two-way communication enable information from smart meters to utility companies and vice versa.
c) ***Meter Data Management System (MDMS):*** Host system which receives, stores and analyzes the metering information. It provides a platform to assess the performance of the energy usage on a real-time basis. By using the VEE (Validation, Edit, Estimation) Rule, MDMS generates Business Intelligence Reports, which helps in

identifying the underperforming areas and initiate the planning for performance improvement.

Key Benefits

The main advantages of smart metering system over the conventional metering system are as under:

1. AT&C Loss Reduction	• Improved billing efficiency due to accurate and near real-time data capture of energy consumption and load profile • Allows for identifying pockets of pilferage for taking remedial measures – loss monitoring and action • Improved utility cash flows in case of pre-paid billing mode • Remote connect/disconnect from remote in case of no payment
2. Enhanced Energy Accounting	• Near real time data enables mapping of consumer demand, feeder / DT wise loading, etc., enabling enhanced energy accounting to allow operational performance improvement interventions and optimise resources
3. Ease in Operations & System Control	• Ability to enforce commercial principles like 'Disconnections' of non-paying consumers remotely without manual intervention, as per Regulatory provisions • Instantaneous update of regulatory directives such as tariff changes, preventing any revenue loss or dispute from consumer
4. Cost Savings for Utilities	• Reduction in manpower cost for meter reading and billing activities – manpower can be redeployed for optimising performance in other areas such as power purchase management, project implementation etc. • Remote connection /disconnection of meters without any manpower • Reduced operational expenditures on call centres with preventive compliant management and app enabled complaint resolution
5. Improved Network Planning & Performance	• Data analytics to accurately estimate consumer demand to forecast system load requirements appropriately • Improved CAPEX planning with analysis of consumer data/system data • Greater visibility of network with real time assessment of system performance and faults – blackouts / brownouts
6. Enables Demand Management	• Possibility of flattening demand curve through ToU and Demand Response (DR) / Demand Side Management (DSM) measures
7. Enables Dynamic Pricing	• Accurate view on Maximum Demand / Connected Load of consumer leading to accurate recovery of fixed charges upon implementation of two-part tariff • Ease of implementation of Time of Use (ToU) pricing for DSM • Market linked tariff mechanism is possible

8. Scalability to Future Market Structure	• Step towards wire and content separated market structure • Block-chain ratification of green energy supply • Compliant with prosumer model and net metering compliant • Ease of integration with Behind the Meter solutions including EV
9. Improved Customer Satisfaction	• Less fault handling time through Outage Management system (OMS) • Accurate monitoring of reliability Indices like SAIFI, SAIDI, CAIFI, CAIDI etc. • Faster response time to specific consumer complaints such as billing, tariff issues etc., through near real time remote meter access • Consumer has control over consumption through app with spend management and data analytics for consumption management

3.2 SUPERVISORY CONTROL & DATA ACQUISITION (SCADA)

Sub-transmission (33 kV) and primary distribution (11 kV) substations serve thousands of customers and any failures at sub transmission & distribution system have widespread impacts. Historically, substations relied on electromechanical relays and lacked real-time monitoring. The absence of data limited fault diagnosis and delayed restoration. With increasing DER complexity and reliability expectations, utilities require automated, remotely operated substations capable of communicating operating conditions, faults, and equipment health.

Sub-station Automation System (SAS) is first part of SCADA/DMS as it uses the Intelligent Electronic Devices (IEDs) for measurement & control of data and communicate via IEC standards to control centres and support time synchronization for sequence-of-events recording. It uses Real-time data for diagnostics and analysis facilitating enhanced reliability of switching and protection, condition-based maintenance replacing periodic schedules, reduced downtime and labour requirements along with better interoperability when implemented using open protocols

Sub-station Automation System (SAS) provides essential data inputs to SCADA systems. SCADA systems enable centralized monitoring and control of distribution assets. They collect real-time data related to voltage, current, breaker status, alarms, and protective relay events. SCADA enhances the situational awareness of operators and supports remote switching, thereby reducing the Mean Time to Restore (MTTR) and increasing Mean Time Between Failures (MTBF).

Key Benefits

- Faster restoration and fewer outages
- Asset health visibility
- Enhanced safety
- Support for unmanned substations
- Improved reliability indices (SAIDI, SAIFI, CAIDI, CAIFI)

3.3 REAL-TIME DATA ACQUISITION (RT-DAS)-MINI SCADA

For smaller towns where full SCADA is financially unviable, RT-DAS offers an intermediate step. It focuses on real-time feeder monitoring using FRTUs (Feeder Remote Telemetry Unit) and MFTs (Multi Functional Transducers), enabling utilities to measure SAIFI/SAIDI, track outages, and identify reliability issues.

Key Benefits:

- Accurate outage measurement
- Cost-effective deployment
- Compatibility with SCADA/AMI systems
- Event notifications and MIS analytics

RT-DAS significantly enhances reliability assessment and supports targeted maintenance.

3.4 DISTRIBUTION MANAGEMENT SYSTEM (DMS) /ADMS

DMS is an integrated suite of various applications which involves installing sensors, automated switches, and communication-enabled field devices to remotely monitor and control distribution circuits, immediate fault detection, isolation, and service restoration - often without human intervention along with analyzing and optimizing the medium-voltage network. Its key functions include:

- Fault Location, Isolation, and Service Restoration (FLISR)
- Volt/VAR optimization
- Load forecasting and feeder reconfiguration
- Power quality monitoring
- Operational decision support

Key Benefits:

- Improved reliability and reduced outage durations
- Better use of reactive power and voltage optimization
- Enhanced load shedding management
- Reduction in manual switching errors
- Optimal network configuration for minimal losses
- Real-time analysis for operational planning

DMS form the intelligence layer of a modern distribution network. Further, ADMS integrates SCADA, DMS, and OMS into a unified platform. This integration eliminates data silos and enables end-to-end visibility and control of the distribution system.

Key Capabilities:

- FLISR for automated restoration
- Volt/VAR optimization and Conservation Voltage Reduction
- Peak demand management and DER coordination
- Microgrids and EV support
- Enhanced situational awareness

- Predictive analytics

ADMS relies heavily on accurate GIS data for network modelling. Without up-to-date asset and consumer information, ADMS functions cannot operate effectively.

Recommended architecture for Indian DISCOMs: ADMS should be implemented as an integrated operational platform over a common distribution network model, using SCADA/RT-DAS, GIS, AMI/MDMS and OMS as core data sources and secure interfaces to EAM/WFM, CIS/CRM, DERMS and enterprise systems. Existing legacy systems should be integrated progressively rather than replaced indiscriminately.

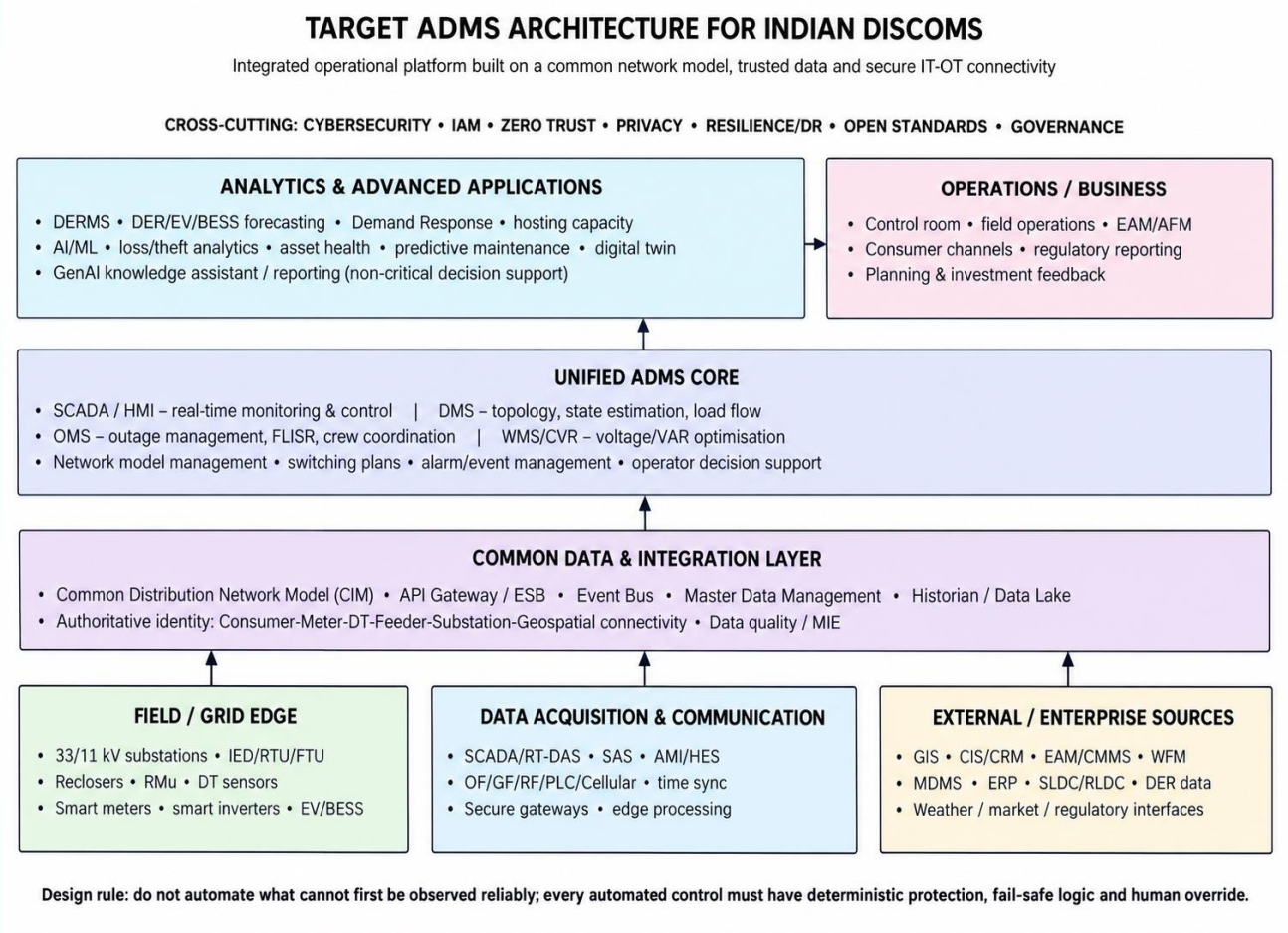


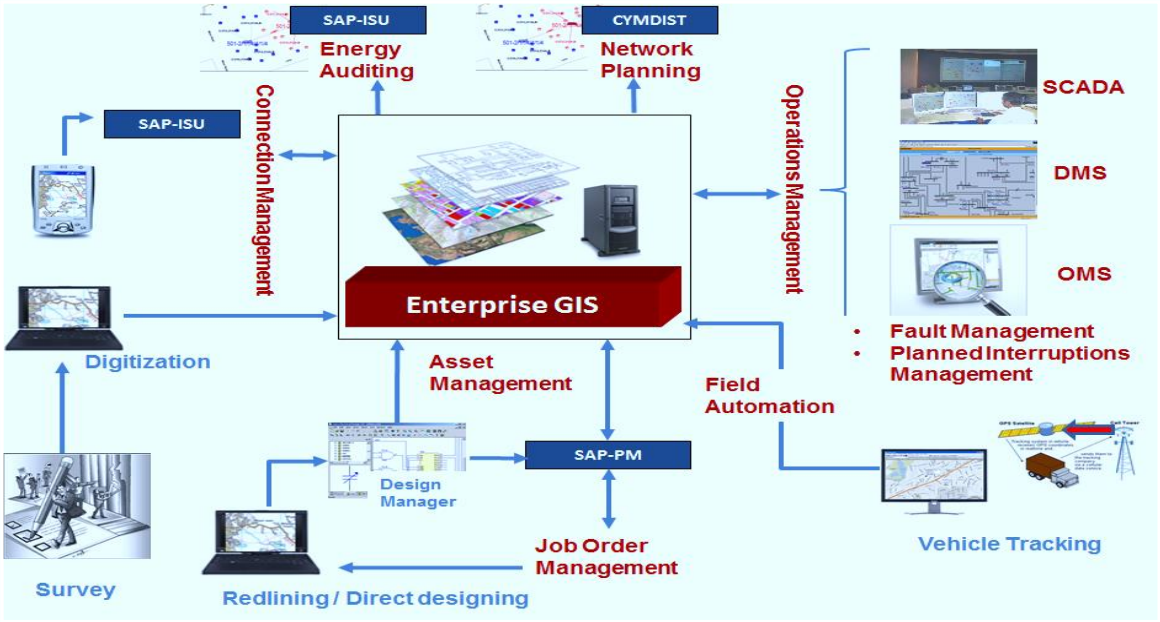
Figure 3A. Recommended target ADMS architecture for Indian DISCOMs.

The architecture separates deterministic real-time control from analytics and AI. Protection and safety functions remain deterministic; AI/ML and GenAI are initially decision-support tools. Any future autonomous function should operate within validated safety envelopes, with human override, fail-safe modes and auditability. The Detailed Architecture of ADMS is given at 7.2.

3.5 GEOGRAPHICAL INFORMATION SYSTEM (GIS)

GIS provides a spatially accurate digital representation of all utility assets, networks, and consumer locations. It is a foundational component that links technical, commercial, and operational data. This is the optimal platform and foundation technology for utilities which contains the complete information as mentioned below:

- Geo coordinates-controlled Asset record management.
- Network topology for operation service management.
- Consumer's location and indexing with network and asset for service delivery.
- Field Crew movement and tracking for ease of services to the customers.
- Geo-fencing of consumers for both commercial & maintenance operations, alongside vigilance activities
- Commercial operations and O&M staff tagged to the assets and consumers with each geo-location



Applications of GIS

- **Operation Management:** Supports DMS/OMS for switching decisions and outage localization.
- **Asset Management:** Enables integrated asset lifecycle management via GIS-SAP integration.
- **Commercial Operations:** Verifies due payments, technical feasibility, and mapping of new connections.
- **Energy Auditing:** Facilitates feeder/DT consumer indexing and loss analysis.
- **Network Planning:** Helps optimize investments and assess capacity requirements.
- **Field Crew Management:** Supports vehicle tracking and optimal routing.

Generally, GIS is required for regular data updation as per changes in the actual field conditions but sometimes GIS loses its shine due to lack of timely data updation in GIS. With lack of latest data, the integration of GIS with other business systems gets impacted and the overall objective of GIS gets completely derailed. The use of GIS can help various other processes which include SCADA, Distribution Management System, Outage Management System, Network Planning, Energy Auditing, Field Force Automation, Asset Management, Customer Relationship Management and other associated processes.

3.6 OUTAGE MANAGEMENT SYSTEM (OMS)

OMS predicts, analyses, and manages outages by integrating data from GIS, CIS, SCADA, and AMI. It identifies affected consumers, pinpoints fault locations, and assigns crews.

Key Benefits:

- Real-time outage prediction and updates
- Better customer communication
- Reduced restoration time
- Improved regulatory compliance
- Optimized crew dispatch and resource use
- Historical data for reliability planning

OMS is essential for utilities aiming to improve service quality and meet regulatory reliability targets.

3.7 CUSTOMER RELATIONSHIP MANAGEMENT (CRM)

CRM systems improve customer interaction and facilitate service requests. They integrate with metering, billing, OMS, and technical systems to provide a unified customer experience.

Key Benefits:

- Higher productivity in call centres
- Faster resolution of billing and supply complaints
- Unified handling of operational and commercial complaints
- Reduced Average Talk Time (ATT)
- Improved customer satisfaction

CRM serves as the customer engagement layer of smart distribution system.

3.8 AUTOMATED DEMAND RESPONSE (ADR)

Demand Response is a vital component of modern grid flexibility. It enables temporary reduction or shifting of customer load in response to grid conditions, price signals, or DR events automatically initiated by the utility.

Typical DR Setup

- Utility generates DR signals based on system conditions.
- Customer devices or automation hubs receive signals and adjust loads.
- Measurement and verification systems confirm participation.

DR helps avoid new peaking capacity, reduce operational costs, and support grid stability while enabling consumers to lower electricity bills.

3.9 ENTERPRISE RESOURCE PLANNING (ERP)

ERP systems integrate financial, operational, commercial, and maintenance processes across the utility.

Key Benefits

- Improved billing and collections
- Enhanced energy accounting
- Faster adaptation to tariff changes
- Effective cash flow management
- Condition-based maintenance integration
- Improved materials and inventory management
- Real-time dashboards for decision-making

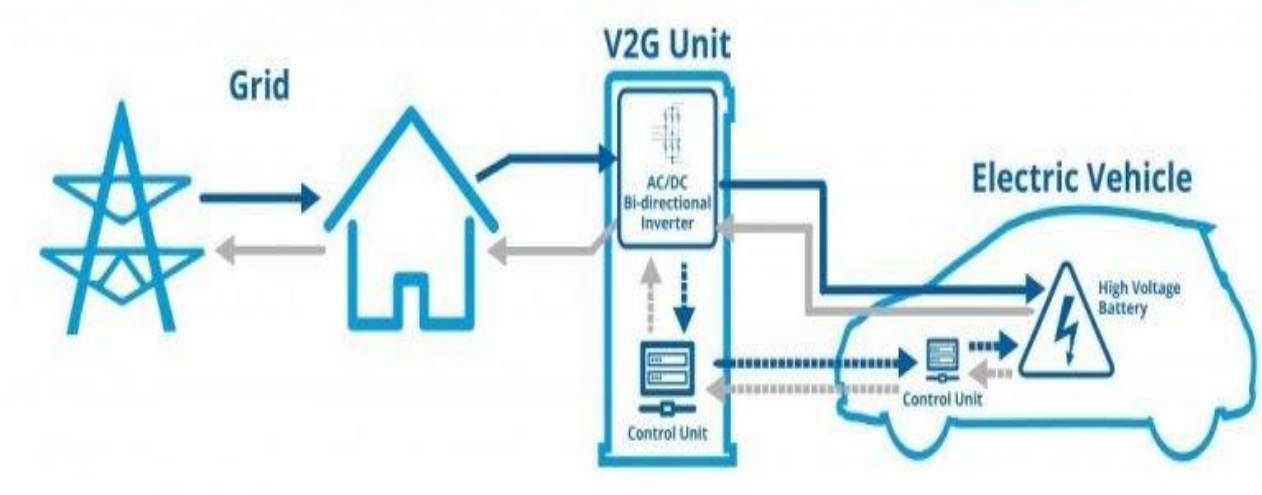
ERP supports end-to-end operational efficiency and governance in distribution utilities.

3.10 EV-TO-GRID INTEGRATION (V2G)

EV batteries can act as distributed storage resources. Smart meters and communication infrastructure enable controlled charging and potential discharging back to the grid.

Challenges and Considerations

- Technical limitations in current grid infrastructure
- Limited experience in managing reverse flows from EVs
- Energy losses during charge/discharge cycles (10–15%)
- Need for advanced algorithms and real-time grid visibility



Although, it is still early in adoption, V2G is expected to play a significant role in future grid balancing.

3.11 SMART INVERTERS

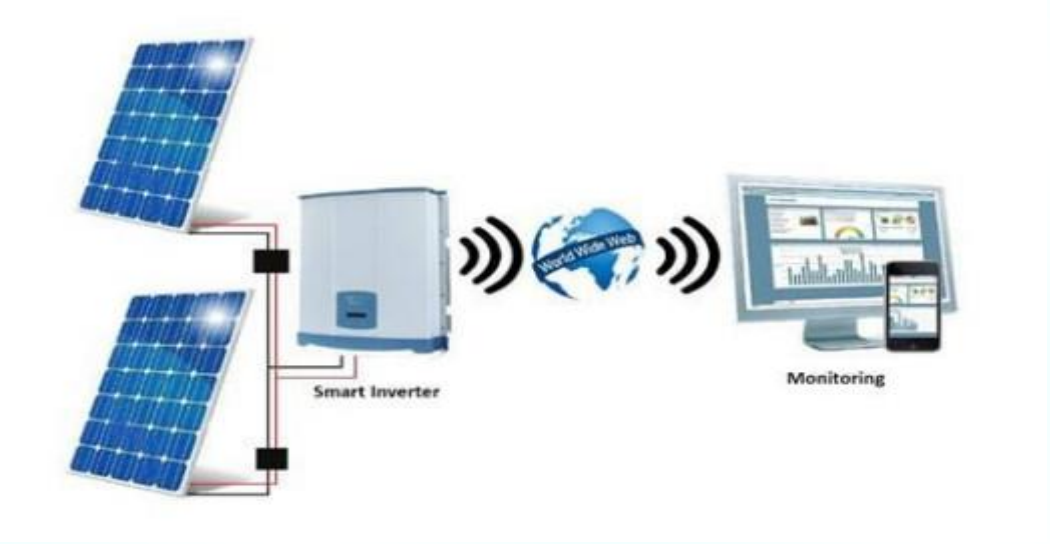
Smart inverters enhance DER integration by providing grid support functionalities beyond simple DC-AC conversion.

Key Capabilities

- Voltage regulation
- Frequency support
- Ride-through capability during disturbances
- Two-way communication with utility systems
- Autonomous grid support actions

Smart inverters help mitigate voltage fluctuations caused by high solar penetration and increase overall system resilience.

Bureau of Indian Standards (BIS) has adopted IEEE 1547-2018 as an Indian Standard, designated as IS 18968:2025. This standard sets out the technical requirements for the interconnection and interoperability of distributed energy resources (DERs), including smart inverters, with the electric grid. These standards have to be adopted in India , as per Rules & regulations, to facilitate remotely manageable inverters from the Utility control center.



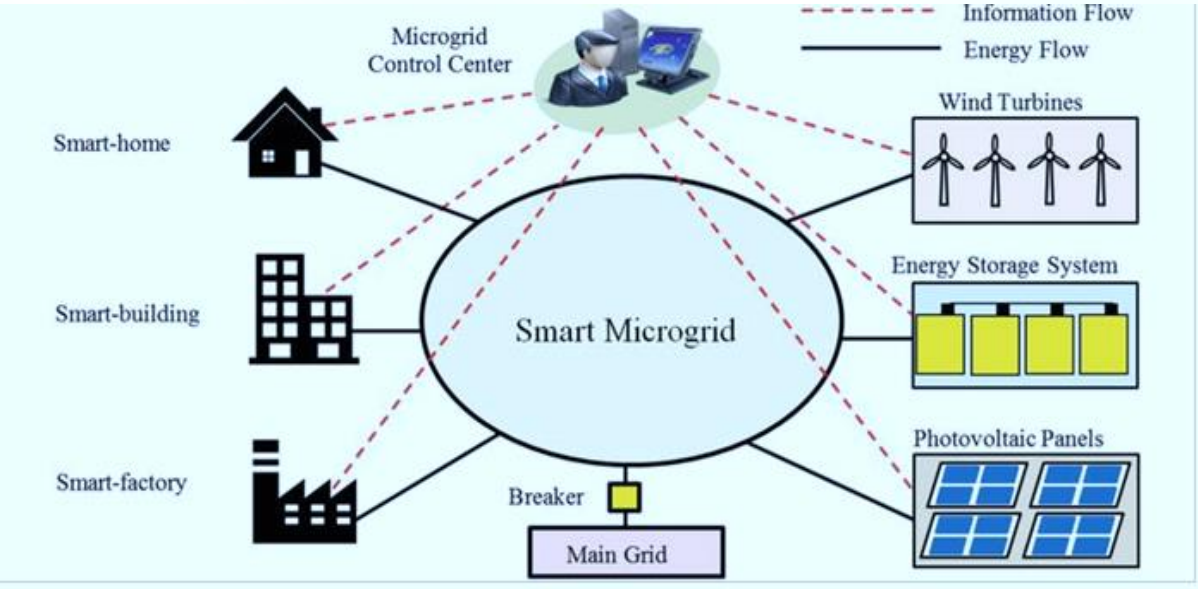
3.12 SMART MICRO GRIDS

Smart microgrids consist of localized generation, storage, and controllable loads capable of operating in both grid-connected and islanded modes.

Key Benefits:

- Enhanced reliability for critical facilities
- Support during emergencies and natural disasters
- Reduced transmission losses due to local generation
- High penetration of renewable energy
- Improved energy independence and security
- Localized carbon emission reduction

Smart microgrids apply automation, protection, forecasting, and DER management to achieve optimal operation. Smart Micro grid leverages the various functionalities of smart automation system to take the decision for providing the green, optimal, reliable and quality power in the area of operation.



Smart microgrids can island from the main grid when required and reconnect. During islanded operations, the smart microgrids will switch-off interruptible loads and service the most critical loads for longer durations.

3.13 HOME AUTOMATION AND SMART HOMES

Home automation systems connect electrical devices, appliances, and security systems through IoT-enabled controllers.

Key Functions:

- Remote monitoring and control
- Energy management
- Automated lighting and appliance scheduling
- Security and surveillance integration
- Smart thermostats and environmental control
- Voice assistant integration

Key Benefits:

- Energy savings
- Enhanced safety
- Convenience and remote access
- Better control and user experience

3.14 HEALTH MONITORING OF DISTRIBUTION TRANSFORMER

Monitoring distribution transformer health is critical for LV network visibility and reliability.

Key Benefits

- Early detection of overloads and failure risks
- Real-time monitoring of voltage, current, harmonics
- Reduced outage durations
- Better planning for transformer augmentation
- Improved asset management
- Enhanced energy audit accuracy
- Identification of high-loss or theft-prone areas

Distribution Transformer Monitoring Unit(DTMU) helps utilities optimize the loading of the transformers and minimize transformer failures to improve the reliability of the system.

3.15 ENERGY STORAGE SYSTEMS (ESS)

Energy storage is essential for integrating large volumes of intermittent RE. ESS technologies, particularly Battery Energy Storage Systems (BESS) and pumped hydro, are becoming indispensable for grid stability.

Applications:

- Renewable integration
- Peak load management
- Microgrids support
- Frequency regulation
- Replacement of diesel generators
- EV ecosystem support

3.16 DATA ANALYTICS USING AI/ML

The advanced ICT like Artificial Intelligence, Machine Learning and Blockchain Technology may be leveraged to analyse data generated through IT/OT devices including System Meters & Smart meters to prepare actionable MIS from system generated energy accounting reports so as to enable the DISCOMs to take informed decisions on loss reduction, demand forecasting, asset management, Time of Day (ToD) tariff, Renewable Energy (RE) Integration and for other predictive analysis. This would contribute a great deal towards enhancing operational efficiency and financial sustainability of the DISCOMs. With the installation of smart meters, utilities will be able to efficiently manage their cash flows thereby leading to feasible reduction in AT&C loss levels. Data analysis of smart metering system will also help utilities to improving their load forecasting, which will help them in optimizing their power procurement thereby reducing the cost of power supply.

4 EMERGING SMART TECHNOLOGIES

The evolution of smart distribution is entering a new phase, driven by the integration of advanced and emerging digital technologies. Beyond the foundational systems already deployed under various schemes, utilities are now exploring cutting-edge solutions such as Artificial Intelligence (AI), Machine Learning (ML), Virtual Reality (VR), Augmented Reality (AR), Robotics and Automation, and Digital Twins. These technologies extend the scope of digitalization by enabling predictive analytics, immersive visualization, automated operations, and real-time simulation of grid behaviour. Emerging technologies are not only reshaping operational practices but also redefining the strategic capabilities of distribution utilities. They allow Discoms to move from reactive management to proactive and predictive decision-making, enhance workforce productivity through automation and immersive training, and strengthen consumer-centric services. By leveraging these innovations, the distribution sector can achieve higher levels of efficiency, resilience, and adaptability, while aligning with national oobjectives of sustainability and energy transition. This chapter introduces the key emerging technologies relevant to smart distribution, outlining their role, potential applications, and anticipated impact. The following sections examine each technology in detail, highlighting how they can complement existing digital infrastructure and accelerate the transformation of India's distribution sector.

Across the world, advanced digital solutions are steadily becoming embedded in distribution networks, moving from pilot projects to mainstream practice. Utilities, regulators, and technology providers are adopting these innovations to tackle persistent challenges such as outage management, loss reduction, workforce training, and renewable integration. The applications are increasingly immersive and operational, ranging from predictive analytics and theft detection to immersive training environments, drone-based inspections, and real-time digital replicas of grid assets. Some of the notable use cases are highlighted in the following matrix, which captures how different stakeholders are deploying these technologies to solve specific problems faced by distribution companies.

Global Use Cases of Emerging Technologies

Technology	Specific Use Case	Implementing Agency (Utility/DSO/Regulator)
Artificial Intelligence (AI)	• Predictive fault detection in distribution transformers	• Enel (Italy)
	• AI-driven outage prediction and restoration planning	• Florida Power & Light (USA)
	• AI-enabled customer service chatbots for billing and outage queries	• State Grid Corporation of China
Machine Learning (ML)	• Load forecasting to optimize procurement and reduce AT&C losses	• Pacific Gas & Electric (USA)
	• ML-based theft detection in smart metering data	• Tata Power Delhi Distribution Ltd. (India)
	• ML algorithms for voltage stability and reactive power optimization	• Iberdrola (Spain)

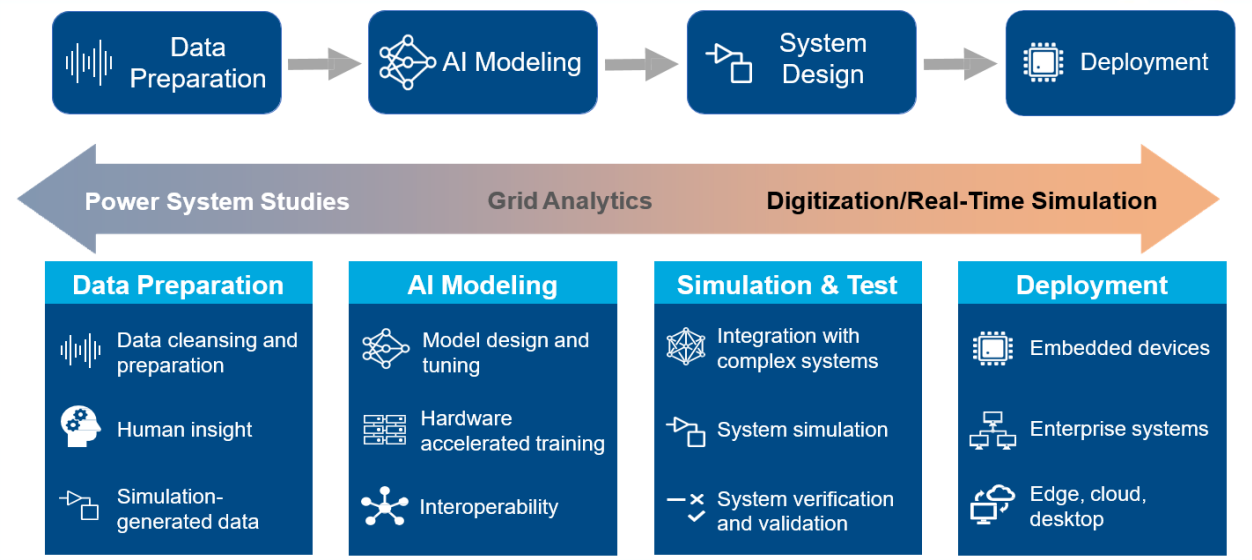
Technology	Specific Use Case	Implementing Agency (Utility/DSO/Regulator)
Virtual Reality (VR)	• Immersive training for field technicians on fault isolation	• EDF Energy (UK)
	• VR-based safety training for substation operations	• National Grid (UK)
Augmented Reality (AR)	• Real-time overlay of asset data during field inspections	• Duke Energy (USA)
	• AR-enabled remote assistance for maintenance crews	• Tokyo Electric Power Company (Japan)
Robotics & Automation	• Drone-based inspection of distribution lines and substations	• TEPCO (Japan)
	• Robotic process automation (RPA) for billing and customer service	• E.ON (Germany)
	• Automated fault detection robots in underground cables	• CLP Power (Hong Kong)
Digital Twins	• Virtual replica of distribution networks for predictive maintenance	• Ørsted (Denmark)
	• Digital twin of smart grid for renewable integration and demand response	• Singapore Power Group (Singapore)
	• Digital twin for outage simulation and restoration planning	• National Grid (UK)

4.1 ARTIFICIAL INTELLIGENCE (AI)

Artificial Intelligence (AI) refers to a constellation of advanced technologies that empower machines particularly computers to replicate human-like cognitive functions. These capabilities include perceiving visual information, interpreting and generating natural language texts (spoken or written), making informed decisions, learning from experience, and adapting to new information. As a transformative force in digital technology, AI is redefining how we interact with data, machines, and one another. At its essence, AI simulates human intelligence in software and hardware systems. It allows computers to not just follow static instructions but to dynamically assess their environment, analyse complex datasets, recognize patterns, and respond with contextually relevant actions. This adaptability - AI's capacity to learn from historical data and refine its performance - is what distinguishes it from traditional rule-based computing systems.

It is a broad field that encompasses many different disciplines, including data science, data analytics and statistics, hardware and software engineering, linguistics, neuroscience, and even philosophy and psychology. On an operational level for business use, AI is a set of technologies based primarily on machine learning and deep learning, used for data analytics, predictions and forecasting, object categorization, natural language processing, recommendations, intelligent data retrieval, and more.

AI Workflow in Power Systems:



The above figure illustrates end-to-end AI workflow for power systems and grid analytics, highlighting how AI technologies are integrated through four key stages: Data Preparation, AI Modelling, Simulation and Test; and Deployment.

1. Data Preparation is the foundational step, involving data cleansing and preparation, human insights, and simulation-generated data. This ensures that the data fed into models is high-quality, relevant, and structured for effective analysis.
2. AI Modelling involves the design and tuning of AI models, often enhanced with hardware-accelerated training for efficiency. Interoperability is also emphasized, allowing AI models to integrate seamlessly with various tools and platforms across the grid ecosystem.
3. Simulation and Test is the next critical phase where AI models are evaluated in complex system environments. This includes system-level simulation and rigorous verification and validation to ensure the models behave as expected under different scenarios, especially in high-risk or real-time grid operations.
4. Deployment marks the final stage where tested AI solutions are implemented into embedded devices, enterprise systems, and across edge, cloud, or desktop infrastructures. This allows for scalable, real-time execution of AI models in live grid environments.

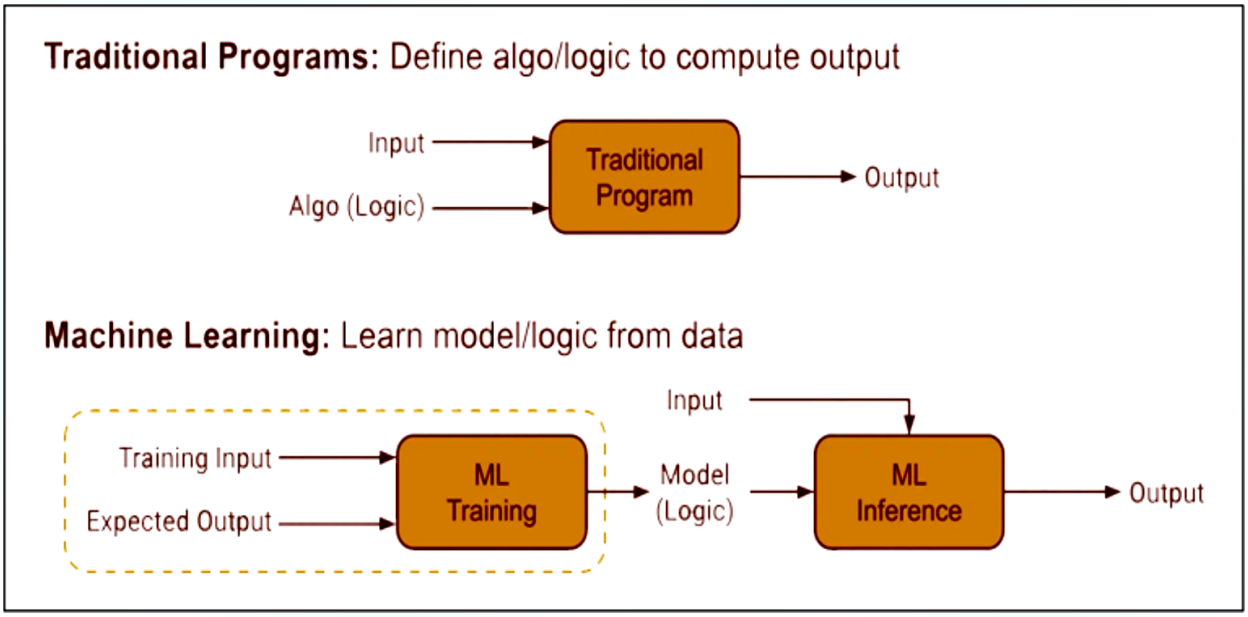
Applications:

- Dynamic Load and Generation Forecasting: AI models process weather data, consumption history, and economic data to accurately predict demand and renewable energy output. This enables grid operators to optimize dispatch, reduce imbalances, and integrate renewables efficiently.
- Real-Time Congestion and Power Flow Management: AI analyses grid conditions to detect and resolve congestion through reconfiguration or demand-side actions, improving grid utilization.

- Self-Healing Grids: Advanced AI-driven Fault Location, Isolation, and Service Restoration (FLISR) systems detect faults, isolate affected segments, and restore service autonomously and rapidly, significantly reducing outage durations.
- Predictive Maintenance with Asset Health Monitoring: AI analyses sensor data (e.g., thermal, acoustic) from transformers, turbines, etc., enabling pre-emptive failure detection and condition-based maintenance. Resulting lower maintenance costs and reduced downtime.
- Intelligent Maintenance Scheduling: AI optimizes maintenance timing by balancing operational impact, costs, and asset health - maximizing uptime and spare parts availability.
- Cyber and Physical Security with Anomaly Detection: AI protects IT/OT systems by continuously monitoring network and operational data to detect cyber intrusions, malware, or insider threats. It also enhances surveillance through computer vision-based threat detection.
- Enhanced Outage Prediction and Resilience: AI identifies potential outages by correlating diverse data (meter readings, weather and asset health) enabling proactive mitigation and improved post-incident management.
- Smart Customer Engagement and DR Integration: AI-powered analytics deliver personalized energy-saving recommendations via smart meters, while chatbots automate customer support. AI also supports real-time demand response through smart-home coordination.
- Renewable Asset Siting and Performance Optimization: AI evaluates geographic, weather, and environmental data to identify ideal wind/solar sites and improve turbine efficiency by adjusting pitch/yaw in real-time enhancing yield and reducing wear and tear.
- Advanced Grid Simulation and Digital Twins: AI-driven grid models and simulations enable scenario analysis, outage planning, and resilience testing - including digital twins that can accelerate design validation and optimize operations.
- Smart Metering and Loss/Fraud Detection: AI algorithms detect anomalies in consumption data, hiding faulty meters or tampering and supporting energy theft prevention.
- Energy Storage Optimization: AI optimizes battery charge/discharge cycles by predicting demand spikes, enhancing system stability and increasing efficiency .
- Security and Resilience Insights: AI-enabled dynamic security assessment tools model system vulnerabilities (e.g., renewable integration, cyber risk), enhancing stability and supporting proactive controls.
- Operational Efficiency in Smart Grids: AI supports grid modernization - such as the deployment of smart meters and grid intelligence - leading to fewer outages, lower operational costs, and enhanced prosumers engagement.

4.2 MACHINE LEARNING (ML)

Machine learning is a branch of artificial intelligence that enables algorithms to uncover hidden patterns within datasets. It allows them to predict new, similar data without explicit programming for each task. Tools like Tableau, Power BI, Python’s Matplotlib / Seaborn, etc. are often used here. In utilities, dashboards might display predictive maintenance alerts, energy consumption forecasts, or outage probability maps.



Machine Learning Process:

- **Step 1: Data Collection** – Gathering Data from Various Sources.
- **Step 2: Data Cleaning and Pre-processing** – Achieving Homogeneity.
- **Step 3: Model Building** – Selecting and Training the Right ML Algorithm.
- **Step 4: Model Evaluation and Insight Generation** – Understanding Results.
- **Step 5: Data Visualization** – Presenting Results through Visual Tools.

Comparison of Machine Learning Categories: Category

Category	Supervised Learning	Unsupervised Learning	Deep Learning	Ensemble Learning
ML Techniques	• Classification • Logistic/Linear Regression • Multivariate Regression	• Clustering • Natural Language Processing (NLP)	• Neural Networks	• Random Forest
Potential Customer Problem	• Classifying product segments • Predicting machine problems to avoid downtime • Identifying linear patterns in machine behaviour	• Identifying similarities or characteristics e.g. if it is shaped like a car, it could be grouped as a car	• Solving complex problems involving multimodal inputs (e.g., smart plant facility)	• Capturing nonlinear and probabilistic relationships between an outcome and its components using Bootstrap Aggregation
Data/Input Format	• Structured imagery, numeric, strings /characters, sensory data	• Unstructured imagery, numeric, strings /characters, sensory data with	• Multiple structured data types e.g. imagery, audio, numeric,	• Structured imagery, numeric, strings /characters, sensory data

	with well identified labels	semi identified labels	strings /characters, sensory etc. from multiple sources	with well identified labels
Applications	• Predictive and prescriptive maintenance • Predictive decision support • Production optimization • Product optimization • Product segmentation • Predictive root cause analysis • Asset management and quality control.	• Pattern processing • Anomaly or defect detection for quality control • Asset performance management	• Complex production optimization • Quality control • Speech and pattern recognition • Complex anomaly detection • Autonomous processing • Asset management	• Powerful and accurate Predictive and prescriptive maintenance • Predictive decision support • Product segmentation • Predictive root cause analysis • Asset performance analysis and quality control.

Applications

- Accurate Load and Renewable Forecasting: ML models effectively predict short, mid and long-term electricity demand and renewable energy output by analysing historical consumption patterns, weather data, and market trends - significantly improving grid stability and resource scheduling.
- Predictive Maintenance and Asset Health: ML identifies subtle signs of asset degradation using sensor data (vibration, heat, sound, etc.) to enable proactive maintenance strategies - reducing equipment downtime and repair costs.
- Fault Detection, Diagnosis and Self-Healing: ML algorithms detect, classify, and localize faults in the grid. They support self-healing capabilities by automating fault isolation and reconfiguration.
- Optimized Demand-Side Management: By learning consumer behaviour from smart meter data, ML enables personalized load control strategies, peak shaving, and dynamic pricing - resulting in energy savings and demand balancing.
- Asset Siting and Performance Optimization: ML analyses environmental and operational data to determine optimal locations for solar/wind farms and enhance turbine performance by dynamically adjusting operational parameters.
- Energy Trading and Market Forecasting: ML enables precise forecasting of market prices, asset availability, and trading volumes, supporting informed energy bidding and risk mitigation strategies.
- Digital Twins and Grid Simulation: ML-enhanced digital twins provide real-time simulation and optimization of grid operations. They help operator’s model load, outages, DER impacts, and resilience scenarios.

- Smart Meter Data Analytics and Theft Detection: ML models detect irregularities in consumption patterns - helping utilities identify meter faults or energy theft, thus improving revenue protection.
- Energy Storage Optimization: ML algorithms optimize battery usage by predicting demand peaks and adjusting charge/discharge cycles, enhancing overall system flexibility.
- Operational Efficiency through Automation: ML automates grid dispatch, outage detection, and load balancing, reducing manual intervention and enhancing operational efficiency.
- Cyber-Physical Security: ML detects cybersecurity threats and abnormal activities in OT/IT environments by analysing traffic and device behaviour in real time.
- Support for Decarbonisation and Sustainability: ML contributes to emission reductions by optimizing renewable integration, improving energy efficiency, and enhancing system flexibility to accommodate clean energy sources.

4.3 VIRTUAL REALITY (VR)

Virtual Reality (VR) is a computer-generated three-dimensional (3D) world that lets people explore and interact in ways that are similar to how they would in real life. It makes the user feel like they are in a different place by stimulating their vision, hearing, and sometimes touch, putting them in a believable, interactive virtual space. Head-Mounted Displays (HMDs), also known as VR headsets, are usually used to do this. They split the visual display between the eyes to create stereoscopic 3D effects, and they also have spatial audio and motion tracking.

Application of VR in Power Sector:

VR's unique ability to create realistic, immersive simulations makes it an exceptionally powerful tool for the complex and high-risk environment of the power sector:

- Immersive Training for High-Risk Tasks: VR enables safe, realistic training in live-line maintenance, power plant operations, substation procedures, and grid control tasks without endangering personnel or disrupting operations
- Accelerated On-boarding and Knowledge Retention: Utilities may achieve faster training and higher retention through immersive VR programs, helping new employees gain hands-on skills more efficiently
- Emergency Response Preparedness: Operators can practice responses to critical events like live-line working, power outages, gas leaks, fires, equipment failure, or natural disasters in a virtual, risk-free environment - building muscle memory and procedural accuracy
- Hazardous Environment Familiarization: Field staff can explore dangerous or remote locations (e.g., offshore wind farms, nuclear facilities) virtually before deployment, improving preparedness and situational awareness
- Design and Engineering Visualization: Engineers and planners can explore 3D models of substations, transmission networks, and plant infrastructure to identify design flaws early, optimize layouts, and improve inter-disciplinary collaboration
- Grid Infrastructure Planning and Siting: VR supports urban planners and utilities in visualizing how new lines or assets integrate into existing environments, helping make informed siting decisions and engage stakeholders

- Virtual Equipment Familiarization: Technicians can interactively explore internal machinery, disassemble/reassemble virtual equipment, and understand fault points - boosting maintenance readiness
- SCADA and Control System Simulation: Operators can interact with virtual control rooms and SCADA panels, practicing system sequences, alarm responses, and load management in a controlled virtual environment
- Remote Supervision and Virtual Inspections: Utility staff can conduct remote inspections and virtual site walkthroughs of substations, control centers, or transmission lines, saving time and reducing travel
- Enhanced Predictive Maintenance Planning: When combined with sensor data and AI, VR visualizations help identify asset degradation and forecast maintenance needs in advance
- Regulatory and Public Engagement: VR-based project walkthroughs help utilities explain plans to regulators and the public, fostering trust and transparency in project development
- Cost Efficiency and Risk Mitigation: Reduces the need for physical training infrastructure, minimizes downtime, lowers accident risks, and enables early error detection - delivering long-term savings

4.4 AUGMENTED REALITY (AR)

Augmented Reality (AR) is an interactive technology that overlays real-world environments in real-time with computer-generated content, such as text, images, 3D models, animations, or sensor data, to improve the physical world. In contrast to Virtual Reality (VR), which substitutes a completely simulated environment for reality, Augmented Reality (AR) incorporates digital elements into the user's real-world surroundings, enabling users to stay grounded while gaining access to richer contextual information. AR works with gadgets that have GPS, accelerometers, cameras, and the ability to map space. These may consist of AR headsets, tablets, smartphones, or smart glasses. The main concept is to make digital content appear anchored to real-world objects or spaces by aligning it with coordinates, which improves situational awareness, perception, and decision-making.

Characteristics and Features of Augmented Reality:

- Real-World Context Awareness: AR systems are designed to perceive and interpret the physical environment using cameras and sensors, enabling digital content to align precisely with the physical world (e.g., attaching a digital label to a machine or showing hidden infrastructure below the ground).
- Interactive User Experience: Users can engage with AR elements through gestures, touch, voice commands, or controllers. For example, tapping on a virtual valve overlay can trigger a simulation of its operation.
- Live Spatial Mapping: AR uses Simultaneous Localization and Mapping (SLAM) algorithms to understand the geometry of the surroundings in real time, allowing digital elements to maintain stable positions even as the user moves.
- Multi-Sensory Integration: Some AR applications incorporate spatial audio, haptics, or gaze tracking to provide immersive and responsive feedback, improving user focus and engagement.

- Persistent Digital Content: AR systems can remember and maintain the location of virtual content across sessions, enabling shared experiences or long-term projects (e.g., persistent notes on a substation cabinet).
- Cross-Platform Compatibility: AR experiences can be deployed across smartphones, tablets, smart glasses, or even vehicle windshields tailored to the use case and mobility requirements.
- Hands-Free Operation: With AR headsets or smart glasses, users can access information without using their hands ideal for field technicians, linemen, and control room operators needing uninterrupted workflow.

Applications of AR in Power Sector:

Field Operations and Maintenance:

- Guided Workflows: Technicians can receive step-by-step visual instructions overlaid on equipment (e.g., transformers, switchgear), ensuring accuracy and faster task completion.
- Live Data Visualization: Real-time parameters like voltage, temperature, and fault codes from SCADA/sensor systems appear directly on physical assets - enabling instant diagnostics.
- Digital Twin Overlay: Historical performance, predicted failures, and 3D schematics from digital twins are layered onto real-world assets, providing a complete operational view.
- Asset Identification and Data Access - Instant Recognition: AR devices can identify equipment and retrieve associated metadata like maintenance history, manuals, serial numbers, and inspection records - eliminating manual searches.

Safety and Compliance:

- Hazard Overlays: AR highlights danger zones (e.g., high-voltage areas), shows lockout/tagout (LOTO) procedures, and provides proactive safety alerts
- Digital Checklists: Inspectors and technicians can access interactive regulatory checklists, ensuring thorough compliance during audits and field checks
- Subsurface Utility Mapping - Augmented Excavation Planning: AR can display 3D maps of underground infrastructure (e.g., cables, water and gas lines), helping crews avoid accidental strikes and improve excavation safety
- Infrastructure Visualization and Grid Planning - Urban Planning Support: Engineers and planners can visualize new substations, transmission lines, or smart grid layouts in real-world settings - supporting accurate siting and stakeholder engagement
- Training and Knowledge Transfer - Immersive Learning: New employees can learn in simulated real environments using AR, improving spatial understanding and retention without exposure to live systems
- Augmented Inspections and Predictive Maintenance - Anomaly Detection: AR enables real-time tagging of equipment issues (e.g., corrosion, leaks, hot spots), with direct updates to asset management systems - enhancing predictive maintenance strategies
- Enhanced Control Room Operations - SCADA and Digital Twin Integration: Operators can visualize system data and alarms projected onto physical control panels, improving situational awareness and decision speed.

4.5 ASSISTED REALITY (AR)

Assisted Reality (aR) is a sub-category of Augmented Reality that focusses on giving users hands-free, heads-up information, usually through a monocular optical display in their peripheral vision. Assisted Reality focusses on presenting important data, documents, checklists, and remote video feeds in a less invasive, "information-at-a-glance" way than more immersive AR systems, which seek to seamlessly blend complex 3D virtual objects directly into the user's immediate physical perception. The fundamental idea is to provide necessary digital assistance while allowing the employee to keep their hands free and retain complete situational awareness of their physical surroundings.

Relevance of aR in Power Sector:

1) Remote Expert Guidance and Troubleshooting:
   - Live “See-What-I-See” Support: Field technicians can stream their viewpoint to remote experts who provide real-time guidance through voice, annotations, or shared documents - minimizing downtime and travel needs
   - On-the-Job Mentorship: Senior personnel can coach junior staff remotely, accelerating knowledge transfer and building workforce capabilities in real time

2) Digital Work Instructions and Task Execution:
   - Hands-Free Procedure Guidance: Technicians can follow SOPs, checklists, and diagrams directly in their line of sight using voice commands - reducing errors and improving procedural compliance during maintenance or repair
   - Real-Time Data Capture: Workers can log progress, report faults, or update digital work orders via voice - streamlining reporting and eliminating manual paperwork

3) Information Access and Asset Reference:
   - On-Demand Data Retrieval: Field workers can access equipment specs, past maintenance records, sensor data, and technical documents instantly - without interrupting their tasks
   - QR/Barcode Integration: Quick scanning enables instant access to asset histories and manuals, improving speed and accuracy during inspections or repairs

4) Safety and Compliance:
   - PPE-Compatible, Rugged Devices: aR headsets are built for industrial use, functioning seamlessly with helmets, gloves, and in high-noise or hazardous environments
   - Proactive Safety Alerts: Real-time safety warnings (e.g., voltage hazards, LOTO steps) and checklists can be displayed during tasks, ensuring compliance and reducing risk

5) Training and Workforce Enablement:
   - Immersive On-the-Job Learning: New hires can follow guided steps in real work settings, gaining hands-on experience without simulation

- Scalable Remote Training: Experts can supervise multiple sites remotely, improving training reach and resource utilization

6) Inspections and Audits:
   - Guided Inspection Workflows: aR devices can display inspection checklists and enable voice-controlled image/video capture - boosting efficiency and accuracy in routine audits
   - Instant Documentation: Observations and compliance notes can be logged hands-free and synced directly with asset management systems

4.6 ROBOTICS AND AUTOMATION

Robotics is an interdisciplinary field of science, engineering, and artificial intelligence that focusses on the development, production, use, and maintenance of programmable machines that can carry out tasks either fully or partially on their own. Simple repetitive motions in industrial settings or intricate operations involving artificial intelligence and machine learning in dynamic real-world settings are examples of these tasks. Computer science (for logic and control), mechanical engineering (for movement and physical structure), electrical and electronic engineering (for sensing and power), and increasingly artificial intelligence (AI) and data analytics (for perception, prediction, and learning) are all combined in robotics.

Relevance of Robotics in Power System:

Robotics is reshaping how utilities and infrastructure providers operate by enhancing safety, efficiency, inspection, and maintenance of energy assets. Its relevance in the power sector includes:

1) Grid Asset Inspection, Monitoring and Asset Mapping:
   - Drones and climbing robots inspect transmission towers, lines, substations without shutting down equipment.
   - IoT-based Thermal and visual imaging allows early detection of hot spots or faults.

2) Substation Monitoring:
   - Mobile robots autonomously patrol substations, monitor conditions, and relay live video and data to control centres.
   - Reduces human exposure to high-voltage environments.

3) Underground Cable Inspection:
   - Wheeled or crawler robots navigate tunnels and conduits for real-time condition monitoring, reducing manual labour and enhancing safety.
   - Use of partial discharge sensors/analysers for underground cable health monitoring.

4) Power Plant Inspection and Maintenance:

- Robots perform tasks like boiler inspection, pipe cleaning, and turbine blade inspection in hazardous environments (e.g., nuclear or thermal plants).
- Use of robotic arms and snake-like robots for confined spaces.
- Disaster Recovery and Emergency Response: Post-earthquake or cyclone, robots can assess damage, restore communication, and detect faults in critical power infrastructure.
- AI-Enabled Predictive Maintenance: Integration of robotics with AI models to predict component failure, enabling condition-based rather than schedule-based maintenance.
- Real Time Data Collection from Electric Meters: Robotics combined with computer vision can automate reading, collection of images and converting them into real time digital data for subsequent analysis and warnings.
- Training and Simulation: Robotic simulators replicate substation or control room environments, helping train staff without exposing them to live equipment.
- Warehousing and Material Handling: Automated guided vehicles (AGVs) move components and spares in utility warehouses, improving logistics and inventory control.
- Material Handling in Construction Sites: Automated technologies such as robotic cranes and Automated Guided Vehicles (AGVs) are used on power plant, substation and transmission line construction sites to transport and put heavy, bulky and often hazardous components such as transformers and generator turbines. This automation eliminates human exposure to high-risk areas, streamlines labour-intensive operations, and provides improved assembly accuracy.
- Military Robots: They provide persistent surveillance, conduct security patrols, and enable rapid damage assessment of grid components following an attack, thereby enhancing grid resilience. Conversely, these energy-intensive robotic platforms are critically dependent on reliable electricity for their operation, driving the development of secure and mobile power solutions such as tactical micro-grids.

4.7 DIGITAL TWINS

The energy grid is the backbone of the modern economy, powering everything from homes and businesses to critical infrastructure. But with the global shift toward renewable energy, grid operators now navigate in uncertain territory. They must juggle the unpredictable nature of renewables, rising energy demands, and aging infrastructure all while ensuring a reliable and sustainable energy supply.

A digital twin is a digital representation of a target entity with data connections that enable convergence between the physical and digital states at an appropriate rate of synchronization. Digital Twin technology can transform the power sector by creating virtual replicas of physical assets, processes, or systems. These virtual models enable real-time monitoring, analysis, and optimization, driving significant improvements in efficiency and performance.

Key Benefits:

- High-Fidelity Asset Modeling: i.e. integrating geospatial data into Digital Twin enhances the accuracy of asset model.
- Advanced Sensor Networks: enables precise anomaly detection and proactive maintenance scheduling, enhancing overall energy management. Moreover, sensors in power transformers or generators provide real-time data on factors such as insulation degradation and temperature fluctuations.
- Integration of AI and Machine Learning: i.e. AI analyzing the historical and real time data from Digital Twins to predict equipment failures. In smart grids, these models re-adjust the distribution of electricity in response to demand changes and grid conditions. Operators also use Digital Twins to test various operational scenarios without affecting real-world operations.
- Revolution in Predictive Maintenance: Digital twins empower energy companies to monitor and analyze every aspect of their infrastructure in real-time. This leads to a shift from reactive to predictive maintenance, where data driven insights predict potential failures before they occur.
- Unparalleled Energy Efficiency: Digital twins facilitate the simulation of various operational scenarios, enabling precise analysis of energy production and consumption patterns. Moreover, this heightened efficiency contributes to lowering carbon emissions, aligning with global sustainability goals.
- Data-Driven Decision Making: These virtual models enable the testing of multiple strategies and configurations in a risk-free environment, allowing companies to refine their approaches before real-world implementation. This results in more effective strategies, reduced operational risks, and enhanced overall performance.
- Accelerated Technological Innovation: Digital twins serve as a powerful platform for experimentation and innovation. Energy companies can rapidly prototype and test new technologies, designs, and materials within the virtual environment, significantly speeding up the development cycle. This ability to innovate swiftly not only reduces time-to-market but also drives the adoption of next-gen technologies to transform the power sector.
- Significant Cost Reductions: The adoption of digital twins translates to substantial cost savings across multiple dimensions. By optimizing asset performance and operational processes, companies can reduce energy consumption, maintenance expenses, and the need for physical prototypes. Additionally, the ability to conduct virtual trials reduces the risks and costs associated with testing new technologies in real-world environments.

5 TECHNOLOGY CONVERGENCE

As the power sector transforms into a digital, decentralized, and intelligent ecosystem, the convergence of multiple advanced technologies is reshaping utility operations. It is no longer the isolated application of technologies that delivers value, but their integration - creating intelligent, responsive, and autonomous cyber-physical systems. Key technologies such as Artificial Intelligence (AI), Machine Learning (ML), Augmented and Virtual Reality (AR/VR), Robotics, Supervisory Control and Data Acquisition (SCADA), Internet of Things (IoT), Digital Twins, Drones, and Blockchain are forming interdependent ecosystems that enhance monitoring, control, analytics, and decision-making across the power value chain.

5.1 ROBOTICS AND INTELLIGENT AUTOMATION

Application - Autonomous Agents

The fusion of AI and robotics empowers autonomous agents to perform critical tasks in harsh or high-risk utility environments such as inspection and monitoring of transmission towers, substations, and thermal and nuclear generation plants. AI provides the intelligence layer - enabling object recognition, navigation, pattern detection, and real-time decision-making - while robotics offers physical mobility and actuation.

- AI-driven perception and control: Robots use AI for computer vision, object detection, and obstacle avoidance.
- Autonomous navigation: Path planning and environmental mapping enable safe movement in dynamic settings.
- Predictive maintenance: AI enables robots to schedule and prioritize inspections based on asset condition data.

5.2 AR AND SCADA

Application - Contextual Data Visualization

Integrating Augmented Reality (AR) with SCADA systems delivers real-time operational intelligence in the field. Through AR headsets or mobile devices, field operators can visualize live SCADA data overlaid on physical assets, such as transformers, breakers, or control panels.

- Live telemetry visualization: Voltage, pressure, and alarm indicators are superimposed on real equipment
- Step-by-step guidance: AR interfaces provide visual instructions tailored to SCADA alarm codes
- Emergency response support: Operators can see fault locations, safe access paths, and component status on site

5.3 ML AND DIGITAL TWIN

Application - Self-Learning Grid

Digital Twins replicate the physical behavior of grid infrastructure, and when powered by ML, they become self-learning systems capable of adapting over time. Real-time and historical data fed ML models embedded in digital twins, which continuously simulate asset behavior and update predictive forecasts.

- Scenario simulation: Predictive analytics help simulate weather events, overloads, and component failure
- Degradation modelling: Digital Twins track and forecast wear and tear based on environmental and operational data
- Decision optimization: Enables data-driven planning and maintenance scheduling

5.4 AI AND IOT

Application - Real-Time Grid Intelligence

The integration of AI with edge IoT devices enables local decision-making and rapid response at the grid edge. IoT sensors collect granular data, and AI models deployed at substations or distribution transformers analyse this data in real time.

- Edge intelligence: Minimizes latency in detecting anomalies and triggering control actions.
- Grid balancing: AI uses local data to dynamically manage voltage, frequency, and loads.
- Consumer responsiveness: Enables real-time pricing and load adjustment in smart homes.

5.5 AR/VR AND DIGITAL TWIN

Application - Interactive Asset Visualization

AR/VR technologies combined with digital twins offer immersive, three-dimensional interfaces for utility staff to interact with complex assets. Operators can visualize internal structures of machinery, simulate operations, or train for rare fault scenarios.

- Immersive training: Trainees experience lifelike simulations of critical incidents.
- Augmented inspection: Field staff can identify issues by visualizing internal parameters
- Retrofit planning: 3D overlays assist in spatial planning and equipment alignment

5.6 GENERATIVE AI AND KNOWLEDGE MANAGEMENT:

Application - Structured Data

Generative AI enhances traditional knowledge management systems by converting unstructured data - manuals, logs, schematics - into dynamic, query able knowledge bases. AI co-pilots and assistants can provide real-time guidance or generate content on demand.

- Content generation: Drafts SOPs, reports, and procedures based on real-time data
- Searchable manuals: Converts PDF repositories into AI-driven query systems
- Training personalization: tailors learning content to individual skill levels and asset types

5.7 AI AND SCADA

Application - Predictive and Autonomous Operation

AI-augmented SCADA systems move beyond real-time monitoring to predictive and autonomous control. AI models identify early signs of anomalies and initiate corrective actions without operator intervention.

- Early fault detection: Identifies subtle variations in load or frequency
- Self-healing grid: AI triggers automated grid reconfiguration to isolate faults
- Load forecasting: Enhances capacity planning and congestion management

5.8 AI AND BLOCKCHAIN

Application - Decentralized Grid Transactions

The combination of AI and Blockchain supports transparent and secure energy markets, especially in decentralized generation and microgrids. Blockchain ensures data integrity, while AI optimizes trading, pricing, and forecasting.

- Peer-to-peer (P2P) transactions: Automated through smart contracts
- Anomaly detection: AI flags suspicious trading patterns
- Dynamic pricing: Adjusts based on demand-supply trends and forecasts

5.9 DRONE AND AI

Application - Aerial Intelligence

Drones equipped with high-resolution cameras and AI analytics are revolutionizing infrastructure inspections. Aerial imagery is analysed in real time for structural defects, thermal anomalies, and vegetation encroachment.

- Remote inspections: Reduces human risk and operational downtime
- AI-based analysis: Identifies and prioritizes maintenance actions
- Scalability: Enables rapid inspection of widespread assets

5.10 USE CASES OF EMERGING TECHNOLOGIES ACROSS THE INDIAN DISTRIBUTION SECTOR

Technology	Case / Application	Implementing Agency	Impact Created
AI / ML	• Smart meter data analytics to detect theft and reduce commercial losses	BSPHCL with Bidgely (India)	• Flagged 136 theft cases in one month; 57% confirmed. • moving toward AI-based demand forecasting and energy accounting; tackling high AT&C losses
	• Appliance-level consumption analysis, theft detection, transformer loss monitoring, and localized demand prediction	Tata Power (Mumbai & Delhi, India)	• Real-time loss monitoring. • Optimized network design. • Personalized consumer insights via mobile app. • improved billing efficiency
	• Fault prediction on HT cables, transformer health indexing, AI-powered multilingual voicebot “Aastha” for CRM/OMS	CESC Kolkata (India)	• Reduced outage response times. • Improved customer service. • enhanced grid reliability and billing accuracy
Robotics / Automation	• Drone-based grid inspection and predictive fault analytics	MSEDCL, ISGF	• Identified 52 faults (urban feeder) and 101 faults (rural feeder). • Cost Benefit Ratio of 4.5. • Validated predictive maintenance approach. • improved grid reliability and cost-efficiency

6 UNIFIED FRAMEWORK FOR DIGITIZATION

The core objectives for Unified framework for Digitization of Distribution Sector framework are:

- **Enabling Integration of DERs:** Accommodate high penetration of renewable energy, EVs, and energy storage systems while supporting decarbonization goals.
- **Empowering Customers:** Provide customers with tools to manage their consumption, access dynamic pricing, and participate in demand response.
- **Improve Reliability and Power Quality:** Improve SAIDI/SAIFI indices, reduce outage frequency and duration, and enhance voltage stability.
- **Strengthen Network:** Modernize assets, reduce AT&C losses to below 10%, and enable accurate energy accounting.
- **Building Resilience and Cybersecurity:** Protect grid data, communication networks, and customer information against cyber threats. (this to be re-looked)

6.1 KEY FOCUS AREAS OF UNIFIED FRAMEWORK:

To address the structural and operational challenges facing the distribution sector, a unified digital framework must focus on a set of critical pillars. These pillars capture the critical dimensions that determine the success of digital transformation in the distribution sector-ensuring that technology adoption is supported by appropriate governance, data capabilities, cybersecurity, standards, workforce readiness, and organizational change.

Implementation principle: The Unified Framework for Digitization should be treated as a utility transformation framework, not as a technology procurement catalogue. Each DISCOM should first establish its current digital maturity and business pain points, then sequence investments according to dependencies. The recommended progression is: visibility → data quality → integration → controllability → automation → optimization → selective autonomy.

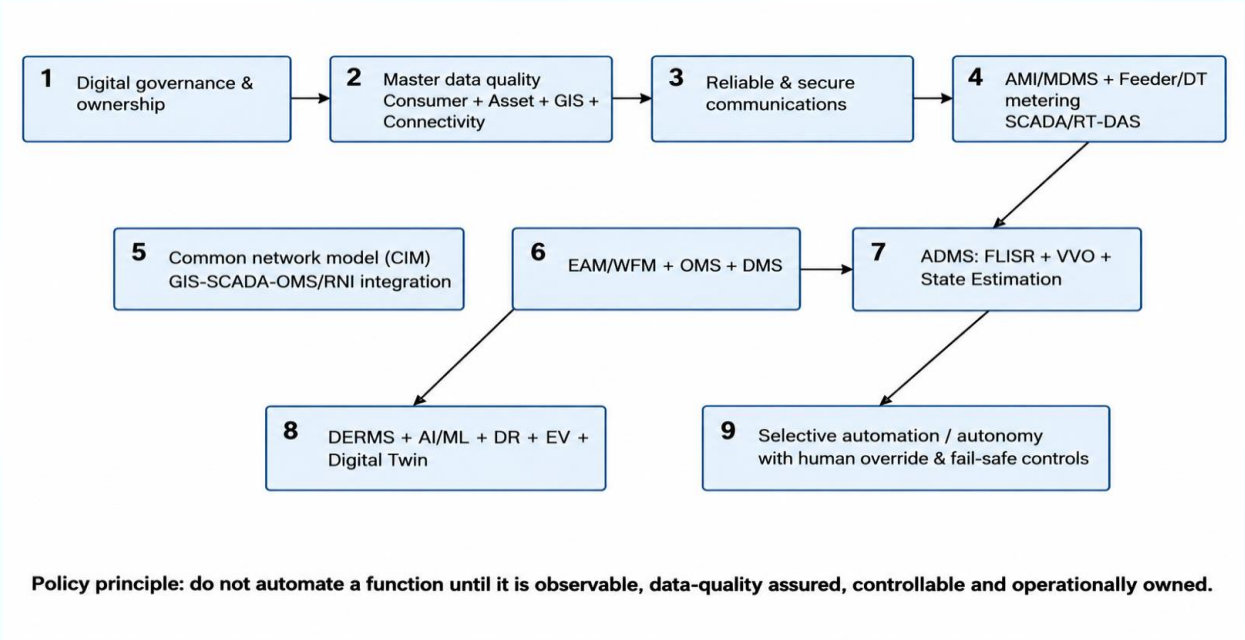
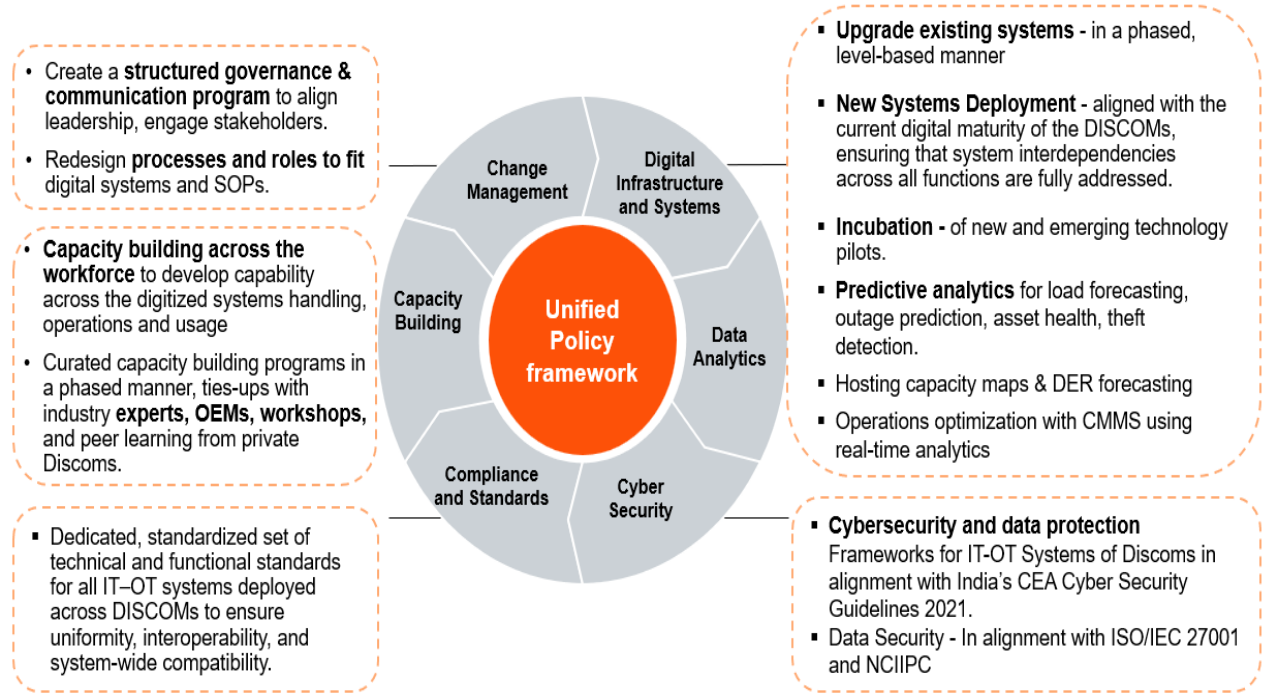


Figure 6A. Digital dependency chain—foundations before automation.

Key Focus Areas



Digital Infrastructure and Systems with Data Analytics

The digital infrastructure and data analytics are best viewed as two inseparable components of a single operational continuum. Core systems such as AMI, SCADA, GIS, OMS, ADMS, DERMS, enterprise applications, and field systems provide the foundational digital capability and real-time visibility across the network. Data analytics builds on this foundation to convert operational data into actionable insights that support planning, operations, and commercial decision-making.

The framework therefore treats infrastructure deployment and analytics capability as a linked progression, encouraging DISCOMs to upgrade existing systems in a phased, level-based manner while introducing new systems aligned to current digital maturity and functional interdependencies.

It also recognizes the role of controlled incubation of emerging technologies and pilots. Analytics use cases-such as load and DER forecasting, outage prediction, asset health assessment, theft detection, hosting-capacity mapping, and real-time operations optimization through CMMS - derive value only when they are embedded into live operational workflows.

Change Management

Change management provides the organizational glue that connects technology, people, and processes. As DISCOMs transition from manual or semi-digital workflows to increasingly integrated digital operations, structured change management helps align leadership, engage stakeholders, and redesign processes and roles to fit new systems and SOPs. Within the framework, change management is framed as a continuous activity - covering communication, role clarity, process alignment, and feedback mechanisms - rather than a project-specific exercise.

Capacity Building

Capacity building is recognized as a critical enabler of sustained digital adoption. The framework emphasizes that the effectiveness of digital systems ultimately depends on the ability of the workforce to operate, interpret, and act on digital tools and insights.

Accordingly, this pillar highlights the need for structured and phased capability development across the systems. It encourages the use of curated training programs aligned with system rollouts, partnerships with OEMs and industry experts, hands-on workshops, and peer learning from more digitally mature utilities.

Compliance and Standards

Compliance and Standards provided as a reference guide to support consistency and interoperability. Given the diversity of digital systems deployed across DISCOMs through multiple initiatives and vendors, the intent of this pillar is to provide common points of alignment for technical and functional standards that utilities may choose to adopt while planning new systems or integrating existing ones.

Cyber Security

The unified framework encourages DISCOMs to adopt cyber risk management, aligned with prevailing national guidance and good practices. This includes attention to secure system design, protection of operational data, governance of access and identities, incident preparedness, and ongoing monitoring across IT-OT environments.

In practical terms, the Unified Framework creates the readiness layer for Digital adoption in the sector including for initiatives like IES by standardizing master data, integrating IT-OT systems, enabling real-time data availability, and embedding analytics and automation into core utility workflows. This farmwork shall formulate a coherent pathway from foundational digitization to ecosystem-level transformation, enabling innovation, efficiency, and value creation across the energy value chain.

Digital procurement and lifecycle management: RFPs should specify open APIs, data ownership, interoperability, cybersecurity, measurable performance SLAs, FAT/SAT requirements, data portability, documentation/configuration obligations and an exit/transition strategy. Evaluation should consider total cost of ownership—including communications, licenses, integration, cyber controls, training, upgrades and recurring O&M—not only initial CAPEX.

Communication as a utility service: requirements should be application-specific. AMI, SCADA/RT-DAS, field automation and DER telemetry should have defined availability, latency, data-success, redundancy, time-synchronisation, monitoring and restoration SLAs.

Cybersecurity and resilience: IT-OT segmentation, identity and access management, secure remote access, asset inventory, patch/vulnerability management, logging/SIEM, backup/disaster recovery, incident response and supply-chain security should be designed into the architecture and contracts from the outset.

7 IMPLEMENTATION ROADMAP

This chapter presents a proposed implementation roadmap to guide DISCOMs in translating the unified digital framework into actionable initiatives over time. Recognizing the diversity in starting conditions, digital maturity, and institutional capacity across utilities, the roadmap is intended as a flexible reference structure rather than a uniform prescription. While the overarching principles remain consistent, the pace, sequencing, and emphasis of implementation are expected to vary across different focus areas - such as digital infrastructure, data, capacity building, and change management - based on local priorities, dependencies, and readiness. The roadmap therefore provides an indicative pathway to support phased, context-sensitive adoption of digital capabilities.

Recommended pre-implementation gate: Before a DISCOM undertakes a major digitalisation , it should complete a DISCOM Digital Readiness Assessment (DDRA) covering data, network model, metering, OT visibility, communications, integration, cybersecurity, people/processes and financial/procurement readiness as under:

DDRA Dimension	Indicative Assessment Checks
Consumer & meter data	Consumer master accuracy; meter mapping; tariff/category; active/inactive accounts,
Network & GIS	Asset completeness; feeder/DT/LV connectivity; phase mapping; normally-open points; geospatial accuracy
AMI / metering	Consumer, feeder and DT coverage; HES/MDMS; VEE; communication performance
SCADA / RT-DAS	Telemetry coverage; data quality; remote control; time synchronization; sequence of events (SOE)/event capture
Integration	GIS–SCADA–OMS–AMI–ERP (Asset/ Workforce Management) interfaces; API/CIM readiness; master data ownership
Cybersecurity	Asset inventory; segmentation; SOC/SIEM; backup/DR; incident response
People & process	Control-room capability; field digital skills; SOPs; change champions; training
Financial / procurement	Business case; recurring OPEX; SLAs; vendor lock-in; exit strategy
Benefits & KPIs	Reliability, losses, restoration, consumer service and asset-performance baselines

7.1 ROADMAP FOR DIGITAL INFRASTRUCTURE AND DATA ANALYTICS

The implementation roadmap adopts a function-wise, maturity-aligned approach that enables DISCOMs to progress systematically toward digital transformation. Recognizing that utilities operate with varying degrees of technological readiness, the approach focuses on mapping core operational functions to clearly defined maturity levels (L0–L3) and identifying the digital systems, processes, and capabilities required at each stage. This allows DISCOMs to first establish foundational systems, then integrate IT–OT platforms,

and ultimately scale toward intelligent and autonomous operations. Further, to establish the baseline maturity level of Discoms, an as-is assessment may be carried out.

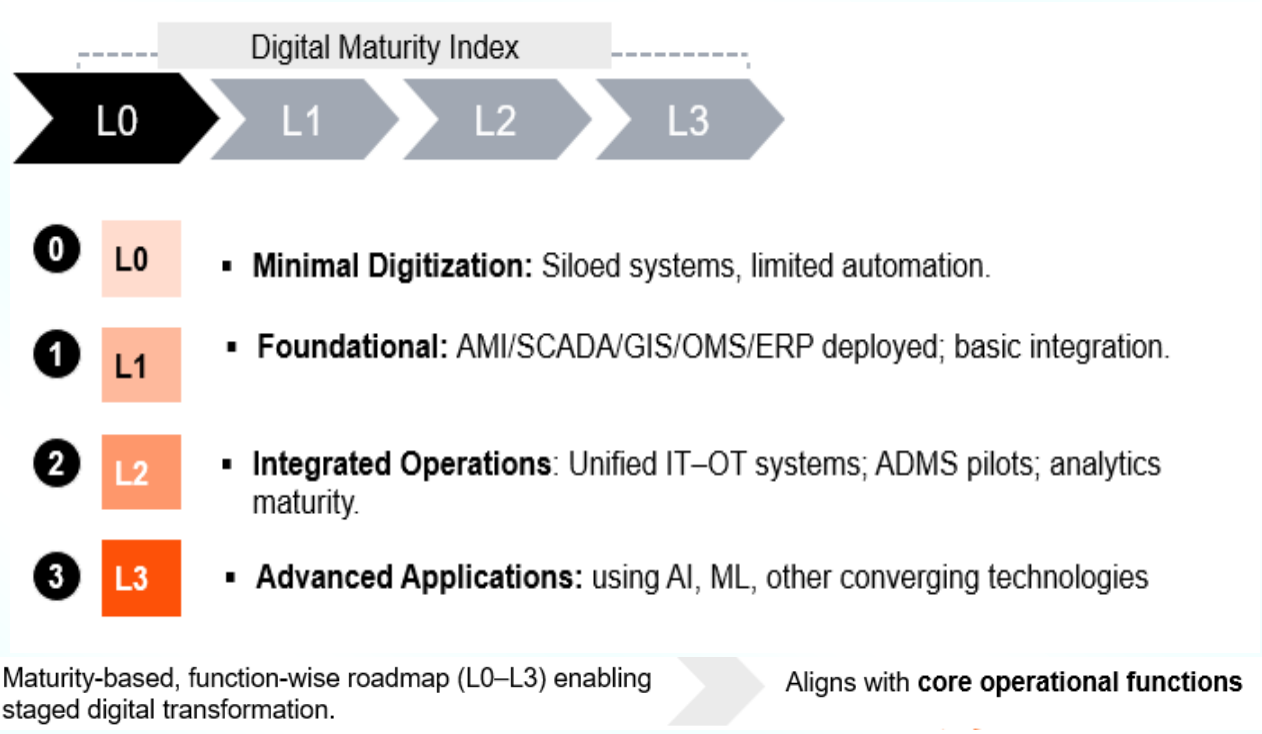
Proposed Approach

Recommended five-year+ implementation sequence: the roadmap for each discom should be dependency-driven rather than a uniform technology rollout. Individual DISCOMs may advance faster or slower based on requirement/ readiness assessment, however, advanced functions should be scaled only with the availability of necessary data, communications, network-model, operational and cybersecurity prerequisites.

Period	Phase	Priority implementation	Advanced / pilot
2026–29	Foundation	DDRA; master data/GIS; connectivity; AMI/HES/MDMS as applicable; feeder/DT metering; SCADA/RT-DAS where required; cyber/governance baseline/ capacity building	AI analytics and critical-asset pilots
2029–32	Integrated operation	GIS–AMI–SCADA–OMS–ERP – CRM; common network model/CIM; API/event bus; mobile workforce; DMS/ADMS pilots	FLISR; DER forecasting; digital-twin pilots
2032–35	Intelligence & Automation	ADMS scale-up; state estimation; FLISR; Volt Var Optimization (VVO); asset analytics; operational AI; DERMS/DR/EV charging	AI-assisted restoration; flexibility
2035+	Selective Advanced	Digital twins by use case; advanced DER orchestration; mature flexibility services; autonomy only within validated safety envelopes	Agentic AI / autonomous control pilots
2026–29	Foundation	DDRA; master data/GIS; connectivity; AMI/HES/MDMS as applicable; feeder/DT metering; SCADA/RT-DAS where required; cyber/governance baseline/ capacity building	AI analytics and critical-asset pilots

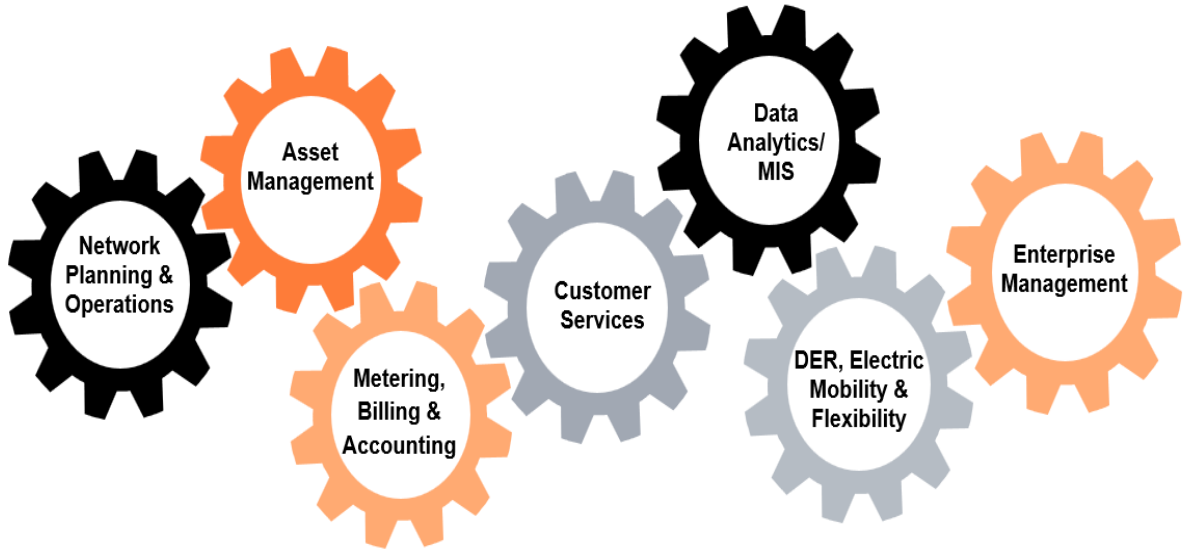
Maturity Based Indexing

Maturity Index:



Level	Description
▪ ***Level 0 – Minimal Digitization***	▪ Limited digital systems; basic metering; scattered automation; no integrated IT/OT capabilities.
▪ ***Level 1 – Foundational Systems***	▪ Core digital systems deployed in major urban areas; initial AMI, SCADA, DMS, GIS, ERP, and OMS present; emerging analytics; early consumer-facing digital tools.
▪ ***Level 2 – Integrated Operations***	▪ Enterprise-wide system integration across IT/OT; full AMI coverage; ADMS implementation; digital twins for major assets; established analytics capability; structured field automation.
▪ ***Level 3 – Advanced Intelligence and Autonomous Operations***	▪ Fully orchestrated grid operations; digital twin of the entire network; AI-enabled grid optimization; large-scale robotics/drones; advanced consumer and prosumer services; autonomous grid functions.

Core Functions



1) Network Planning and Management

Network planning involves network planning studies (substations, feeders, distribution transformers, LV networks) expansion and modernization to meet load growth, integration of distributed energy resources (DER).
Primary enabling systems: GIS for asset base mapping, Load flow and planning tools

Network Management involves maintaining safe, reliability, and efficient operation (Monitoring, switching, fault location, isolation and service restoration, power quality management (voltage/VAR), congestion management, load transfer) of the distribution grid in real time.
Primary enabling systems: SCADA, DMS/ADMS for automation functions (FLISR, VVO/CVR), OMS, integration with GIS for network topology to advanced ADMS.

2) Asset Management

Optimize reliability, safety, and lifecycle cost of network and enterprise assets by condition monitoring, risk-based maintenance planning, work order management, spares and inventory control, inspections and compliance.
Primary enabling systems: EAM/CMMS integrated with GIS and OMS/DMS; workforce management; condition-based maintenance; drone/robotic inspection; digital twins.

3) Metering, Billing, and Accounting

Accurate measurement, billing, reconciliation of energy flows, and revenue protection across all customer categories.
Primary enabling systems: AMI with HES/MDMS; CIS/CRM; integration with GIS for service mapping; analytics for theft/revenue leakage; pre-paid/post-paid configurations.

4) **Customer Services and Market Interfaces**

Deliver responsive, transparent, and inclusive customer services and enable prosumer participation. New connections and service alterations, complaint handling, planned outage communications, customer education, prosumer onboarding, demand response enrolment.
Primary enabling systems: CRM/CMS, omni-channel portals and mobile applications, integration with OMS for real-time status, analytics for segmentation and demand response programs.

5) **Distributed Energy Resources, Electric Mobility, and Flexibility**

Managing bi-directional flows led by DERs (solar rooftop, storage, small wind), integrate EV charging, and enable flexibility services. It involves - hosting capacity assessment, curtailment planning, and demand response dispatch.
Primary enabling systems: DERMS linked with ADMS; forecasting tools; Settlement systems in MDMS/CIS, Smart EV charging infrastructure for dynamic load & grid congestion management.

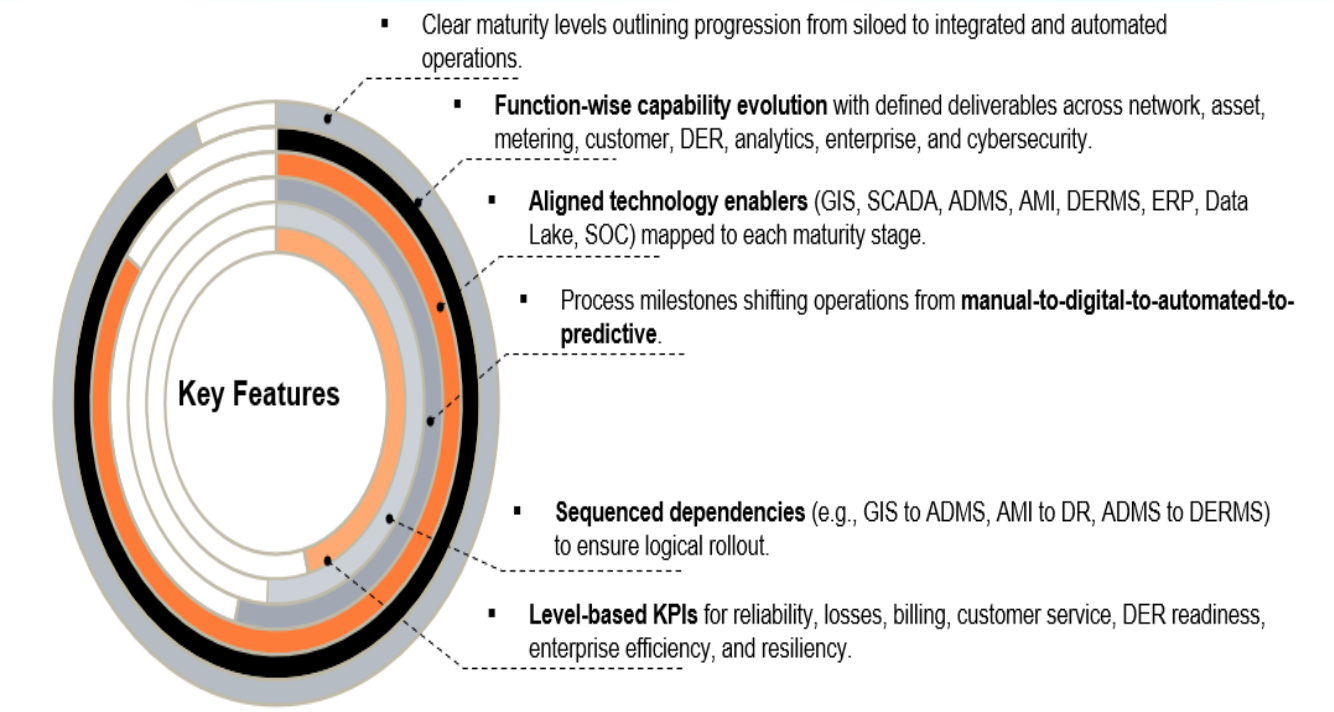
6) **Data Management, Analytics, Cybersecurity**

All technical, commercial, and customer-facing operations are supported by secure, high-quality, and well-governed data flows. It integrates enterprise data management, system interoperability, analytics, and cybersecurity into a single cohesive domain. It covers data acquisition from IT and OT systems, governance of shared datasets, analytical insight generation, and the protection of digital infrastructure to ensure continuity, compliance, and resilience.
Primary enabling systems: Data Lake/warehouse, ESB/API, BI, BI and AI/ML platforms for analytics and operational insights, MLOps for model lifecycle management, Master Data Governance systems, SOC/SIEM for threat monitoring, Identity and Access Management (IAM).

7) **Enterprise Management (Finance, Procurement, HR, Compliance)**

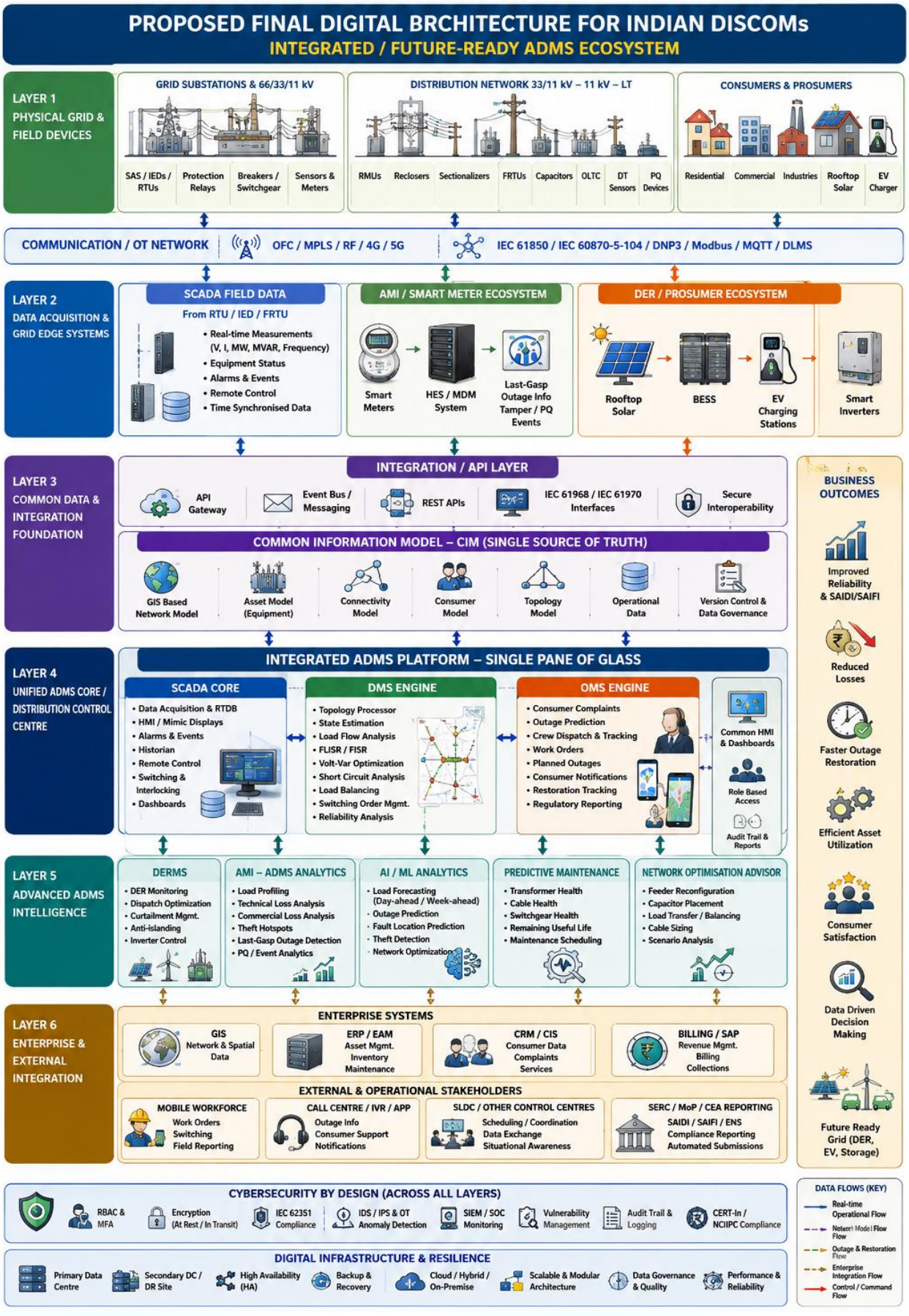
Provide financial discipline, efficient procurement, workforce capability development, and compliance with regulatory obligations. Its key processes include – Budgeting, cost control, procurement, vendor management.
Primary enabling systems: ERP (finance, HR, procurement), contract and document management.

Key Features



However, it may be noted that the Digitalization shall complement, but not a substitute of physical network strengthening where network constraints cannot be addressed through operational optimization. Digital investments shall be prioritized together with distribution network augmentation, protection improvement, sectionalization, power-quality improvement and reliability enhancement.

7.2 PROPOSED ADMS ARCHITECTURE



7.3 Level Based Implementation Roadmap for Digital Infrastructure and Data Analytics

Identify Current Level for the given operational implementation

Based on Interdependency mapped next level of implementation

Function	Level 0 - Baseline	Level 1 – Foundational Systems	Level 2 – Integrated Operations	Level 3 – Advanced & Autonomous
Network Planning & Management	• SCADA/DMS at wide urban service areas. • GIS Pilots • Basic load-flow and planning tools introduced	• SCADA/DMS/OMS operational in major cities. • GIS in key urban/critical areas • Load-flow/planning tools operational **Pilot Planned based on Successive Layers**	• Harmonized Full scale SCADA–OMS–GIS–AMI models; plan-operate feedback • ADMS pilot on select corridors • Enterprise GIS with near-complete asset mapping • Predictive reliability/constraint analytics introduced	• ADMS at scale with FLISR, VVO/CVR & state estimation • Full-network digital twin supporting planning & operations • Full network analytics self-driven reliability/constraint - Self-healing grid, optimal volt/VAR, congestion Mgmt.
Asset Management	• Limited to standard O&M practices with any intelligent systems in place.	• EAM/CMMS with basic asset registry • Preventive maintenance, • Mobile work orders in pilots • Condition sensors on critical assets (limited) • Digital twin pilots for critical assets	• EAM integrated with GIS/OMS/DMS • Automated defect identification & work-order triggers • Drone/robotic inspection in priority zones pilots • Digital twin models for critical assets	• Scaled drone/robotic inspection cycles • Digital twins for entire asset classes **Planned pilot to implementation**

Function	Level 0 - Baseline	Level 1 – Foundational Systems	Level 2 – Integrated Operations	Level 3 – Advanced & Autonomous
Metering, Billing & Accounting	• Pilot AMI, smart meters	• AMI Scaling • Communicable feeder & DT meters • MDMS operational with VEE (Validation, Estimation, and Editing) • CIS/CRM integrated with billing	• AMI for all consumers (as applicable) • MDMS–CIS–GIS fully integrated • Automated billing cycles & reconciliations	• High-frequency AMI + event bus. • Event-driven MDMS integration with OMS/ADMS • AI-enabled revenue assurance & anomaly detection
Customer Services & Market Interfaces	• Basic web/SMS; manual grievance tracking	• Portal + mobile app; CRM/CMS operational • OMS status visible to consumers • Omni-channel CRM Chatbot-enabled grievance handling	• Usage-based insights via MDMS • DR program management • Prosumer platform pilots for P2P and other market models • AI led DSM pilots	• Immersive (AR/VR) advisory & education tools • Real-time consumption nudges & load-shaping tools • AI enabled DSM tools in implementation
Distributed Energy Resources, EV & Flexibility	• Manual registry DER assets. • Hosting capacity evaluation EV/BESS/rooftop facilitation (manual)	• Digitalized registry and visibility • AI tools pilots for hosting capacity assessment • Analytics led - PQ monitoring • Demand Response pilots (manual or semi-automated signals) • Pilot - Telemetry-enabled smart inverters (Volt/VAR modes, PF control, ride-through).	• DERMS integrated with ADMS • Automated PQ management based on inverter settings, VVO/CVR, and reactive dispatch. • Automated - DR with AMI-data integrated • Pilot AI led - EV charging smart charging, scheduler. • Telemetry-enabled smart inverters (Volt/VAR modes, PF control, ride-through). • Pilots V2G-enabled chargers + aggregator platforms. • Pilot DER forecasting DER, EV, storage, load, PQ.	• Full-scale DERMS with market interfacing modules. • Real-time PQ automation integrated with ADMS. • AI/ML-based variability prediction & automated corrective dispatch. • Digital twin of DER-dense feeders / entire LV networks. • V2G-enabled chargers + aggregator platforms. • Transactive energy platforms (P2P, flexibility markets). • Unified forecasting engine for DER, EV, storage, load, PQ.

Function	Level 0 - Baseline	Level 1 – Foundational Systems	Level 2 – Integrated Operations	Level 3 – Advanced & Autonomous
Data Management, Analytics	• Siloed data/MIS; • Nightly backups • Basic access controls	• BI platform • Enterprise Data Lake/Warehouse • Pilot AI-ML real time dashboards • ESB/API Gateway • AI/ML Pilot Stack - models for DSM, theft, and predictive maintenance.	• Streaming Ingestion - near-real-time AMI/SCADA/OMS data for operations analytics. • Loss Analytics • GenAI Pilots for MIS and Reporting • MLOps Platform • Master Data Management (enterprise) • Synthetic data & digital-twin analytics	• Event-Driven Data Fabric/Data Mesh • Prescriptive Engines - automated decision support for ADMS/DERMS • GenAI for consumer analytics/tariffs/load patterns & regulatory reporting • AI-assisted SOC & zero-trust controls
Enterprise Management (Finance, Procurement, HR, Compliance)	• Stand-alone finance/HR; paper-based procurement	• ERP (Finance/HR/Procurement) operational • Contract & document management. • performance dashboards	• ERP integrated with OMS/MDMS/GIS/ADMS • Outcome-linked budgeting & vendor performance analytics	• Enterprise performance management tied to operational data & digital twins • Automated compliance packs • Workforce capability forecasting & optimization

L-H – level of Integration

8 PROPOSED DIGITALIZATION PLAN FOR DISCOMS

Technology prioritization: not every DISCOM requires every advanced technology at the same time. The framework should distinguish between national digital foundations, utility-specific capabilities, controlled pilots and research/sandbox technologies.

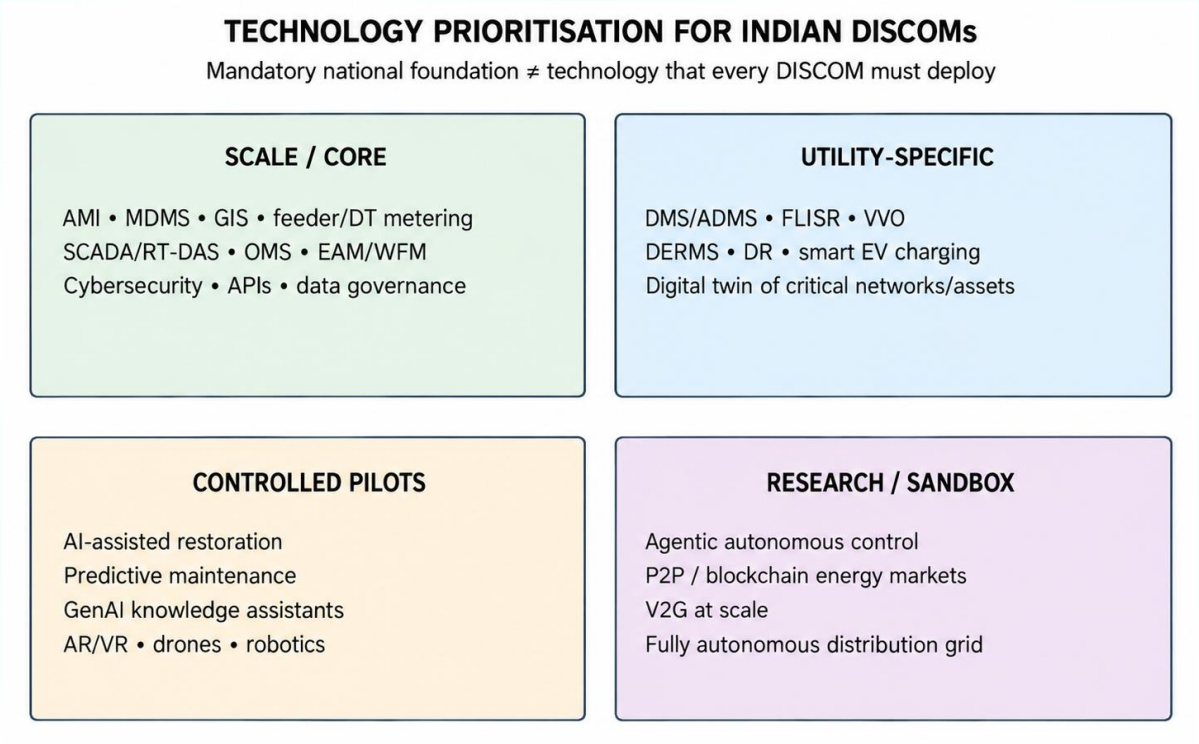


Figure 8A. Technology prioritisation for Indian DISCOMs.

1ST PHASE – (2026–2029): ESTABLISHING THE FOUNDATION

In this phase, the focus would be on building the essential digital infrastructure and institutional readiness required for a technology enabled transformation at discom level. This phase lays the groundwork for future adoption of AI, ML, automation, and immersive tools by improving visibility, data quality, and workforce capability. Depending on the current maturity, the following digitization activities are proposed under 1st Phase:

Discoms Having Minimal Digitization	Leading Discoms Having AMI/SCADA/DMS/GIS etc
• AMI implementation for consumers except Agriculture including communicable meters on all feeders and Transformers • Implementation of SCADA,DMS,GIS, ERP,OMS in all major cities etc. • Deploy AI/ML models for Demand Side Management (DSM) , Predictive maintenance of transformers and	• Implement ADMS • Initiate Digital Twins for key assets and load flow analysis based on digital twin models • Launch AR/VR-based immersive training programmes for substation staff and engineers

feeders, Theft detection and revenue leakage mitigation • Launch IT capacity-building initiatives through partnerships with technical training institutes • Pilot AI/ML based dashboards to support data-driver decision-making at the executive level • Facilitation of EV, BESS, Solar Roof top system • Pilot on Digital Twins/AR/VR/Drones/V2G/P2P • Launch consumer centric mobile apps to improve customer engagement, billing transparency, and complaint resolution	• Deploy robotic tools for automated inspection in substations and transmission assets • Optimise distributed energy resource (DER) management using real-time visualisation and control through DERMS • Establish in-house data science or analytics cells to identify, test, and scale AI use cases • Implement Block chain technology • Pilot on Digital Twins / AR /VR /Drones /V2G/P2P

2ND PHASE – (2029–2032): INTEGRATION AND OPERATIONAL DIGITIZATION

Discoms Having Minimal Digitization	Leading Discoms Having AMI/SCADA/DMS/GIS etc
• AMI implementation for all consumers • Expand SCADA/DMS to cover whole discom area and GIS coverage to achieve 100% asset mapping • Implement ADMS by integrating various IT/OT system with ERP/ OMS /CMS etc. • Deploy AI/ML models for Demand Side Management (DSM) , Predictive & preventive maintenance of transformers and feeders, Theft detection and revenue leakage mitigation, data-driver decision-making at the executive level • Digital Twins for major assets & load flow analysis based on digital twin model	Digital Twin for full network • Implement AI/ML based outage management systems with predictive fault location and auto-restoration capabilities • Deploy robotic tools for automated inspection in substations and transmission assets • Optimise DER and prosumer integration using AI for real-time load balancing, dynamic pricing, and power quality management • Drone based Asset mapping • Use AR/VR/aR tools for remote maintenance, field crew guidance, and real-time fault resolution

Discoms Having Minimal Digitization	Leading Discoms Having AMI/SCADA/DMS/GIS etc
• Launch AR/VR-based immersive training programmes for substation staff and engineers • Deploy robotic tools for automated inspection in substations and transmission assets • Optimise distributed energy resource (DER) management using real-time visualisation and control through DERMS • Establish in-house data science or analytics cells to identify, test, and scale AI use cases • Pilots on Deploy drone-based robotic systems for infrastructure inspection in remote or high-risk areas / AR-VR based maintenance, Drone based Asset mapping , robotic tools in Sub-station etc. • Digitize grievance redressal workflows using chatbots for real-time support • Pilot on Generative AI for advanced consumer analytics, tariff analysis and load pattern analysis	• Deploy drone-based robotic systems for infrastructure inspection in remote or high-risk areas

3RD PHASE – (2032–2035+): INTELLIGENCE AND AUTOMATION; 2035+ SELECTIVE ADVANCED CAPABILITIES

Discoms Having Minimal Digitization	Leading Discoms Having AMI/SCADA/DMS/GIS etc
• Implement ADMS with full integration of SCADA, DMS, and AMI for intelligent load management and two-way communication between the utility and the customers • Enable real-time outage communication and resolution through AI-powered customer portals	• AI/ML based outage management systems with predictive fault location and auto-restoration capabilities • Transition to self-operating grids with autonomous fault detection, DER orchestration, and AI-optimised dispatch systems

Discoms Having Minimal Digitization	Leading Discoms Having AMI/SCADA/DMS/GIS etc
• Digital Twin of the network • Implement AI/ML based outage management systems with predictive fault location and auto-restoration capabilities • Deploy robotic tools for automated inspection in substations and transmission assets • Optimise DER and prosumer integration using AI for real-time load balancing, dynamic pricing, and power quality management • Drone based Asset mapping • Use AR/VR/aR tools for remote maintenance, field crew guidance, and real-time fault resolution • Deploy drone-based robotic systems for infrastructure inspection in remote or high-risk areas • AI-supported Vehicle-to-Grid (V2G) and Peer-to-Peer (P2P) energy trading systems based on Future market structure • Establish internal AI labs or Centres of Excellence in partnership with academic institutions and start-ups • Leverage AI/ML for regulatory reporting, performance benchmarking, and predictive safety compliance • Digital Twins integrated with Automation and IT Systems	• Deploy robotic tools for automated inspection in substations and transmission assets • Optimise DER and prosumer integration using AI for real-time load balancing, dynamic pricing, and power quality management • Drone based Asset mapping • Use AR/VR/aR tools for remote maintenance, field crew guidance, and real-time fault resolution • Deploy drone-based robotic systems for infrastructure inspection in remote or high-risk areas • Lead innovation through Generative AI for synthetic data creation, digital twin simulations, and asset design • Deploy immersive AR/VR platforms for interactive billing, customer education, and home energy advisory services • Scale robotic systems for continuous infrastructure surveillance, predictive maintenance, and safety inspections • Play an active role in shaping national AI and energy policies through field-proven innovation leadership

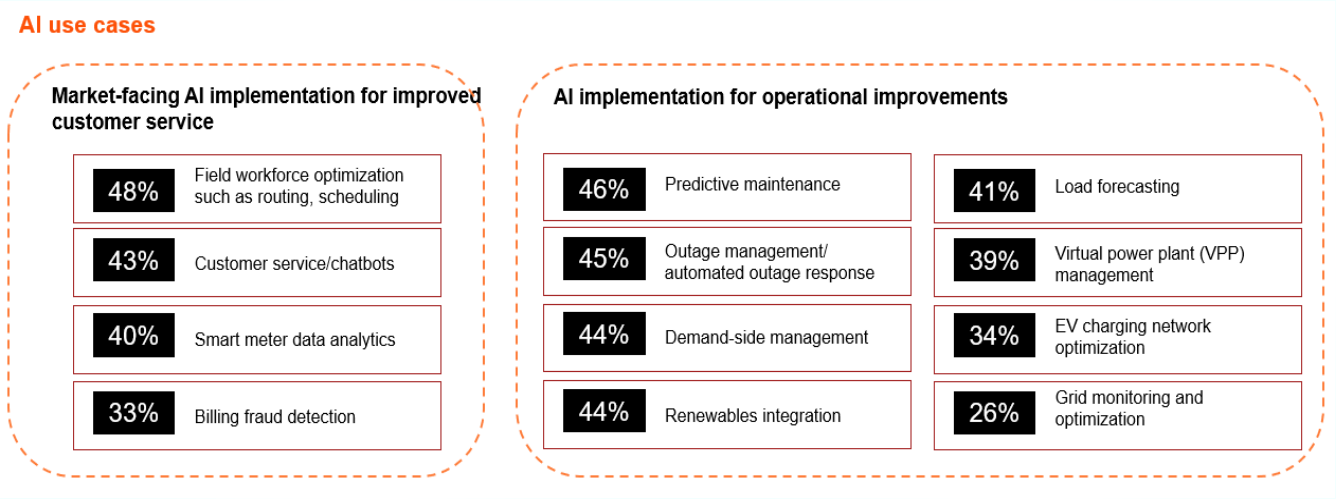
9 AI DRIVING POWER UTILITIES & INCUBATION OF PILOTS

AI use cases will grow rapidly as AI is becoming as important enabling technology in helping to manage increasingly intricate grids with two-way energy flows

- AI powers new energy business models
- AI is driving measurable improvements in grid performance and customer outcomes
- AI is reshaping how utilities plan, operate, and manage the grid

Agentic AI systems[7] - which are capable of making autonomous decisions - are beginning to reshape critical utility operations. These intelligent agents analyze real-time data and act independently to optimize performance. Currently, utilities are piloting agentic AI most actively in smart home ecosystem control (39%) and automated outage response (36%), where intelligent agents can help balance load and accelerate outage resolution.

Policy safeguard for critical operations: During initial adoption, AI should normally remain decision-supporting rather than decision-authorising for protection and switching. Autonomous control should require deterministic safety boundaries, human override, fail-safe operation, audit trails, model monitoring, cybersecurity testing and simulation/FAT/SAT validation.

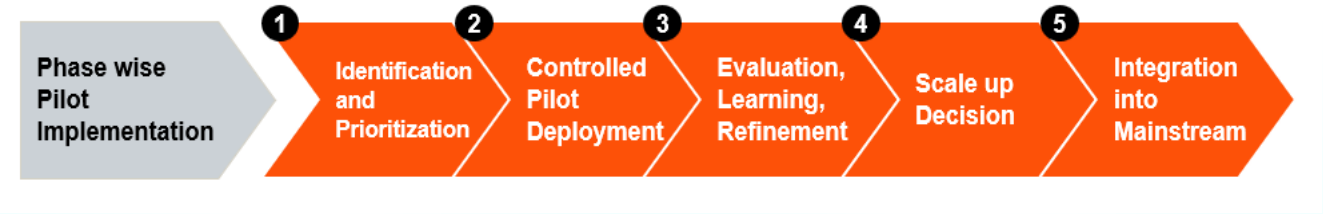


1. Incubation of Pilots

The incubation of new and emerging technologies encourages as incubation of pilots are low-risk pathway through which DISCOMs can explore, test, and validate innovative digital solutions before large-scale adoption.

The discoms can adopt the following approach:

7 https://www.ibm.com/downloads/documents/us-en/1443d5df104f480f



1) **Phase 1: Identification and Prioritization of Use Cases**

Identifying problem-led use cases, potential pilot areas may emerge from operational (unique to discoms) pain points (e.g., recurring outages, high technical losses, DER congestion), planning constraints (e.g., hosting capacity uncertainty), or emerging business requirements (e.g., EV integration, flexibility management). DISCOMs may shortlist use cases based on criteria such as expected operational impact, alignment with digital maturity, data availability, and relevance to future system requirements.

Pilots are framed with clear objectives and success criteria, ensuring that experimentation is linked to measurable outcomes rather than proof-of-concept demonstrations alone. Prioritization is expected to differ across utilities depending on network characteristics, consumer mix, and readiness.

2) **Phase 2: Design and Controlled Pilot Deployment**

Once a use case is identified, pilots are designed for limited-scope deployment within selected feeders, substations, divisions, or consumer segments. The emphasis is on controlled environments that allow testing without disrupting core operations. Pilot design considers interoperability with existing systems (AMI, SCADA, GIS, OMS, MDMS), data flows, cybersecurity considerations, and operational ownership.

During this phase, DISCOMs may engage with technology providers, startups, research institutions, or OEM partners, while ensuring clarity on roles, data usage, and intellectual property. Pilots are deliberately kept time-bound and resource-light, allowing utilities to learn quickly and iterate without committing to large capital or long-term contracts.

3) **Phase 3: Evaluation, Learning, and Refinement**

Pilot performance is assessed against predefined objectives, focusing on both technical outcomes and operational usability. Evaluation typically includes improvements in reliability, efficiency, visibility, response times, or decision quality, as well as feedback from control-room operators, field staff, and planners.

Equally important is capturing implementation learnings - data dependencies, integration challenges, process changes required, and skill gaps observed.

4) **Phase 4: Scale-up Decision**

Based on evaluation outcomes, DISCOMs may take one of three paths:

- Scale-up, where the pilot demonstrates clear value and readiness for broader rollout,
- Refinement, where limited adjustments are needed before retesting or expansion, or
- Exit, where the pilot is discontinued with learnings captured for future reference.

Scale-up decisions are expected to align with the broader digital infrastructure roadmap and system interdependencies, ensuring that new technologies complement existing platforms rather than introduce parallel solutions.

5) **Phase 5: Integration into Mainstream Digital Programs**

Successful pilots are gradually integrated into mainstream digital programs, procurement plans, or standard operating procedures. This phase ensures that innovation does not remain isolated, but becomes part of routine planning, operations, or customer service workflows. Where relevant, pilots may inform updates to standards, data models, training programs, and change management initiatives.

Each pilot should have a documented baseline, target KPI, data-readiness assessment, cybersecurity review, named operational owner, time-bound evaluation period and a scale-up/refinement/exit decision. Successful pilots should be converted into standard operating procedures, training packages, procurement specifications and support/O&M arrangements.

10 CHANGE MANAGEMENT & CAPACITY BUILDING

10.1 CHANGE MANAGEMENT

The digital transformation of DISCOMs requires a structured and sequenced management programme to ensure adoption of new systems, alignment of processes, and sustained behavioral shifts across the organization. The roadmap below provides a phased view of the change interventions needed as DISCOMs progress from foundational digitization to advanced autonomous operations.

Phase	Time Horizon	Key Change Management Measures
Phase-1 Preparing for Change	0–12 Months	• Establish **Digital Governance & Steering Committee** to oversee change. • Launch change communication plan explaining the 'why' of digitization (AMI, ADMS, DERMS, MDMS etc.). • Conduct **stakeholder mapping** (operations, commercial, IT, HR, field, consumer-facing teams). • Develop **process transition maps** for functions shifting from manual to digital workflows. • **Initiate baseline readiness assessments** for people, processes, data, and culture. • Identify change champions.
Phase 2: Enabling Adoption	12–18 Months	• Implement **structured orientation programs** during system go-lives (AMI, MDMS, OMS, GIS updates, ERP modules). • Provide **SOPs, scripts, and digital handbooks** for new workflows. • Establish feedback loops to resolve adoption **challenges and stabilize usage**. • Update internal **policies & approval processes** (e.g., outage escalation, data handling, cyber protocols). • Drive leadership alignment through review meetings, performance dashboards, and progress scorecards.

Phase	Time Horizon	Key Change Management Measures
Phase-3 Embedding New Ways of Working	18–36 Months	• Institutionalize digital KPIs across functions (data quality, reliability indices, billing cycle adherence, consumer services, cyber compliance). • **Integrate change KPIs into performance management** (system usage, SOP compliance, adoption behavior). • Strengthen cross-functional coordination mechanisms (Ops-Commercial-Planning-IT review forums). • **Standardize IT-OT governance frameworks**, including data ownership and integration protocols. • Roll out process harmonization workshops across circles/divisions.
Phase-4 Sustaining and Scaling Change	Beyond 36 Months	• Establish a Digital **Transformation Office (DTO)** for enterprise-wide oversight. • Conduct annual **digital maturity reassessments** linked to roadmap progression. • Implement **continuous improvement** cycles. • Create an internal knowledge repository (case libraries, SOPs, learning content).Strengthen consumer-facing change management

10.2 CAPACITY BUILDING

The current workforce capabilities within most DISCOMs are insufficient to support the scale and complexity of emerging digital systems.

- Existing workforce skills are insufficient for advanced digital systems (AMI, MDMS, ADMS, DERMS, Analytics, Cyber-security, GIS applications, etc.).
- Current IT cells focus is limited to basic operations and maintenance, not on NextGen digital technologies.
- Scaling digital maturity requires technical, analytical, and operational upskilling, plus organizational restructuring to embed digital roles.

Addressing this gap requires a deliberate and sustained capacity-building effort that equips personnel with the technical, analytical, and cyber-operational skills needed to work effectively with next-generation digital infrastructure. In parallel, an organizational governance shift is essential to embed digital roles, clarify responsibilities, and support the cultural and procedural changes necessary for successful transformation.

The Capacity building can be achieved through:

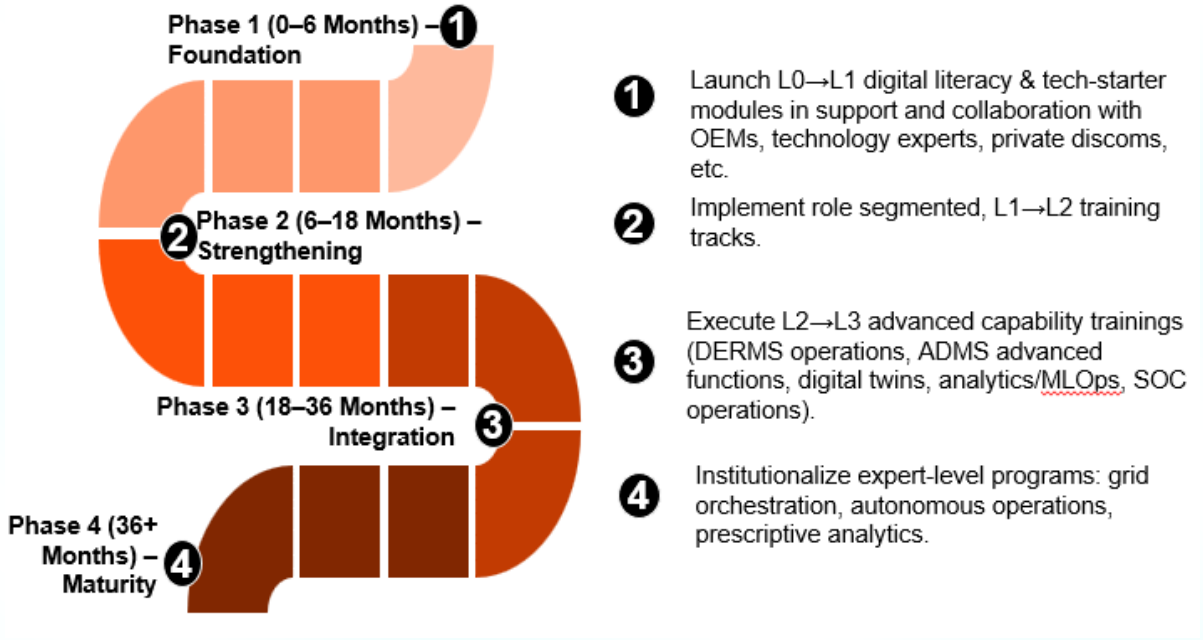
Existing Workforce Digital Skill Development

- **Level-Based Training** - Digital maturity–aligned training (L0→L3).
- **OEM & Technology Partnerships** - Training + certifications from OEMs
- **Centralized Support Workshops** – by national/state nodal agencies.
- **Best-Practice -** Cross-utility learning.

Capacity Strengthening (Addition of New Workforce)

- **New roles:** Data Engineers, Cyber Analysts, SCADA/ADMS Engineers, DER Planners, GIS Specialists, Digital Twin Engineers, AI/ML Analysts.
- **Defined competencies**, career paths, and recruitment standards.

Phased Implementation



CAPACITY BUILDING ROADMAP

For smaller DISCOMs, selected non-real-time capabilities—such as cybersecurity monitoring, analytics/MLOps, disaster recovery, training and common data services—may be delivered through shared or managed services, subject to data-governance and security controls. Critical OT control should remain under clearly defined utility accountability.

A national distribution digitalisation test bed is recommended for interoperability testing of AMI, CIM/API, ADMS, DERMS, smart inverters, BESS, EV, AI and indigenous SCADA/DMS solutions. It can support vendor qualification, cybersecurity validation, FAT/SAT methodology and workforce training before large-scale deployment.

Phase	Time Horizon	Capacity-Building Measures
Phase 1: Foundation	• 0–6 Months	• Launch targeted, level-based **digital literacy for all staff (L0→L1).** • Begin technology-specific starter trainings on AMI/MDMS, GIS, OMS, CRM. • Conduct central/**nodal workshops** on IT-OT basics. • Form **cross-utility learnings for knowledge exchange.** • Begin learning from **best practices from advanced DISCOMs.** • Initiate **OEM-supported Digital Learning.** • Start groundwork **for Digital Cadre design (roles, competencies, etc.).**
Phase 2: Strengthening	• 6–18 Months	• Implement role-segmented, **L1→L2 training role-based OEM certification programmes for advanced operations and application usage.** • Formalize **Digital Cadre structure and begin phased induction**. • Initiate hiring from ICT, data science, and cybersecurity industries for **critical IT/OT roles.**
Phase 3: Integration	• 18–36 Months	• Execute **L2→L3 advanced capability** trainings (ADMS advanced functions, DERMS operations, digital twins, analytics/MLOps, SOC operations). • **Expand Digital Cadre with specialist hires** - Data Engineers, ADMS/SCADA Engineers, Cyber Analysts, DER Planners, GIS SMEs, Digital Twin Engineers, etc. • Establish **career progression pathways, competency levels**, and continuous learning cycles.
Phase 4: Maturity	• Beyond 36 Months	• **Digital Transformation Office / Digital PMO** overseeing architecture, cybersecurity, integration, and quality assurance. • Build internal trainers (train-the-trainer) and **centers of excellence.**

10.3 STANDARDS AND COMPLIANCES

Standards

The detailed technical standards and reference frameworks relevant to emerging digital technologies in the power sector - including artificial intelligence, machine learning, IoT, cybersecurity, digital twins, and immersive technologies - are consolidated in the Annexure to this Framework. The annexure is intended to serve as a reference compendium of internationally recognized and nationally adopted standards issued by relevant standard-setting bodies, to support informed planning, procurement, and implementation by utilities. These references are indicative and may be updated periodically to reflect the evolution of technologies and standards.

Compliances

The compliance approach under this framework is intended to provide structured guidance and assurance, rather than prescriptive mandates. It outlines the minimum compliance dimensions that DISCOMs should consider while planning, piloting, or scaling digital and emerging technology initiatives, to ensure safety, security, interoperability, and sustainability.

- Align new systems and pilots with recognized technical and interoperability standards (e.g., IEC 61850/62351, IEC CIM/IEC 61968/61970 where applicable), and with Indian adoptions via BIS (IS/ISO/IEC/IEEE) to avoid vendor lock-in and ensure long-term maintainability.
- Ensure cybersecurity-by-design across IT–OT: asset inventory, network segmentation, hardening of field devices, secure remote access, identity and access management, event logging/monitoring, vulnerability and patch management, incident response playbooks, and supplier/third-party security clauses.
- Apply data governance controls for all analytics/AI/digital-twin use: data ownership and stewardship, data quality checks, lineage and versioning, retention/minimization, approved data-sharing, and audit trails for model inputs/outputs.
- Implement AI/ML governance practices: model risk assessment, validation and testing, bias and drift monitoring, explainability/traceability proportionate to use, change control for models, and fallback/manual-override procedures for operational decisions.
- Follow information security management practices consistent with recognized frameworks (e.g., ISO/IEC 27001/27002 type controls), including periodic risk assessments and internal audits covering cloud, edge, and on-prem environments.
- Meet safety and human-factors requirements for field and control-room technologies (e.g., ergonomics for AR/VR/assisted-reality devices; safe operating procedures for robotics/drones; crew training and PPE integration).
- Maintain regulatory alignment with prevailing grid codes, metering and protection requirements, and state commission directions; seek limited, time-bound permissions for market- or consumer-facing pilots where required.
- Build procurement compliance into RFPs and contracts: conformance to referenced standards, interoperability and API requirements, cybersecurity baselines, data protection clauses, service levels, acceptance tests (FAT/SAT), and escrow/exit provisions.
- Establish documentation and assurance artifacts: approved solution architectures, configuration baselines, data protection impact notes (where consumer data is involved), test results, pilot evaluation reports, and go-live/rollback plans.
- Run training and authorization for all impacted roles before go-live; track completion and competency for control-room operators, field staff, planners, data/AI teams, and cyber/IT support.
- Operate change management controls: mapped process changes, SOP updates, communications to stakeholders, hyper-care support post go-live, and adoption dashboards with clearly defined owners.
- Set up performance and compliance monitoring: define KPIs (reliability, loss reduction, billing accuracy, DR MWs delivered, restoration time), track against baselines, and review quarterly with governance forums.

- Preserve consumer protections where applicable: explicit opt-in for pilots, clear incentives/benefits, transparent notices on data use, and easy grievance/opt-out paths.
- Ensure business continuity readiness: backup/restore for operational data, failover for critical applications, tested disaster recovery procedures, and periodic drills.

10.4 CYBER SECURITY

Cybersecurity for all digital, IT–OT, and emerging technology deployments in the distribution sector shall be guided by the existing regulations, guidelines, and advisories issued by the Central Electricity Authority (CEA) for the power sector including Cyber Security in Power Sector Guidelines, 2021; periodic alignment with mitigation measures as suggested by CSIRT-Power, etc.

In addition, applicable national cybersecurity policies, frameworks, and directions issued by the Ministry of Electronics and Information Technology (MeitY) - including those related to information security, data protection, incident reporting, and critical information infrastructure - shall be referenced to ensure alignment with the broader national cybersecurity ecosystem.

ANNEXURE I: SUITABLE COMMUNICATION TECHNOLOGY FOR DIGITIZATION IN DISTRIBUTION SYSTEM

RECOMMENDED OUTCOME-BASED KPI FRAMEWORK FOR DIGITALISATION

KPI area	Illustrative measures
Reliability	SAIDI, SAIFI, CAIDI; restoration time; FLISR success; voltage quality
Commercial	AT&C/DT losses; billing and collection efficiency; actionable theft detection
AMI / data	Communication success; data availability; VEE rate; remote service success; event/last-gasp performance
Digital model	GIS/asset completeness; consumer–meter–DT–feeder connectivity accuracy
Cybersecurity	Asset inventory; patch/MFA coverage; incident response; vulnerability closure
Adoption	System utilisation; SOP compliance; trained personnel; digital workflow completion
Financial	CAPEX/OPEX against business case; quantified benefit realisation; lifecycle cost

The back bone of all the smart technologies is the availability of a reliable communication system between the devices and the utility control center. Currently, the distribution grid faces challenges in terms of reliability and security with both wired and wireless communication technologies. In particular, grid monitoring is one of the key elements of critical infrastructure resilience. An important aspect of grid monitoring is outage management that could prevent a cascading failure in the grid network. Nowadays, the use of smart metering (AMI) of consumers , use of Phasor Measurement Units (PMU's) in transmission lines, automatic control of RMUs etc require a suitable and reliable communication system for proper functioning However, the most difficult challenge is a lack of a reliable communication network infrastructure at reasonable cost for the distribution utilities, which is a key factor in deploying the various smart grid technologies. . The wireless communication system is often viewed as the most cost effective alternative to the wired communication system.

Presently, the following communication system are in operation in power sector for different uses / purposes:

Wireless Systems

- Radio Frequency (RF)
- Mobile /GPRS (3G/4G/5G)
- Zigbee
- WiFi
- NB-IOT

Wired Systems

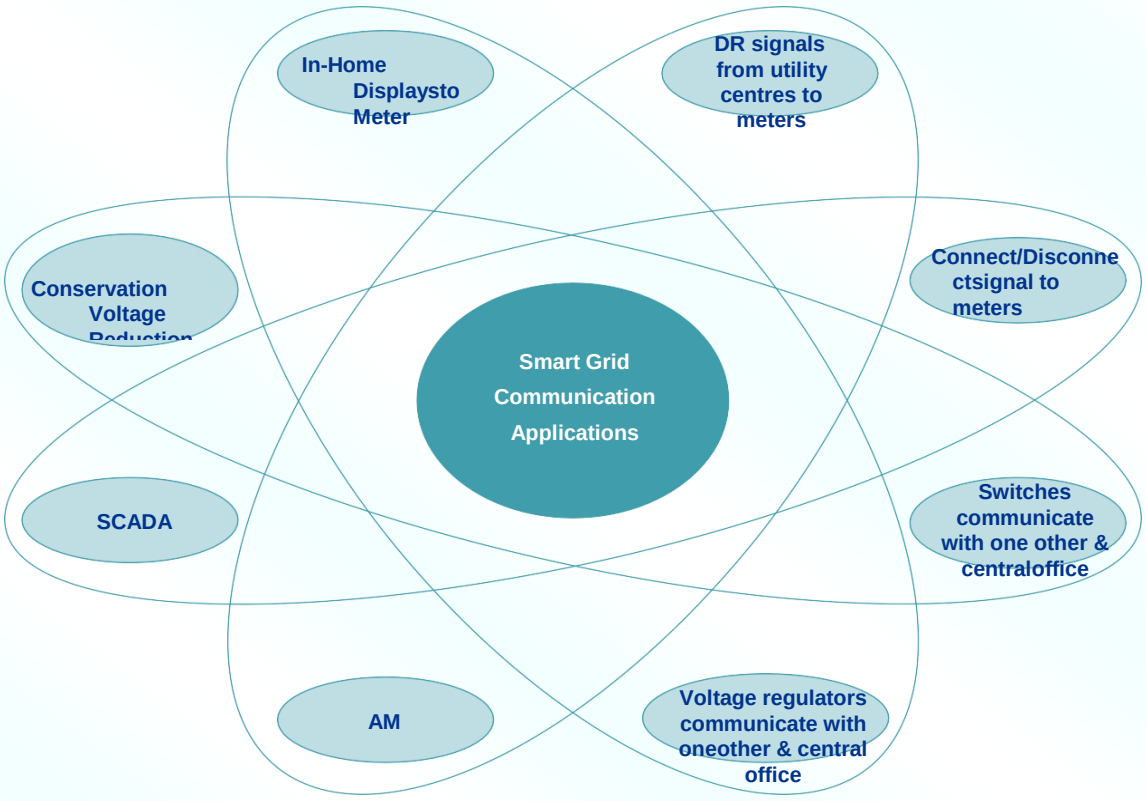
- Power Line Communications (PLC)
- Fiber Optical Communication, Ethernet

In the Smart metering operation, the suitable communication technology and associated infrastructure facilitates the data communication between the smart meters and the Utility's data acquisition systems viz. Head End System (HES) / Meter Data Acquisition System (MDAS). The data from the smart meter is sent to the HES / MDAS either directly, or through Data Concentrator Units (DCUs)/ Access points depending on the architecture of the AMI system.

At present, the following communication technologies are typically used for AMI systems:

- **Power Line Communication (PLC):** Smart Meters use the power line itself for data communication between the meter and a DCU placed at appropriate location connecting 100 to 200 meters at customer premises. The DCUs are connected to the Utility's systems through GPRS or fibre-optic networks.
- **Radio Frequency (RF) Mesh:** Smart Meters use RF for data communication between the meter and a DCU which is connected to the the Utility's systems through GPRS or fibre-optic networks. Typically, 100 to 200 smart meters are connected to a DCU in a RF mesh which further communicates the data to the control centre (HES/MDMS) through the cellular data network, Optical Fibre Cables, DSL, etc. In a mesh network, number of smart meters communicating to any DCU/access point/router is dynamic in nature as the self-configuring mesh will find the most optimal route for communicating the meter data to the HES/MDAS through nearest available DCU/access point/router The failure of any DCU/access point/router leads to re-designing of the network automatically to use another nearby DCU so that data communication is uninterrupted between the meter and the control centre.
- **Cellular Technology (GSM/GPRS/3G/4G/NBIoT):** Smart Meters directly communicate the data to the control centre by utilising the Telecom cellular data network (GPRS/3G/4G/NBIoT) and this system typically does not require any DCUs.

Recently, the use of devices based on 'Internet of Things' (IoT), or simply 'Machine to Machine' (M2M) communication for wide ranging sensory devices have increased on a great pace.



The following table captures the details of most commonly used communication technologies for Smart Metering / AMI across the world.

Metric	Optical Fibre (OFC)	PLC	RF Mesh	GSM / GPRS
General Usage	Advantageous over electrical transmissions, OF have largely replaced copper wire networks	Broadband over Power Lines; Systems for carrying data on a power conductor for WAN Applications	Point-to-point wireless transport for voice, data, video etc.	Very wide network reach and can be used easily on remote locations
Frequency Range	180 THz to 330 THz	1.7-80 MHz Most providers rely on the 1-30 MHz spectrum bandwidth for BPL transmission	Licence Free bands: 865-867[8] MHz; 2.4 GHz Licensed bands: 433	900 to 1990 MHz
Peak Single user Data rate	15 to 101 Tbit/s	Low frequency (100-200 kHz) carriers: Few hundred bps; Speeds up to 10	Typical 4-16 Mbps	Upto 2 Mbps

Metric	Optical Fibre (OFC)	PLC	RF Mesh	GSM / GPRS
		Mbps have been achieved.		
Coverage capabilities	Upto 100 km on a single network	Distances of more than 15 km can be achieved over a medium voltage network	Up to: 1 Kms; longer distances capable with lower bit rates	Several kilometres (in low traffic conditions)
Cost	High initial investment and also depends upon the distance and other conditions	High cost of implementation and lack of vendors	Moderate	Moderate
Technology maturity	Latest with the scope of future developments	More popular in Europe where quality of existing infrastructure is good	Mature; 500+ deployments worldwide	Fairly mature (4G LTE / NBioT is the latest technology)
Type of Signal	Optical Signal	Electrical signal	RF signal	Digital, Circuit switched network signal

For implementation in the Indian context, wherein the cost of implementation plays a key role in ensuring that the solution is affordable, Optical Fibre Cable for communication between each smart meter may not be a feasible alternative.

Accordingly, the pros & cons of major three technologies have been compared below.

Technology	Pros	Cons
Power Line Communication (PLC)	• *Infrastructure:* Leveraging use of existing infrastructure. • *Cost-effective:* Use of existing infrastructure and can transmit over long distances; advantage for utilities serving rural areas • *Useful grid analytics:* Enables preventive maintenance; Use of the distribution network to send signals, which enables analytics to isolate and troubleshoot problems with insulators, transformers and other grid devices	• *Network interference:* Large industrial customers may introduce noise and harmonics on the power line that may affect performance and distort communications • *Less bandwidth:* Narrower available bandwidth can impact data capacity and the speed or rate at which data can be accessed in some applications • *Poor Network conditions:* The existing network conditions in India may cause data loss

Technology	Pros	Cons
Radio Frequency Mesh (RF)	• *Distributed regionally:* Can target specific areas for deployment • *Self-healing:* In case of network failure in any particular link, the network automatically finds another path to communicate with the HES • *Self-forming:* The network's intelligence enables the signal to find the optimal route back to the HES; Important in areas with obstructions, like mountains or high-rise buildings	• *Infrastructure*: May require more infrastructure deployment /DCU than other options, especially in rural areas, where meters are more spread out across the service territory • *Proprietary technology:* The communication technology is proprietary to each vendor and therefore inter-operability becomes a challenge.
Cellular Network – 3G/4G/NBIoT Technology	• *Faster deployment:* Enables long-range communication and can be rolled out quickly using the existing cellular data infrastructure • *Optimal for targeted applications:* Can be deployed cost-effectively to support even marginal consumer groups • *Proven technology:* In use for more than a decade, well established and fairly reliable • *Secure:* Serving billions of customers worldwide, Cellular networks provide standard telecom security mechanisms, advantage of which can be reaped by Utilities • *Common protocol:* Standardised protocol compliant which is vendor agnostic, making inter-operability seamless	• *Obsolescence issues:* Cellular networks tend to roll over prior to the useful life of the metering technology, raising concerns about how long a deployed technology will remain viable • *Network availability issue*: Sharing public cellular networks, often completely dependent on the carrier's (TSP's) priorities in the event of an outage

A suitable communication technology for various smart grid operations may be selected by the utilities as per the actual site conditions.

ANNEXURE II: RELEVANT INTERNATIONAL/INDIAN STANDARDS FOR NEW TECHNOLOGIES

To ensure safe, secure, and interoperable deployment of emerging technologies across the power sector, it is essential to align with international standards. These standards not only guide the technical implementation but also ensure regulatory compliance, reliability, and cybersecurity.

1) Artificial Intelligence (AI) In Power Utilities

- CIGRÉ D2.52 – Artificial Intelligence applications and technology in the power industry.
- ISO/IEC 22989 – Information technology - Artificial intelligence - Artificial intelligence concepts and terminology
- ISO/IEC 23053 – Framework for Artificial Intelligence (AI) Systems Using Machine Learning (ML)
- IEEE 7001 – IEEE Standard for Transparency of Autonomous Systems
- ISO/IEC JTC 1/SC 42 – Ongoing AI standardization committee relevant to utility adoption.

2) 1.2 Bureau of Indian Standards (BIS) Standards:

- ISO/IEC 24668:2022: Information Technology - Artificial Intelligence - Process Management Framework for Big Data Analytics
- ISO/IEC TR 24372:2021: Information technology - Artificial intelligence (AI) - Overview of Computational Approaches for AI Systems
- ISO/IEC 38507:2022: Information technology - Governance of IT - Governance implications of the Use of Artificial Intelligence by Organizations
- IS/ISO/IEC TR 24368:2022: Information technology - Artificial intelligence - Overview of Ethical and Societal Concerns

3) 1.3 Machine Learning (ML) For Grid Intelligence

- **Power-Specific Standards:**
  - IEEE P2781 – IEEE Guide for Load Modeling and Simulations for Power Systems

- **Relevant General Standards from IEC:**
  - ISO/IEC 23894:2023 – Information Technology - Artificial intelligence - Guidance on Risk Management
  - ISO/IEC 20546 – Information Technology - Big Data - Overview and Vocabulary
  - ISO/IEC 25012 – Software Engineering - Software Product Quality Requirements and Evaluation (SQuaRE) - Data Quality model

4) 1.4 Generative AI - General Standards for Governance:

- ISO/IEC 42001:2023 – Information Technology - Artificial Intelligence - Management System
- ISO/IEC 38507 – Information Technology - Governance of IT - Governance Implications of the Use of Artificial Intelligence by Organizations

5) **1.5 Internet of things (IOT)**

- **Power-Sector Specific Standards:**
  - IEC 61850 – Communication Networks and Systems For Power Utility Automation
  - IEC 62351 – Power Systems Management and Associated Information Exchange - Data and Communications Security
  - IEEE 2030.5 – IEEE Standard for Smart Energy Profile Application Protocol - Robotics and Autonomous Inspection

- **Industry-Specific Standards:**
  - IEEE 1872.2 – IEEE Standard for Autonomous Robotics (AuR) Ontology

- **Complementary Frameworks:**
  - ISO 10218-1/2 – Robots and Robotic Devices - Safety Requirements for Industrial Robots
  - ISO/TS 15066 – Robots and Robotic Devices - Collaborative Robots

6) **1.6 Virtual reality (VR) and Augmented reality (AR) for utility training**

- **Standards for Power Sector Use:**
  - IEEE 2048.1 – Standard for Virtual Reality and Augmented Reality: Device Taxonomy and Definitions
  - IEC 62832 – Industrial-Process Measurement, Control And Automation - Digital Factory Framework
  - IEEE P1589 – IEEE Standard for Augmented Reality Learning Experience Models

- **General Supporting Standards:**
  - ISO/IEC 18039 – Information Technology - Mixed and Augmented Reality (MAR) Reference Model
  - ISO 9241-960/391 – Ergonomics of Human-System Interaction

7) **1.7 Assisted reality for field workers**

- **Relevant Industrial Standards:**
  - IEEE P2048.6 – Standard for Virtual Reality and Augmented Reality: Immersive User Interface
  - ISO 9241 Series – Ergonomics of Human-System Interaction

8) **1.8 Cybersecurity In AI/OT Integration**

- **Power System-Specific Standards:**
  - IEC 62443 Series – Security for Industrial Automation And Control Systems
  - IEEE 1686 – IEEE Standard for Intelligent Electronic Devices Cybersecurity Capabilities

- **AI-Focused Cybersecurity:**
  - IEEE 7002 – IEEE Standard for Data Privacy Process
  - ISO/IEC 27001 / 27005 – ISO/IEC 27001 / 27005

9) 1.9 Digital Twin Standards for Power Infrastructure

- **Applicable Standards:**
  - IEC 62832 – Digital Representation of Industrial Assets core for digital twin modelling in substations and plants)
  - ISO 23247 – Digital Twin Framework for Production and Monitoring (Adaptable for Energy Assets)
  - IEEE 2651 – Maturity Framework for Digital Twins in Electric Networks

- **Grid Digitalization And Interoperability**
  - IEC 61968 (CIM – Distribution) – Integration of distribution operations: meters, asset/capacity management, GIS, customer systems
  - IEEE 2030 Series – Interoperability and Integration Standards for Smart Grid Ecosystem