DUM 2025

Handbook of AI, ML, VR and Robotics Solutions and Roadmap for it's Adoption in Electric Utilities

4th November 2025

SESSION 3: AI-ML-VR/AR-ROBOTICS APPLICATIONS FOR UTILITIES

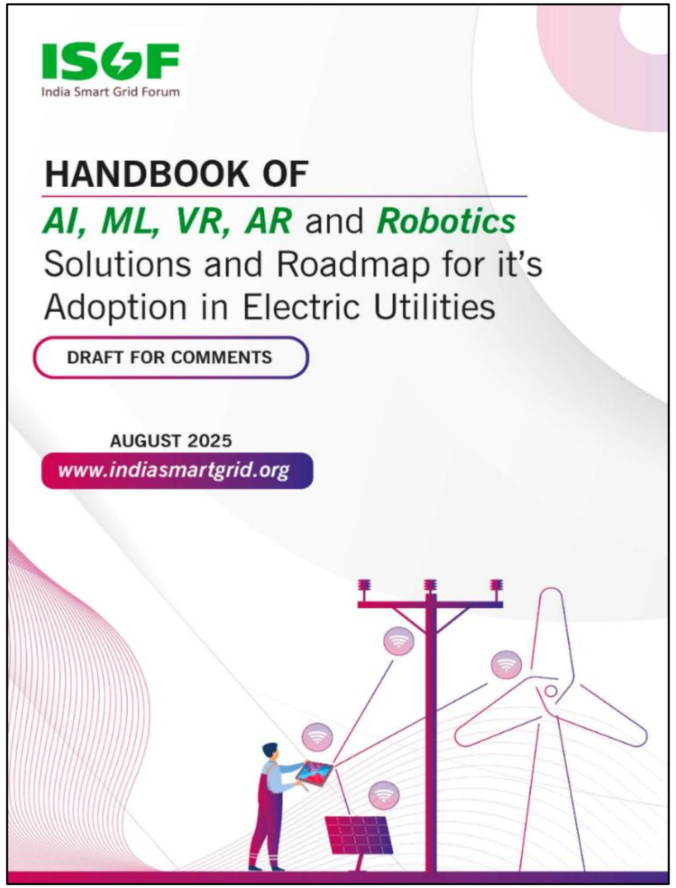
Scope and Objective of the Handbook

Scope

- Serve as a comprehensive guide for Indian utilities to evaluate and adopt AI, ML, VR, AR, and Robotics
- Consolidate global and Indian use cases, best practices, and lessons learned
- Provide practical, context-specific applications to address sector challenges such as renewable integration, grid reliability, peak demand, theft mitigation, and asset optimization
- Outline implementation strategies, challenges, and policy frameworks for large-scale deployment

Objective

- Bridge the gap between emerging digital technologies and ground realities of Indian utilities
- Present a structured roadmap for phased adoption with short-, medium-, and long-term milestones
- Guide stakeholders on critical enablers: infrastructure readiness, workforce skilling, and regulatory support
- Foster inter-agency collaboration, promote PPPs, and build capacity for inclusive and sustainable digital transformation
- Support India's energy transition goals including 24x7 reliable power, carbon reduction, and achievement of 500 GW non-fossil capacity by 2030



Link:

Contents of the Handbook

- **Executive Summary**
- **Chapter -1: Introduction**
- **Chapter 2: AI, ML, AR/VR/aR and Robotics Technologies** - provides a **comprehensive overview** of AI, ML, VR, AR, aR, and Robotics—covering definitions, evolution, tools, and relevance to power utilities.
- **Chapter 3: Curated Library of Successful Use Cases -** The handbook details numerous real-world applications across Generation, Transmission, Distribution, and other domains, providing proven models for utilities to follow. The Handbook has 174 Use Cases from 35 countries including 45 from Indian Utilities . Out of these 47 use cases are explained in details in this chapter.
- **Chapter 4: Policies, Regulations and Standards related to AI, ML, AR/VR/aR and Robotics Technologies**
- **Chapter 5: Implementation Strategy and Roadmap for Adoption**
  - **Utility Readiness Matrix (URM),** a diagnostic framework was developed to classify utilities into three maturity levels: **Initiators, Integrators, and Optimizers**. This allows for tailored recommendations and a customized adoption path for each utility.
  - **A Phased Implementation Roadmap (0-10 Years):** A detailed, actionable roadmap outlining short-term (0-2 years), medium-term (2-5 years), and long-term (5-10 years) strategies for utilities at each maturity level.
- **Appendix – A:** 37 Use cases are presented in Appendix A
- **Appendix –B:** Web Links of 90 use cases are given in Appendix B
- **Appendix – C: Case Study of DBS Bank's Digital Transformation - links of videos and articles**
- **Appendix – D:** presents a country-wise and application wise table of the 174 use cases

Summary of Use Cases Covered Across Power Sector Functions

Use Case Category	Number of Use Cases Covered per Category			Total
	Main Report	Appendix A	Appendix B	
Generation	8	12	16	36
Transmission	6	9	15	30
Distribution	9	12	21	42
System Operations	8	4	18	30
Power Trading	8	-	10	18
Robotic Process Automation (RPA)	6	-	6	12
Security Operations Centre (SOC)	2		4	6
Total	**47**	**37**	**90**	**174**

The Handbook highlights **174 use cases** of AI/ML, AR/VR/aR, Robotics and Digital Twin technologies across **Generation, Transmission, Distribution, System Operations, Power Trading, RPA,** and **SOC** functions.

The distribution of use cases highlights the significant emphasis on **Distribution (42)** and **Generation (36)**, reflecting ongoing innovation in asset management, grid monitoring, and consumer services.

AI Use Cases in Power Sector (1/6)

- **Predictive Maintenance of the Power Infrastructure**: Predictive maintenance models designed using AI algorithms to monitor the condition of critical power assets such as power plants, wind turbines, solar farms, transformers, substations, and transmission and distribution lines. By analysing real-time data from IoT sensors, historical performance metrics, and environmental conditions, AI tools can detect early signs of wear and tear, and potential faults to undertake predictive maintenance – help meet regulatory compliances (SAIDI/SAIFI/CAIDI/CAIFI) and significantly improving customer satisfaction by ensuring uninterrupted power supply.
- **Renewable Energy Forecasting**: AI could play a crucial role in improving the accuracy of renewable energy (RE) generation forecasts, especially for variable sources like solar and wind. Using advanced machine learning models, AI tools could analyse historical generation data, weather forecasts, and satellite imagery to predict energy output with higher precision. More accurate forecasting ensures efficient utilization of renewable energy, reduce RE curtailments, reduce reliance on fossil fuel-based backup generation, and improved grid stability
- **Grid Management with DER**: Through advanced analytics, AI tools could identify grid imbalances, predict fluctuations in demand and supply, and adjust power generation and distribution accordingly. This leads to improved grid stability and reduced transmission losses. AI-powered systems can also automate fault detection and self-healing processes, ensuring faster recovery from outages.

AI Use Cases in Power Sector (2/6)

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- **Power Theft Detection**: Power theft remains a significant challenge in many places in India, contributing to high AT&C losses. AI-based systems could analyse consumption patterns, meter data, and historical usage to detect irregularities and potential cases of unauthorized electricity usage. By deploying machine learning algorithms, utilities can identify theft-prone regions, predict future occurrences, and prioritize inspection efforts. These systems can also differentiate between technical losses and deliberate tampering, ensuring targeted interventions.
- **Dynamic Load Forecasting**: AI-driven dynamic load forecasting models play a critical role in distribution network management by accurately predicting electricity demand at granular levels, such as feeder, transformer, and consumer clusters. By analysing real-time data of energy consumption patterns, weather conditions, and regional demand trends, AI enables utilities to forecast load variations with high precision. This allows for better distribution system planning, reducing the risk of overloading or underutilization of network assets. Additionally, accurate load forecasting reduces the power purchase cost, minimizes technical losses, improves voltage stability, and enhances the reliability of supply.
- **Integration of Electric Vehicles**: AI tools are necessary for efficient management of EV charging operations by optimizing charging schedules with respect to other must-run loads on the distribution grid. ML models predict charging demand based on user behaviour, traffic data, and weather conditions, ensuring efficient utilization of charging infrastructure. AI also enables vehicle-to-grid (V2G) interactions, where EVs can act as distributed energy resources, contributing to grid stability during peak demand periods. AI-driven solutions are essential for managing the rapid growth of EV adoption in India.

AI Use Cases in Power Sector (3/6)

- **Power Trading Optimization**: AI tools transforms power trading by analysing real-time market data, forecasting price trends, and automating bidding strategies. It enables utilities and independent power producers to make informed decisions about power purchases and sales, maximizing revenue and minimizing costs. AI algorithms also identify arbitrage opportunities, optimize contract structures, and manage risk associated with price volatility. This enhances transparency and efficiency in power markets, fostering competition and benefiting end consumers through lower electricity costs.
- **Optimization of Energy Storage Systems**: AI enables intelligent management of energy storage systems (ESS), ensuring their efficient integration into the grid. By analysing grid demand patterns, renewable energy availability, and market price signals, AI can optimize charge and discharge cycles of energy storage systems. This enhances their operational efficiency, reduces degradation, and extends the lifespan of storage assets.
- **Tripping Analysis at Grid / Substation Level:** Deploying AI and ML models for analysing of tripping at the grid or substation level may help effectively examine factors like tripping frequency, voltage levels, fault locations, restoration time, and fault details. By analysing these parameters, utilities can identify patterns and vulnerabilities in specific regions, equipment, or voltage ranges. This helps improve grid reliability, reduce outages, and enhance fault resolution, leading to more efficient and resilient power supply.

AI Use Cases in Power Sector (4/6)

- **Distribution Transformer Monitoring:** Failure of distribution transformers (DTs) is one of the major issues plaguing in the DISCOMs in India. With the help of AI monitoring of distribution transformers may be made robust enough to ensure their optimal performance and predict potential issues. Key variables including the transformer's age, temperature (oil and gases), loading, frequency, user type, dissolved gases in the oil, Buchholz and other relay's breakdown / fault details etc maybe mapped into the AI model to help predict the transformer's lifespan and schedule predictive maintenances, accordingly.

- **Network Reliability Analysis and Regulatory Compliance:** Since reliability indices like SAIFI, SAIDI, CAIFI, CAIDI etc are the most vital and comprehensive indicators of a distribution utility's operational performance, utilizing AI tools can offer valuable insights for reliability improvement by focusing a deep-down analysis on factors like geographic division, contribution of fault types, seasonality effect in reliability, impact of weather factors – wind, precipitation, fog, temperature, etc.

- **Revenue Maximization:** Distribution utilities face challenges in collecting revenue efficiently and timely and seeks ways to receive payments earlier. By deploying AI and ML technologies, utilities can implement solutions like payment behaviour analytics, customer risk scoring models, and customer default forecasting to enhance revenue collection. AI-driven payment behaviour identifies trends and predicts payment patterns, allowing utilities to proactively engage with at-risk customers. Risk scoring models assess customer creditworthiness, enabling targeted follow-ups and flexible payment terms for high-risk accounts. Additionally, forecasting models can predict potential defaults, helping utilities take preventive actions and improve cash flow.

AI Use Cases in Power Sector (5/6)

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- **Textual Data Analytics – Insights from Call Logs:** Analysis of customer service calls and call logs having valuable textual information about issues reported by customers or field teams will help capture details such as the nature of customer complaints, power outages, fault reports, service requests, and maintenance activities. By applying AI tools for data analysis, utilities can extract meaningful insights from this unstructured data. For instance, AI can identify common fault patterns, detect recurring issues in specific areas, and track the frequency and severity of outages. Analysis of customer feedback from these logs helps utilities understand service quality and identification of areas requiring improvement.
- **SCADA Analytics:** Transmission and Distribution utilities face challenges in managing massive SCADA data, analysing historical network behaviour, and linking events to corresponding measurements. By modelling the electrical network using AI based solutions, utilities may simulate scenarios, evaluate the impact of operational changes, and ensure the optimal configuration of assets. This is especially critical for high-voltage networks where reliability and safety are paramount.
- **Training Simulations using Virtual Reality and Metaverse:** Virtual Reality (VR) could transform the training and skill development in the power sector by providing a safe and immersive environment. It allows users to interact with virtual objects and scenarios, offering realistic simulations for complex or high-risk tasks, such as working on live power lines. VR enables workers to practice procedures in a controlled setting, reducing on-the-job accidents and fatalities. It improves knowledge retention of safety protocols and enhances skill development through hands-on experience.

AI Use Cases in Power Sector (6/6)

- **Augmented Reality (AR), Assisted Reality (aR), and Digital Twin based Applications**: The deployment of Augmented Reality (AR), Assisted Reality (aR), and Digital Twins in the power sector may be a revolutionary step toward enhancing operational efficiency, safety, and knowledge management. Digital twins are virtual replicas of physical assets or systems, which can integrate seamlessly with AR/aR to provide immersive, real-time overlays of system conditions, enabling field personnel to visualise and interact with operational data in context. This combination allows remote maintenance and troubleshooting by displaying live system data and offering expert guidance directly to field workers on-site. AR-powered training, supported by Digital Twin simulations, offers hands-on learning experiences using interactive visuals on equipment.

- Key applications include capturing expert knowledge, remote support, virtual installations, digital audits, inspections, and evolving to a predictive maintenance regime, making power systems smarter, safer, and more reliable.

- **Robotics Solutions:** Robots could play a big role in inspecting and maintaining power stations, wind turbines, solar farms, power transmission lines, substations, distribution equipment, and detecting faults, making these tasks safer and more efficient. In renewable energy, robots could improve how solar panels are cleaned and wind turbines are inspected, helping them work better. Drones could also make it easier to inspect power lines, carry-out aerial surveys for identifying load growth areas, identifying illegal constructions and growth of vegetation near / under power lines etc.

Comprehensive Summary of Use Cases by Country and Functional Area

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SL. No.	Countries	Generation			Transmission			Distribution			System Operations and SOC			Power Trading			RPA			Total
	Categories→	M	A1	A2	M	A1	A2	M	A1	A2	M	A1	A2	M	A1	A2	M	A1	A2	
1	Africa	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
2	Australia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
3	Austria	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	Belgium	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2
5	Canada	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
6	Chile	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
7	China	0	0	1	0	1	3	0	0	3	3	0	0	0	0	0	0	0	0	11
8	Colombia	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
9	Denmark	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
10	Estonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
11	Europe	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2
12	France	1	0	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	5
13	Germany	1	1	1	0	0	0	1	0	0	2	0	1	0	0	1	0	0	0	8
14	Global/General	0	2	4	0	1	2	0	0	0	0	0	4	1	0	0	0	0	0	14
15	Greece	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16	Hungary	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
17	India	4	1	2	1	1	2	4	8	11	0	0	4	1	0	1	3	0	2	45
18	Indonesia	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
19	Japan	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
20	Mexico	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
21	Netherlands	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	3
22	Norway	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
23	Portugal	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
24	Russia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
25	Saudi Arabia	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
26	South Korea	0	0	1	0	1	0	0	0	0	0	1	5	0	0	0	0	0	0	8
27	Spain	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
28	Sweeden	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
29	Switzerland	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
30	Turkey	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
31	UAE	0	0	1	0	0	0	2	0	1	0	0	1	0	0	0	0	0	0	5
32	UK	1	1	0	0	1	1	0	0	2	1	1	1	0	0	1	1	0	2	13
33	USA	1	3	0	1	3	2	2	0	2	1	2	3	4	0	1	0	0	0	25
34	Vietnam	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
35	Zambia	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Total Use Cases Covered		174																		

Note: M: Main Report; A1:Appendix A and A2: Appendix B

Relevant International Standards in AI-ML-Robotics Domains (1/2)

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Technology Area	Standard	Description / Relevance
Artificial Intelligence (AI)	CIGRÉ D2.52	Artificial Intelligence applications and technology in the power industry
	ISO/IEC 22989	AI concepts and terminology
	ISO/IEC 23053	Framework for AI Systems Using Machine Learning (ML)
	IEEE 7001	Standard for Transparency of Autonomous Systems
	ISO/IEC JTC 1/SC 42	Ongoing AI standardization committee
	ISO/IEC 24668:2022	Process Management Framework for Big Data Analytics
	ISO/IEC TR 24372:2021	Overview of Computational Approaches for AI Systems
	ISO/IEC 38507:2022	Governance implications of the Use of AI by Organizations
	IS/ISO/IEC TR 24368:2022	Overview of Ethical and Societal Concerns in AI
Machine Learning (ML)	IEEE P2781	Guide for Load Modeling and Simulations for Power Systems
	ISO/IEC 23894:2023	Guidance on AI Risk Management
	ISO/IEC 20546	Big Data — Overview and Vocabulary
	ISO/IEC 25012	Data Quality model (part of SQuaRE)
Generative AI	ISO/IEC 42001:2023	AI - Management System
	ISO/IEC 38507	Governance Implications of the Use Of AI
IoT and Edge AI	IEC 61850	Communication Networks and Systems For Power Utility Automation
	IEC 62351	Power Systems Management - Data and Communications Security
	IEEE 2030.5	Standard for Smart Energy Profile Application Protocol
Robotics & Inspection	IEEE 1872.2	Standard for Autonomous Robotics (AuR) Ontology
	ISO 10218-1/2	Safety Requirements for Industrial Robots
	ISO/TS 15066	Robots and Robotic Devices — Collaborative Robots

Relevant International Standards in AI-ML-Robotics Domains (1/2)

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Technology Area	Standard	Description / Relevance
VR/AR for Training	IEEE 2048.1	VR/AR: Device Taxonomy and Definitions
	IEC 62832	Industrial-Process Measurement, Control And Automation - Digital Factory Framework
	IEEE P1589	Standard for Augmented Reality Learning Experience Models
	ISO/IEC 18039	Mixed and Augmented Reality (MAR) Reference Model
	ISO 9241-960/391	Ergonomics of Human-System Interaction
Assisted Reality	IEEE P2048.6	VR/AR: Immersive User Interface
	ISO 9241 Series	Ergonomics of Human-System Interaction
Cybersecurity (AI/OT)	IEC 62443 Series	Security for Industrial Automation And Control Systems
	IEEE 1686	Standard for Intelligent Electronic Devices Cybersecurity Capabilities
	IEEE 7002	Standard for Data Privacy Process
	ISO/IEC 27001 / 27005	Information Security Management / Risk Management
Digital Twin	IEC 62832	Digital Representation of Industrial Assets
	ISO 23247	Digital Twin Framework for Production and Monitoring
	IEEE 2651	Maturity Framework for Digital Twins in Electric Networks
Integration (AMI)	IEC 62056 (DLMS/COSEM)	Facilitates secure, interoperable exchange of metering data for AI-based analytics and demand forecasting
	IEEE 2030.5	
Integration (DERMS)	IEC 61850-7-420	Supports integration of distributed energy resources and AI-based grid optimization
	IEEE 1547	
	IS 18968 – 2025	
	IEC 61968-5	
Integration (Cybersecurity)	IEC 62443	Provides frameworks for secure AI deployment, access control, and protection of operational and consumer data
	ISO/IEC 27001	
	CEA Guidelines	
Integration (AI Governance)	ISO/IEC 42001	Establishes principles for ethical, reliable, and transparent AI governance in utility environments
	ISO/IEC 5259	
	ISO/IEC 38507	

Overview of Policy and Regulatory Landscape in India

- **Artificial Intelligence / Machine Learning (AI/ML)**
  - **Digital Personal Data Protection (DPDP) Act, 2023**: India's first comprehensive data protection legislation aimed at protecting personal data while allowing its lawful processing. It mandates consent-based processing and establishes clear rights for individuals. Though passed in the Parliament in 2023, the Act is yet to be notified by the GOI
  - **"AI for All" National Strategy (2018)**: NITI Aayog's foundational policy framework aimed at leveraging AI for inclusive economic growth and positioning India as a global leader in AI development

- **Augmented/Virtual Reality (AR/VR) and Robotics/Drones**
  - Currently, no specific regulations govern the use of AR/VR or Robotics in the power sector. However, their adoption is encouraged through national programs like the **Revamped Distribution Sector Scheme (RDSS)**, particularly for applications like workforce training and asset inspection. Several utilities have already adopted drone solutions for thermography, line inspection, and substation maintenance

- **Blockchain-Based Peer-to-Peer (P2P) Energy Trading**
  - India has emerged as a global leader in regulating P2P energy trading, following successful pilot projects
  - **UPERC Guidelines (April 2023)**: The Uttar Pradesh Electricity Regulatory Commission issued the world's first comprehensive regulations for P2P solar energy transactions on blockchain platforms
  - **DERC Guidelines (June 2024)**: The Delhi Electricity Regulatory Commission followed with its own guidelines to facilitate decentralized energy trading and promote renewable adoption in the capital
  - **KERC Regulations (2024):** Karnataka has issued P2P regulations in November 2024 for P2P trading of rooftop solar energy
  - **Kerala Regulations** – KSERC issued Draft regulations for RE which includes P2P and V2G Regulations in June 2025

Implementation Strategy for Indian Utilities

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Framework/Recommendation	Key Pointers covered in Handbook
Phased Implementation Model	• Phased roadmap: Short-term (1–2 yrs) – pilots & data integration; Medium-term (3–5 yrs) – scaling across utilities; Long-term (5–10 yrs) – AI-driven automation & resilience • Align implementation with RDSS AMI, India Energy Stack (IES), and NEP targets
Utility Readiness Matrix (URM) Framework	• Framework to assess digital maturity of utilities across five pillars: Data Infrastructure, Digital Skills, Technology Maturity, Cybersecurity, and Leadership/Innovation • Three maturity levels defined: – Initiators: Early-stage utilities with limited GIS and IT systems. – Integrators: Utilities with moderate digital systems (partial GIS, SCADA/DMS, AMI, ERP) seeking better integration. – Optimizers: Advanced utilities with integrated GIS, SCADA/DMS, AMI, OMS, ERP, and AI/ML-enabled innovation • Guides capacity-building, investment priorities, and sequencing of AI adoption
Capacity Building and Workforce Enablement	• Dedicated Training Budget and Targeted training on AI/ML, AR/VR, and Digital Twin tools • To establish central and regional digital skill centers and partnerships with academia/start-ups • Focus on long term engagement with organizations/consultants for development of technology
Data Governance and Cybersecurity	• Adopt open APIs and unified data standards under IES • Implement ISO 27001 and CERT-In–aligned protocols for cybersecurity
Institutional and Regulatory Enablers	• Form an AI-in-Power Task Force for policy alignment • Encourage regulatory sandboxes and innovation pilots under CEA/MoP • Integrate AI metrics into RDSS evaluation frameworks
Investment and Partnerships	• Promote PPP models for AI/Robotics platforms • Access global digitalization funding • Support Indian start-ups for localized AI solutions
Sustainability and Climate Resilience	• Embed AI/ML in climate risk, disaster recovery, and asset resilience planning • Align with NEP and NAPCC adaptation priorities

Key Recommendations for Different Stakeholders

Stakeholder Group	Key Recommendations
Government and Policymakers	• **National Digital Roadmap**: Embed AI, AR/VR, Robotics, and Digital Twin milestones in RDSS & IES • **Digital Maturity Index (DMI):** Benchmark utilities' digital readiness • **Fund for Innovation**: Establish National AI/ML Innovation Fund for early-stage experimentation and scaling
CERC and State Regulators	• **Revise Investment Guidelines**: Classify AI, AR/VR, Robotics as capital investments with cost recovery • **Regulatory Sandbox**: Enable low-risk pilots (Generative AI, P2P trading, robotic inspections) • **Digital KPIs**: Integrate AI/ML performance metrics into tariff orders.
Utility Leadership	• **Appoint Digital Champions**: CDOs or AI champions to lead transformation • **Build In-House Talent**: Dedicated data science and analytics teams • **Quick-Win Projects**: Early AI/ML use cases (theft detection, outage prediction) to demonstrate value
Technology Providers and Start-ups	• **Design for Integration**: Modular, standards-compliant solutions (SAP, SCADA, GIS, ERP) • **Pilot-First Models: Flexible testing before full deployment** • Co-Develop Solutions: Partner with utilities for DER optimization, digital twins, grid analytics
Training Institutes and Academia	• **National Certification Programs**: Partner with NPTI, IITs, NITs for AI, AR/VR, Robotics • **VR Simulation Training**: Immersive training for safety, grid ops, substations • **AI Literacy Programs**: Multi-level modules for engineers, managers, and leadership

Contact Us

ISGF India Smart Grid Forum

reji@rejikumar.com @rejipillai

India Smart Grid Forum

CBIP Building, Malcha Marg, Chanakyapuri, Delhi-110021

www.indiasmartgrid.org

www.globalsmartenergy.org

www.rejikumar.com

www.isuw.in

www.dumindia.in

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