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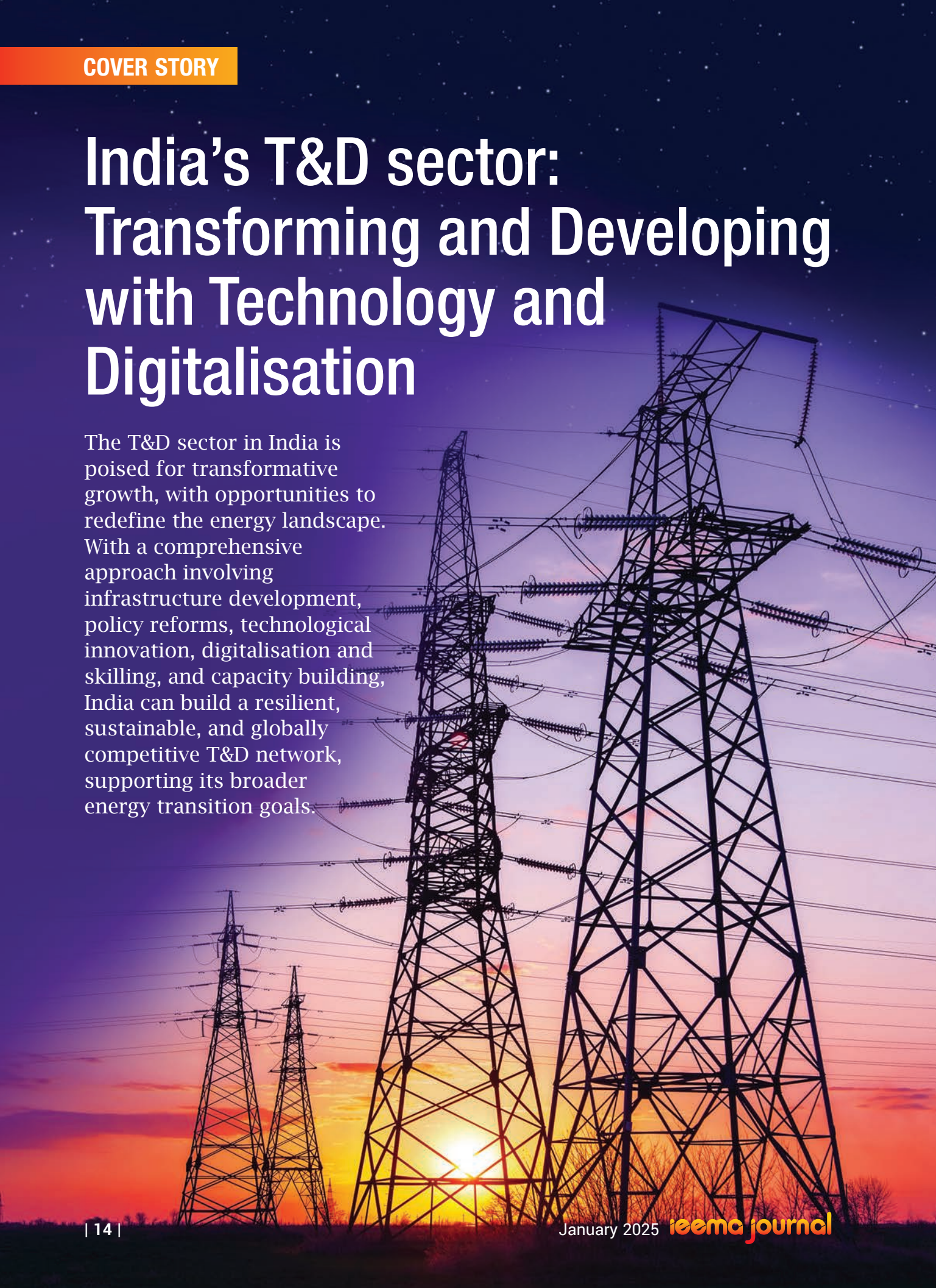
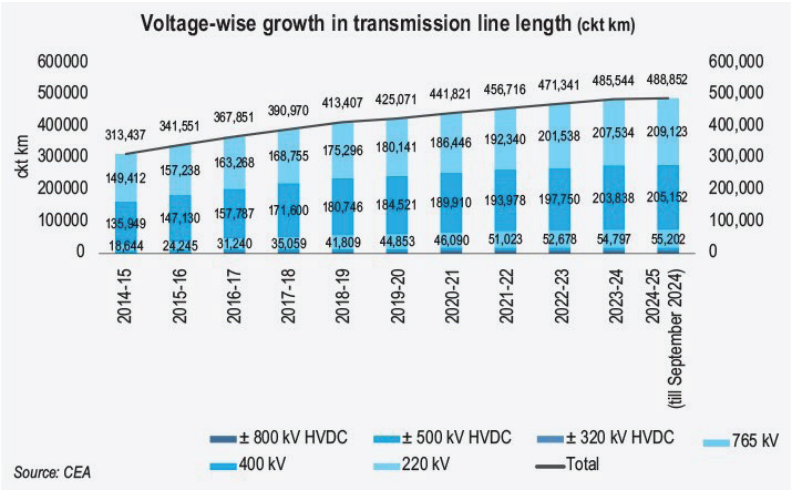
India's T&D sector: Transforming and Developing with Technology and Digitalisation

The T&D sector in India is poised for transformative growth, with opportunities to redefine the energy landscape. With a comprehensive approach involving infrastructure development, policy reforms, technological innovation, digitalisation and skilling, and capacity building, India can build a resilient, sustainable, and globally competitive T&D network, supporting its broader energy transition goals.



Globally, the power transmission and distribution (T&D) market was valued at US$ 330,287.71 million in 2023 and is expected to grow at a 3.9 percent CAGR from 2024-2030, according to a report.

For India, the T&D segment is expected to get a significant boost with an estimated capex of Rs9.1 trillion between FY25-32, as per India Ratings and Research. The October 2024-released National Electricity Plan (NEP)-Volume II outlines substantial investments in the sector with opportunities for engineering, procurement and construction (EPC) companies operating in the T&D segment in India.



The past decade saw India's T&D segment grow with substation capacity (MVA/MW) increasing to 1,251,080 at FY24-end (FY22: 1,104,450) from 409,551 at FY12-end.

The total transmission lines length of 220 kV and above has reached about more than 488,000 ckm, with plans to expand this significantly, shares **Nilesh Kane, Chief-Distribution (Mumbai Operations), The Tata Power Company Limited.** The draft NEP estimates an addition of about 105,000 ckm and 595,000 MVA of capacity from 2027-2032.

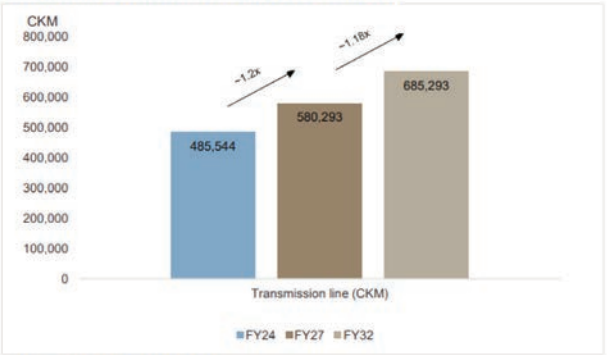
As per the 20th Electric Power Survey report, peak electricity demand is expected to reach 296 GW by FY27 and 388 GW by FY32. As per NEP-Volume II, about 114,687 ckm of transmission lines and 776,330 MVA of transformation capacity (220 kV and above voltage level) are planned to be added from 2022-2027. Furthermore, 1,000 MW of high-voltage direct current (HVDC) bi-pole capacity and 30,690 MW of inter-regional transmission capacity are planned to be added from 2022-2027, with the latter expected to increase the inter-regional power transmission capacity to 142,940 MW by 2027-end.

The targeted transmission system augmentation from 2024-25 is 16,667 ckm of transmission lines and 116,490 MVA of transformation capacity (220 kV and above voltage level). Hence, significant capacity addition is required in India's T&D segment each year up to FY32.

"For India to meet its energy transition goals and become a global leader in T&D, skilling initiatives must focus on bridging technological, operational and regional gaps."

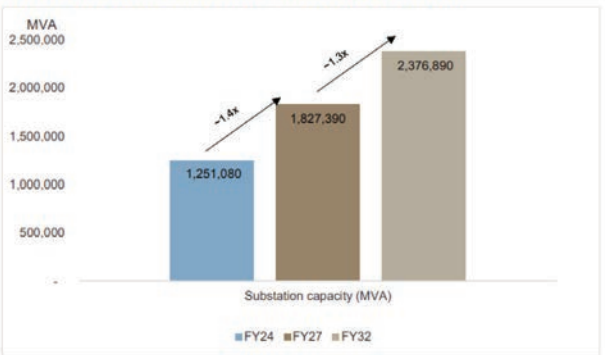
Devendra Kumar Singh from Larsen & Toubro, and Chairman, IEEMA T&D Projects Division

Figure 27: Total transmission line capacity outlined as per NEP



Source: CEA, CRISIL MI&A Research

Figure 28: Total transmission substation capacity outlined as per NEP



Source: CEA, CRISIL MI&A Research

Growth Pillars

For **Sandeep Zanzaria, Managing Director & CEO, GE Vernova T&D India,** the country's T&D sector growth is fundamentally driven by three key pillars: 1) Energy transition – the shift to RE. 2) Per capita energy consumption growth potential. 3) Demand drivers within the sector, including electric vehicles (EVs), green hydrogen, data centres and increased private sector investments. "Collectively, these factors suggest that the ecosystem is not only sustainable but also poised for long-term growth," Zanzaria opines.

"Public-private partnerships (PPPs) will play a key role in achieving the target, expanding T&D networks, in tandem with the growth of RE sources, crucial for effectively meeting future energy demands," opines **Gajanan S Kale, CEO, Tata Power Delhi Distribution Limited (Tata Power-DDL).**

The Government of India (GoI) has rolled out comprehensive growth-oriented transmission projects to evacuate power from green energy/RE power projects and an incremental addition in the thermal projects at 50 GW to meet the base load demand. This will draw an estimated expenditure of Rs4.9 lakh crore involving an addition of 77,000 ckm of transmission lines and 500 GVA of transformation capacity in the transmission segment. Similar expenditure is planned in the distribution segment, which is largely driven by state governments.

"The visibility of these schemes and its priority accorded has motivated key players – equipment manufacturers and engineering, procurement and construction (EPC) companies – to enhance their production capacity, drawing more capex," explains **Rajeev Dalela, President, T&D (India & South Asia), Kalpataru Projects International Limited.** "We can expect the growth momentum to continue, given the government's commitment on climate change," he adds.

Image courtesy: Tata Power Delhi Distribution Limited

Technologies such as smart grids, AMI and DR systems will be essential in improving operational efficiency, reducing outages and ensuring better demand-supply management.

"Capital-intensive projects like green energy corridors and HVDC networks require innovative financing mechanisms such as InvITs."

Sandeep Zanzaria, Managing Director & CEO, GE Vernova T&D India

"Electrifying sectors like railways and metros will increase electricity demand, necessitating further upgrades to the T&D network to accommodate this increased load."

Gajanan S Kale, CEO, Tata Power Delhi Distribution Limited

Key Trends and Market Sentiment

Government initiatives such as 'One Nation-One Grid-One Frequency' and a target of achieving 500 GW RE capacity by 2030 has helped transform India's transmission segment from a fragmented network to a well-integrated and interconnected grid.

Green energy corridors, decentralised systems, smart grids and private investments are key growth drivers, according to **Saurabh Kaushik, Head Business Development-PT&D, G R Infraprojects Limited (GRIL).** He points out to energy storage, global collaboration, EV infrastructure and regional integration as emerging sector trends.

The market sentiment is optimistic, supported by initiatives like the revamped distribution sector scheme (RDSS) and increasing PPPs in transmission, says **Devendra Kumar Singh from Larsen & Toubro,** are **Chairman, IEEMA T&D Projects Division.** "Transmission assets are drawing significant investor interest, especially from infrastructure funds and foreign investors, due to stable long-term returns and clear regulatory mechanisms. However, the distribution sector still faces challenges such as high aggregate technical and commercial losses

"With increased power transfer envisaged across regions, we will see an increased adoption of HVDC technology for higher voltages in a few years."

Rajeev Dalela, President, T&D (India & South Asia), Kalpataru Projects International Limited

"Using AI and digitilisation in T&D projects can enhance operational efficiency, facilitate RE integration and improve grid resilience, among others."

Nilesh Kane, Chief-Distribution (Mumbai Operations), The Tata Power Company Limited

(AT&C) and financial stress in discoms, although reforms are addressing these issues."

The government's allocation of US$ 36.74 billion for RDSS underlines its commitment to enhancing the reliability and efficiency of power supply across the country, opines Kane. He adds that the reduction in aggregate technical and commercial (AT&C) losses to 15.41 percent as of FY22-23 also reflects positive reforms in the sector.

Singh further highlights key trends shaping the sector. Strengthening of interregional transmission corridors to balance regional generation and demand mismatches, focus on green corridors for RE evacuation and offshore wind integration, and digital transformation through technologies like artificial intelligence (AI), internet of things (IoT) and blockchain for grid management and energy trading. "Consumer-centric innovations such as prosumers, net metering, and peer-to-peer energy trading models are gaining traction as discoms adopt more consumer-focused approaches," shares Singh.

Technology All the Way

With increased power transfer envisaged across regions, an increased adoption of HVDC technology for higher voltages will be a key change that we can see in the next few years, shares Dalela. The GoI is also actively considering an option to transmit a large quantum of power at 1,200 kV AC.

HVDC technologies, including line-commutated converter (LCC) and voltage source converter (VSC) systems, are pivotal for managing long-distance power flows and cross-border connectivity, says Zanzaria. Another key trend is the adoption of STATCOM technology, he adds. "STATCOM systems will play a critical role in reactive power management, ensuring voltage stability amid increasing renewable penetration."

Zanzaria further highlights the importance of software. "The energy landscape has become so complex that traditional grid management is no longer adequate. Electric utilities must be able to manage every aspect of the grid ecosystem – from transmission to distribution to the edge and back. This process is called grid orchestration, and it requires digital technology," he observes. With the increasing number of assets in the grid due to RE, managing these assets effectively requires significant digital interventions on two fronts – on the network management side and at the substation level.

"With drones, robots and AI, we are experiencing an enhanced predictable maintenance cycle, leading to better availability of the power system," opines Dalela. "For example, we see an improvement in productivity in overseeing EHV transmission lines with drones, which otherwise was more labour intensive and time consuming," he shares.

Smart grids, advanced metering infrastructure (AMI), energy storage systems (ESS), AI and machine learning (ML), and hybrid technologies such as hybrid switchgear are among key emerging technologies poised to shape the future of India's power grid, points out Kane. "Using AI and digitilisation in T&D projects can enhance operational efficiency, facilitate RE integration, improve grid resilience, promote sustainability and support policy development," he adds.

"To manage the increasing influx of RE, substantial investments are essential for upgrading both, inter-state and intra-state networks."

Saurabh Kaushik, Head Business Development-PT&D, G R Infraprojects Limited

Critical Emerging Technologies for Future Grid Development

India's grid is one of the largest synchronous grids globally. It is set for a transformation through the integration of emerging technologies to boost its efficiency, reliability, and capacity, aligning with the country's ambitious RE targets. **Devendra Kumar Singh from Larsen & Toubro,** and **Chairman, IEEMA T&D Projects Division,** takes us through key technologies for grid development:

- **Energy storage systems:** Essential for managing RE variability, battery energy storage systems (BESS) and pumped hydro storage are vital for grid stabilisation and peak load management. Lithium-ion and emerging alternatives like sodium-ion and flow batteries will play a significant role.
- **Smart grid technologies:** AMI and DR systems improve energy efficiency and demand management. IoT and sensors enhance grid maintenance.
- **FACTS:** Technologies like static VAR compensators and HVDC systems improve voltage stability and facilitate long-distance power transmission with minimal losses, especially for integrating offshore wind and interregional connectivity.
- **AI and ML:** Used for predictive analytics and asset health monitoring, enhancing grid reliability and optimising operations, AI-based algorithms can dynamically optimise grid operations, reducing losses and enhancing efficiency.
- **Renewable energy integration tools:** Hybrid energy systems (combines solar, wind, and storage systems for more consistent power output) and virtual power plants (VPPs) (aggregates distributed energy resources [DERs] like rooftop solar and storage, enabling them to function as a single entity in the grid) ensure consistent power output and efficient resource aggregation.
- **WAMS:** Real-time grid monitoring enhances situational awareness and proactive decision-making during grid disturbances. It helps in real-time grid monitoring, ensuring grid stability and faster fault detection.
- **Cybersecurity solutions:** Essential for protecting digitised grid infrastructure. With increased digitisation, robust cybersecurity measures are critical to protect grid infrastructure from potential threats.
- **RE corridors:** Dedicated transmission infrastructure for RE evacuation and hybrid transmission lines combining AC and DC systems for better efficiency and flexibility.
- **Vehicle-to-grid (V2G) technology:** Enables EVs to act as distributed energy resources, storing and supplying energy back to the grid during peak demand.
- **Offshore wind integration:** Using subsea cables and HVDC links are critical for evacuating power from offshore wind farms.

Facilitating Sustainability and Other Aspects

AI and digitalisation are transformative technologies that can significantly enhance the sustainability, efficiency and reliability of T&D projects. Here's how they can facilitate sustainability and address other critical aspects of T&D:

- **Enhancing grid efficiency and loss reduction:** AI-powered load forecasting, loss detection and prevention, energy optimisation.
- **Facilitating RE integration:** Balancing supply and demand, dynamic grid management, energy storage optimisation.
- **Sustainability improvement:** Reducing carbon footprint, predictive maintenance, smart energy usage.
- **Asset management optimisation:** Digital twins, asset health monitoring.
- **Smart grids enablement:** Grid automation, decentralised energy management, advanced demand response.
- **Reliability and resilience enhancement:** Real-time monitoring, disaster preparedness, cybersecurity.
- **Proactive policy and market mechanisms:** Dynamic pricing models, energy trading platforms.
- **Stakeholder collaboration support:** Digital collaboration tools, consumer engagement.

Key Technologies in Digitalisation

Key technologies in digitalisation include IoT devices and sensors that enable real-time data collection and monitoring of grid components; big data analytics that provide actionable insights from vast amounts of operational data; modern survey techniques such as drone-based survey and satellite imaginary-based survey that provide accurate survey data with greater accuracy levels; edge computing – which processes data locally at

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grid nodes, enabling faster decision-making and reducing dependency on centralised systems; and blockchain – which enhances transparency and trust in energy transactions, particularly for decentralised energy systems.

Case Studies and Applications

AI and digitalisation are gamechangers for the T&D sector, enabling a transition toward more sustainable, efficient, and reliable power systems. They facilitate better resource utilisation, enhance grid flexibility, and promote RE integration, making them indispensable for India's energy transition goals. Here are instances of states, cities and organisations that have applied digitalisation technologies.

- **Smart grid deployments:** Cities like New Delhi and Bengaluru are implementing smart metering and grid automation to improve energy efficiency.
- **RE integration:** AI-powered weather forecasting is being used to predict solar and wind power generation in RE-rich states like Tamil Nadu and Rajasthan.
- **Digital twins in transmission:** The Power Grid Corporation of India uses digital twins to simulate grid behaviour and plan network expansions.

In agreement, Kaushik also highlights HVDC transmission, microgrids, wide-area monitoring and cybersecurity, among others. "Currently, AI-powered drones are used for inspection and monitoring of T&D lines and digital twins for operations and maintenance, design of substations and T&D lines."

"The future grid ought to be equipped with advanced grid automation systems to enable real-time monitoring, control, and optimisation of energy flows," says Kale. He adds that technologies such as smart grids, AMI, and demand response (DR) systems will be essential in improving operational efficiency, reducing outages, and ensuring better demand-supply management.

AI and ML will play a critical role in optimising grid operations, predictive maintenance, and asset management. According to Kale, the growing use of distributed energy resources such as rooftop solar, EVs, and small-scale wind or hydro systems necessitates a shift towards decentralised grid architectures. "More importantly, with India's ambitious goals for EV adoption, integrating EV charging infrastructure into the grid is essential," he adds.

(See box on 'Critical Emerging Technologies for Future Grid Development' for more).

Overcoming Challenges

Despite challenges like the financial health of discoms and grid reliability issues, strong policy thrust, technological advancements and growing private sector involvement are expected to make the sector more robust, integrated, and future-ready.

Laying power transmission lines is among the most challenging tasks in the power sector due to factors like terrain, skilled manpower, weather conditions, construction timelines and environment clearance, to name a few, observes Kale. Lack of clear guidelines for construction of projects passing through eco-sensitive areas is another major challenge in building transmission lines, he adds.

A total of 1,650 GW of RE capacity worldwide is delayed in connecting to the grid due to transmission bottlenecks, points out Kaushik. "To address these challenges, it is essential to focus on localising the supply chain for transmission equipment, as global supply chains are under significant strain." He adds that T&D projects are particularly impacted, facing constraints in expanding transmission capacity due to right of way (RoW) issues and a limited supply of critical equipment. Additionally, land acquisition for grid substations remains a major hurdle. "To mitigate these issues, efforts are made to secure commitments from suppliers and conduct detailed site assessments to address land challenges. There is also a strong need for government support in overcoming these obstacles."

Image courtesy: G R Infraprojects Limited

AI-powered drones are used for inspection and monitoring of T&D lines and digital twins for operations and maintenance, design of substations and T&D lines.

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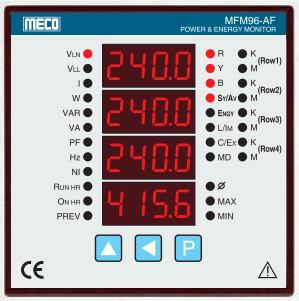

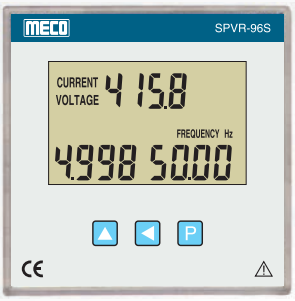

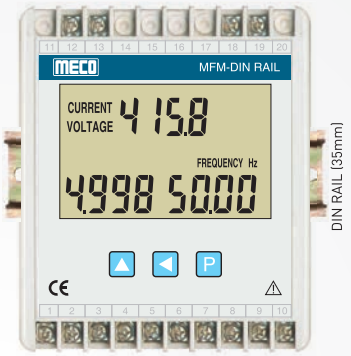

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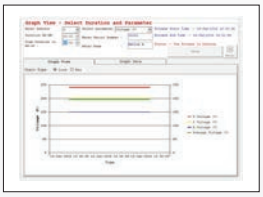

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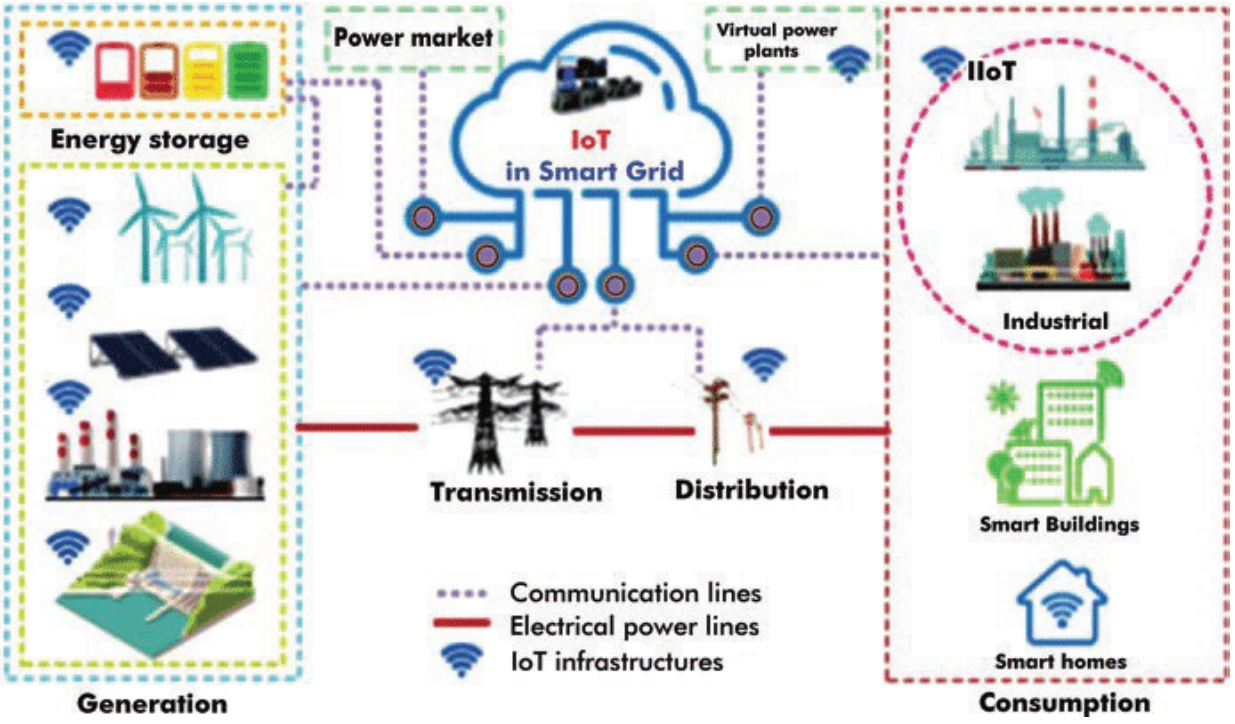

Zanzaria too points out to the key challenge of grid management. He believes that with the increase in RE sources, primarily concentrated in states like Rajasthan and Gujarat, "we will need advanced grid management solutions to efficiently evacuate power and ensure that it reaches consumers across the country." Here, he highlights that technologies such as HVDC systems will be critical in this process. HVDC not only facilitates long distance RE transmission, but also stabilises the grid by managing power flows more effectively.

Another significant challenge is the need for robust forecasting technologies, Zanzaria observes. "We can now leverage strong forecasting tools that incorporate weather data and historical patterns to predict energy generation more accurately. Accurate forecasting is essential for grid operators to balance supply and demand, especially with the increasing integration of intermittent renewable sources like solar and wind."

Dalela shares that with new technologies like narrow-based towers, monopoles and increased adoption of EHV cabling, power transmission is being facilitated to reduce the RoW footprint in the transmission segment.

Highlighting major challenges faced by T&D projects in India, Singh provides solutions to each:

- **RoW issues:** Delays in land acquisition for transmission lines and substations due to landowner resistance and regulatory challenges.
  Solutions: Land reforms, compact transmission technologies like gas-insulated substations (GIS), and high-capacity conductor technology to reduce the special footprint, and underground lines in urban areas to avoid land issues.
- **Financial constraints:** High initial costs and delayed payments from financially stressed state-owned discoms (due to high aggregate technical and commercial AT&C losses).
  Solutions: PPPs, innovative financing models like green bonds, and discom reforms through schemes like RDSS to boost financial health.
- **Transmission congestion:** Power congestion in transmission corridors leads to stranded resources.
  Solutions: Dynamic line rating for real-time monitoring and HVDC systems for efficient long-distance power transmission for minimal losses.
- **RE integration:** Grid stability issues due to the variable nature of solar and wind energy.
  Solutions: BESS, pumped hydro storage to help balance demand and supply, grid flexibility technologies like flexible AC transmission systems (FACTS) and synchronous compensators (STATCOMs) to stabilise voltage and frequency fluctuations and dedicated green energy corridors for RE evacuation/transmission.
- **High AT&C losses:** Losses from theft, inefficient infrastructure and outdated technology in distribution networks.
  Solutions: Smart grids with AMI for real-time monitoring and remote disconnect/reconnect

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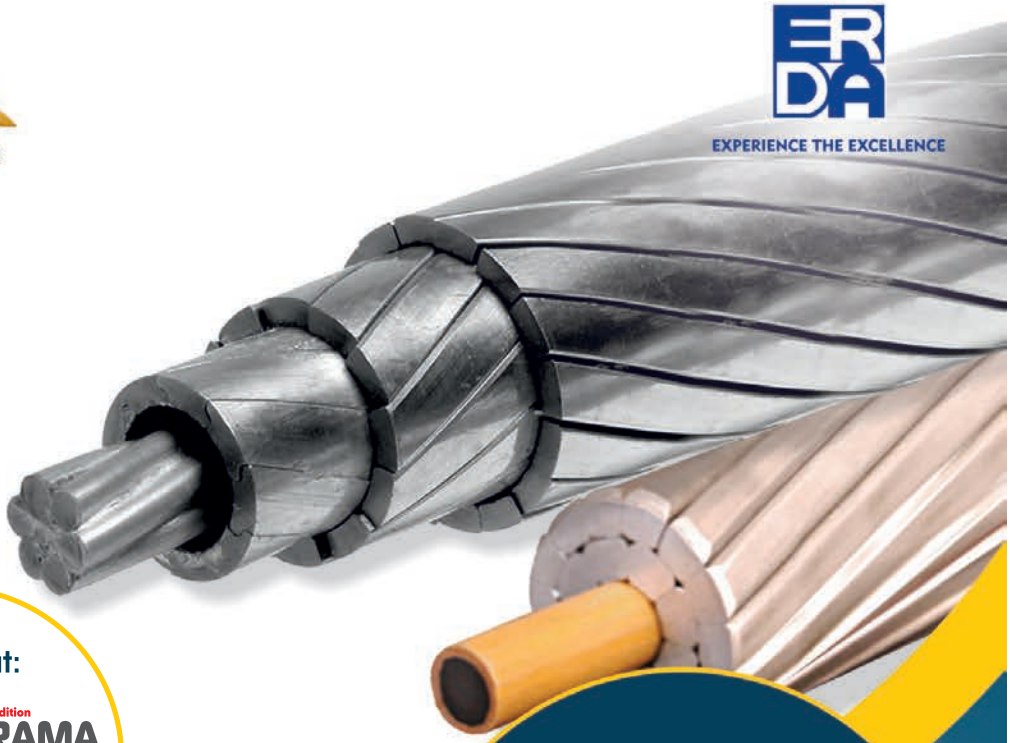

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capabilities, and feeder segregation (separating agriculture/non-agriculture feeders) for better load management.

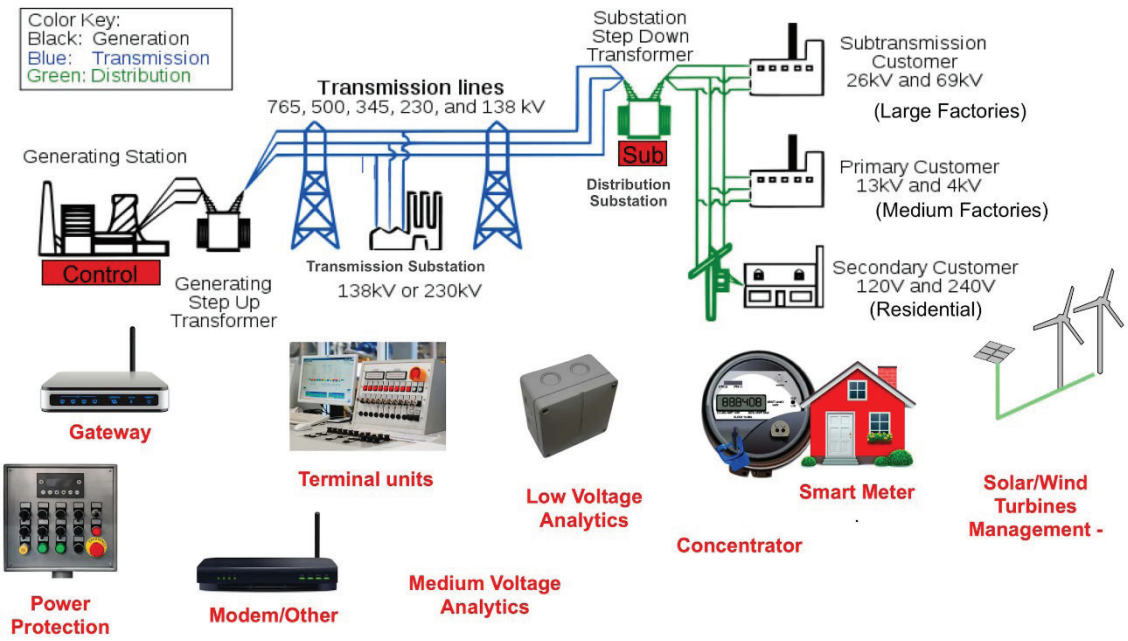
- **Grid resilience and reliability:** Natural disasters, cyberattacks, and aging infrastructure pose threats to grid reliability.
  Solutions: Wide area monitoring systems (WAMS) for real-time data through phasor measurement units (PMU) helps identify and address grid vulnerabilities, and distributed energy resources like microgrids and decentralised generations to improve resilience.
- **Environmental and social impact:** T&D projects often face resistance due to perceived environmental and social disruptions.
  Solutions: Sustainable practices with environmentally friendly construction methods and technologies such as biodegradable oils in transformers, and early stakeholder engagement to address concerns and smooth project execution.
- **Long project timelines:** Delays in approvals, procurement and construction, leading to cost overruns and delayed benefits.
  Solutions: Digital project management tools, the use of AI and data analytics for efficient planning, monitoring and execution; the use of modular and prefabricated solutions to speed up construction.
- **Cybersecurity risks:** Increasing digitalisation of grids make them vulnerable to cyber threats.
  Solutions: Robust cybersecurity frameworks with secure communication protocols and continuous monitoring systems.
- **Inadequate skilled manpower and skill development:** Increasing demands has created a skilling gap and there is acute shortage of industry ready talent, due to inadequate training infrastructure and limited specialised institutions.
  Solutions: Modernising training infrastructure, leveraging digital platforms, fostering industry-academia partnerships, and mechanisation to reduce demands.

The Need for Skilling

Among the several challenges faced, the T&D market in India lacks the availability of skilled manpower in the sector. "This skill gap is particularly evident in emerging technologies like AI and cloud computing, hindering India's competitiveness in the global market," believes Kale.

A skilled workforce is necessary to manage advanced technologies – IoT, AI, AMI, among others; ensure grid reliability; and integrate RE sources. "Key skill areas include digital and smart grid technologies, RE integration, high-voltage transmission (HVDC, FACTS), data analytics, project management (for managing large scale projects particularly in challenging terrains), regulatory and safety compliance, cybersecurity, and soft skills like stakeholder engagement and problem-solving," says Singh.

He adds thar current skilling gaps include inadequate training infrastructure with limited specialised institutions and outdated curricula, a shortage of industry-ready talent, insufficient continuous upskilling opportunities, and geographic imbalances that leave rural and remote areas



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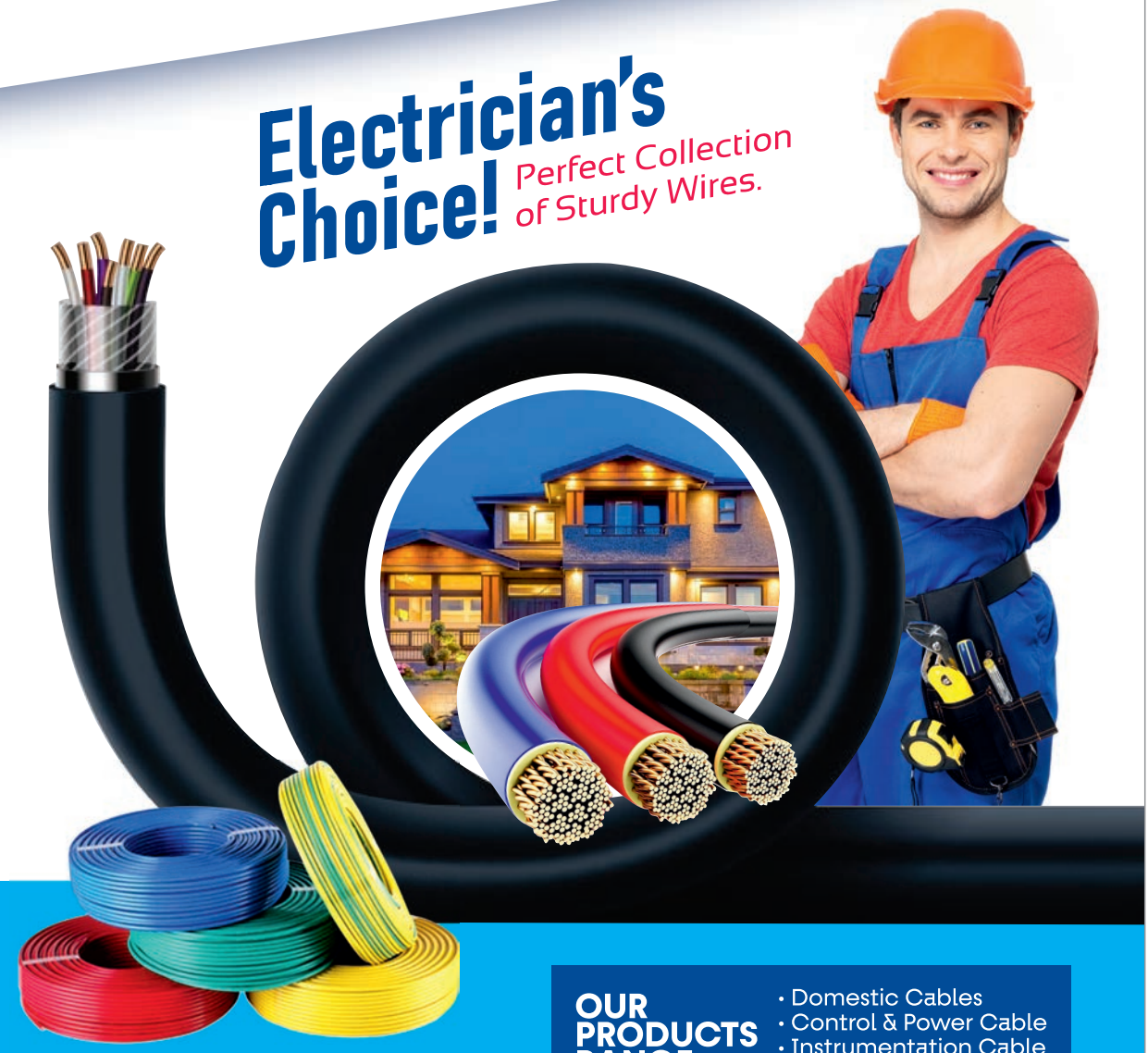

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Image courtesy: Kalpataru Projects International Limited

With new technologies like narrow-based towers, monopoles and increased adoption of EHV cabling, power transmission is being facilitated to reduce the RoW footprint in the transmission segment.

underserved. "Training often lacks focus on emerging technologies such as AI, blockchain, and energy storage."

To overcome these gaps, strategies include expanding and modernising training infrastructure with specialised centres and updated curricula, promoting industry-academia collaboration through internships and certification programmes (in advanced T&D skills like HVDC, STATCOMS, and AMI), encouraging digital learning platforms with online courses and immersive tools, implementing national-level skilling initiatives (like Skill India and the National skill Development corporation [NSDC] to focus on T&D specific skills) with incentives, fostering international collaboration through exchange programmes and alignment with global standards, and supporting continuous reskilling and upskilling via corporate training programmes and micro-credentials.

"For India to meet its energy transition goals and become a global leader in T&D, skilling initiatives must focus on bridging technological, operational, and regional gaps," avers Singh. By modernising training infrastructure, fostering industry-academia partnerships and leveraging digital platforms, India can build a workforce equipped to handle the complexities of future T&D projects. "Continuous learning, international collaboration, and government support will be key to overcoming challenges and ensuring sustained growth in the sector," believes Singh.

Zanzaria agrees that focused programmes on HVDC systems, STATCOM technologies, and digital grid management must be prioritised. "Collaboration between industry, academia, and government can create a pipeline of trained professionals. India also needs to align skill development initiatives with international benchmarks to enhance workforce competitiveness," he adds.

Rebranding T&D as a modern, innovation-driven sector is vital to attract fresh talent. "By reshaping perceptions and building stronger industry-academia partnerships, the T&D sector can secure a skilled workforce ready to power the future," avers Kaushik.

Investments in Inter-State and Intra-State Transmission Networks

The total investment requirement for T&D infrastructure from 2022-2027 is projected at about Rs4,252.22 billion (or Rs4.25 trillion), including both inter-state and intra-state investments, covering components such as transmission lines, substations, and reactive compensation systems, tells us Kane. He shares that looking ahead from 2027-2032, an additional Rs4,909.2 billion (or Rs4.91 trillion) is projected for expanding transmission capacity and the total length of transmission lines are expected to reach about 571,403 km, with transformation capacity increasing to 1,847,280 MVA by the end of this period.

"By 2030, India aims to achieve a total installed generation capacity of about 997 GW, including significant contributions from RE sources. The inter-regional transfer capacity is expected to increase from the current 119 GW to 168 GW by 2032. With a projected total investment exceeding Rs9 trillion by 2032 across phases of development, strategic planning and execution will be essential," explains Kane.

With the Electricity Act paving the way for private players to be a part of the T&D growth story, the industry is also seeing enhanced private participation in successfully implementing the transmission schemes planned under tariff-based competitive bidding (TBCB). "A few states have implemented intrastate transmission projects (InSTS) in TBCB mode; some of these have successfully been implemented and some are in advanced stages of implementation," tells us Dalela. "We also see an increased interest by several states to adopt InSTS under TBCB mode. This will enable effective transfer of power to demand centres within the state," he adds.

To manage the increasing influx of RE, substantial investments are essential for upgrading both, inter-state and intra-state networks. "PPPs and innovative financing mechanisms will play a pivotal role in securing the necessary capital," believes Kaushik.

For the inter-state transmission network, the

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estimated investment from 2022-2027 is about Rs2,691.5 billion (or Rs2.69 trillion) as per the NEP. "The NEP anticipates adding 114,687 ckm of transmission lines and 776,330 MVA of transformation capacity during this period. This expansion is essential to accommodate peak demand projected at 296 GW by 2026-27," says Kane.

Investment needs for inter-state transmission network involve expanding HVDC corridors, creating green energy corridors, and upgrading existing networks, with an estimated requirement of Rs2-3 lakh crore by 2030, opines Singh. He further shares that investment needs in intra-state transmission network involve upgrading aging infrastructure, deploying smart grid technologies, and integrating state-specific RE.

The estimated investment required for intra-state transmission from 2022-27 is about Rs1,560.72 billion (or Rs1.56 trillion) says Kane. "States like Uttar Pradesh, Rajasthan, Madhya Pradesh and Maharashtra have initiated competitive bidding processes for intra-state transmission projects, indicating a proactive approach to enhancing local infrastructure," he adds.

Zanzaria believes that capital-intensive projects like green energy corridors and HVDC networks require innovative financing mechanisms such as infrastructure investment trusts (InvITs). "A proactive approach in transmission corridor development ensures that infrastructure keeps pace with generation capacity, fostering seamless power distribution."

Future Roadmap

The future of India's T&D sector hinges on several key factors. "Strengthening state grids is crucial to ensure reliable electricity reaches even the most remote areas. Investing heavily in grid infrastructure is essential to efficiently transmit and distribute the growing influx of RE," shares Kale. He adds that electrifying sectors like railways and metros will significantly increase electricity demand, necessitating further upgrades to the T&D network to accommodate this increased load.

The global shift towards digital grids and smart cities opens new avenues for T&D exports. "India can play a key role in providing smart grid solutions, digital substations, and energy management systems, which offer real-time monitoring, predictive analytics and automation," believes Kale.

(See box on 'Boosting Exports: International Lessons Learnt' for more).

The T&D sector is poised for transformative growth, driven by the government's focus on RE integration, grid modernisation, and electrification. However, challenges such as aging infrastructure, high losses and financial stress in discoms need to be addressed.

Here's what subject experts have to say on the roadmap forward:

- **Strengthening infrastructure:** Expanding grid capacity by building additional transmission lines and substations to accommodate 500 GW of RE by 2030, developing high-capacity transmission corridors, and upgrading intra-state networks with modern systems to handle growing demand.
- **RE integration:** Accelerating the development of green energy corridors, investing in energy storage systems like BESS and pumped hydro storage, and promoting hybrid solar-wind farms for grid stability.
- **Grid modernisation:** Implementing smart grid technologies for real-time monitoring and efficient management, leveraging digitalisation through IoT, AI and big data analytics, and adopting advanced technologies like HVDC and FACTS for long-distance transmission.
- **Financial sustainability:** Reviving discoms through the RDSS, encouraging privatisation and PPPs, and reforming tariffs to improve financial viability.
- **Focus on energy efficiency:** Reducing losses with AMI and smart metres, promoting energy-efficient appliances, and developing infrastructure for EVs and green industrial processes.

Outlook for 2030

By 2030, India's T&D sector is expected to have transformed into a robust framework capable of supporting a diverse energy mix while ensuring reliability and efficiency. **Nilesh Kane, Chief-Distribution (Mumbai Operations), The Tata Power Company Limited**, shares key expectations from the sector:

- **Increased capacity:** A substantial increase in transmission capacity from approximately 1,251 GVA to about 2,342 GVA will be necessary to meet growing electricity needs.
- **Enhanced interconnectivity:** The inter-regional transfer capacity is projected to rise significantly, facilitating better resource allocation across regions.
- **Sustainability goals:** The integration of RE into the grid will be pivotal for India's climate commitments, with non-fossil fuel sources expected to constitute a larger share of total installed capacity.


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Exports: International Lessons Learnt

India has the potential to significantly boost exports in the T&D sector by leveraging its expertise, cost advantages and experience in managing large projects. Challenges such as stringent quality requirements, competition from global players and lack of brand recognition can be mitigated through investments in testing facilities, focusing on niche markets and building trust through partnerships. By adopting best practices and lessons learned from international markets, India can strengthen its position as a global supplier of T&D equipment, services, and solutions. To achieve this, according to **Devendra Kumar Singh from Larsen & Toubro,** and **Chairman, IEEMA T&D Projects Division,** the country needs to:

- Strengthen its domestic manufacturing capacity
- Build a strong services export portfolio
- Explore emerging markets
- Enter global supply chains
- Enhance competitiveness by focusing on cost-efficiency, timely delivery and high-quality production.
- Strengthen export promotion mechanisms by leveraging export incentives.
- Invest in R&D and innovation and develop advanced technologies and export high-value products.
- Promote skill development and workforce export.

Lessons from International Markets

China's export-driven model

- **Focus on scale and cost-competitiveness:** China leveraged economies of scale to dominate the global T&D equipment market, offering competitively priced products.
- **Government-backed financing:** Chinese firms provided concessional loans tied to infrastructure projects, helping penetrate new markets.

Germany's quality-driven approach

- **Emphasis on technology leadership:** German companies export advanced, high-quality T&D equipment, maintaining a reputation for innovation and reliability.
- **R&D investments:** Germany's focus on continuous innovation in RE integration tools and smart grid solutions serves as a benchmark.

South Korea's strategic partnerships

- **Collaborations for market access:** South Korean firms entered global supply chains through strategic alliances with Western companies.
- **Standardisation:** Their adherence to international standards enabled entry into diverse markets.

Brazil's regional leadership

- **Focus on regional markets:** Brazil targeted neighbouring Latin American countries for T&D exports, benefiting from geographical and cultural proximity.

A combination of government support, private sector innovation, and international collaboration is essential for India to enhance its T&D export potential.

- **Strengthening policy and regulatory framework:** Providing policy clarity for investors, streamlining approvals for faster project execution, and updating grid codes for new technologies and higher RE penetration.
- **Fostering innovation and R&D:** Investing in emerging technologies like AI, ML and blockchain, strengthening domestic manufacturing of T&D equipment, and creating pilot projects for innovations.
- **Workforce development:** Offering skill development programmes, upskilling existing talent, and collaborating with academia to design industry-relevant courses.
- **Strengthening regional and global cooperation:** Expanding cross-border transmission for energy trade, learning from global leaders, and positioning India as a supplier of T&D equipment and services.
- **Enhancing sustainability:** Transitioning to a low-carbon grid, promoting recycling and sustainable disposal of equipment, and engaging communities in development.
- **Mechanisation:** Mechanisation of execution and scaling up for timely project completion.

In India, the T&D sector stands at a pivotal juncture, with opportunities to redefine the energy landscape. The global focus on sustainability and clean energy transition is expected to continue fuelling growth in the power T&D sector in the coming years. A comprehensive approach involving infrastructure development, policy reforms, technological innovation, and capacity building is essential. By addressing challenges and leveraging its strengths, India can build a resilient, sustainable and globally competitive T&D network, supporting its broader energy transition goals.