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सत्यमेव जयते
GRIDCON 2025
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POWERLINE

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GRIDCON 2025 Begins

GRIDCON 2025, being organised by Power Grid Corporation of India Limited (POWERGRID) and CIGRE-India, kicks off today as India's premier power transmission event.

The three-day exhibition and conference is being held on March 9-11, 2025 at the India International Convention & Expo Centre (IICC), Yashobhoomi, Dwarka, Delhi.

The inaugural address will be delivered by Manohar Lal, Union Minister of Power, after a special address by Shripad Yesso Naik, Union Minister of State for Power and New and Renewable Energy, Government of India.

The opening ceremony will also feature addresses by distinguished panellists, including Pankaj Agarwal, Secretary (Power), Government of India; and Nidhi Khare, Secretary, Ministry of New and Renewable Energy, Government of India. This will be followed by a keynote address by Ghanshyam Prasad, Chairman, Central Electricity Authority; Dr Ajay Mathur, Director General, International Solar Alliance; Dr Konstantin O. Papailiou, President, CIGRE; and a theme address by R.K. Tyagi, Chairman and Managing Director, Power Grid Corporation of India Limited.

With participation from more than 2,000 delegates, 150 exhibiting companies and representatives from over 30 countries, GRIDCON 2025 brings together industry leaders, policymakers and experts, regulators, global utility leaders, academia, researchers, and professionals from the power transmission sector to discuss the key trends shaping the transmission sector including grid resilience, asset management and digital transformation.

The key themes for GRIDCON 2025 include disaster resilient design; advances in HVDC systems, particularly hybrid HVDC/MVDC/LVDC configurations; offshore transmission networks with key design and operational insights; lessons on operational excellence in UHVAC systems; latest developments in virtual protection and automation for enhanced grid control; the role of battery energy storage systems in improving grid stability; cybersecurity; digital transformation for modernising utility operations; and digital twins for transformers.

As India witnesses rapid technological and operational shifts, GRIDCON 2025 will provide a platform to explore cutting-edge solutions and strategies for a reliable, efficient and sustainable power grid. It is an unparalleled opportunity to connect with top experts and industry influencers.

The exhibition will showcase cutting-edge technologies and solutions with more than 150 paper/poster presentations. It will also feature dynamic discussions and workshops facilitated by POWERGRID's experts and international thought leaders, ensuring participants benefit from a comprehensive understanding of emerging technologies and practices.

Special events will include a CEO meet, Women in Energy discussions, next-generation networking and technical paper presentations. The event also includes technical visits to the HVDC station in Agra and the National Transmission Asset Management Centre in Manesar, Haryana.

India's transmission sector is the backbone of its energy transition and economic growth, enabling reliable and efficient power delivery. With increasing energy demand, the sector is expanding capacity to ensure reliability. With India playing a significant role in global energy initiatives, its transmission network aims to set a global benchmark by integrating advanced technologies, scaling renewable energy evacuation and ensuring grid stability.

By fostering industry collaboration and knowledge exchange, GRIDCON 2025 is committed to advancing India's power transmission sector by engaging global leaders, industry experts and sector specialists to drive innovation and shape the future of power transmission. ■

"POWERGRID will play a pivotal role in energy transition"

R.K. Tyagi, Chairman and Managing Director, Power Grid Corporation of India Limited

India achieved a record power demand of 250 GW and reduced energy shortages to a mere 0.1 per cent in FY 2024-25. Key advancements in energy conservation, consumer empowerment, and infrastructure development underscore the government's commitment to reliable, affordable, and clean energy.

As of January 2025, the current installed generation capacity in the country stands at approximately 466 GW, which is expected to increase to 900 GW by 2032, as per the National Electricity Plan (Transmission). As India strives to achieve 50% of its generation capacity from non-fossil fuel sources by 2030, and with electricity becoming increasingly vital in the nation's energy mix, significant investments in both interstate and intra-state transmission networks will be crucial.

With a significant projects pipeline worth more than INR 1.5 trillion, POWERGRID will play a pivotal role in this transition and is set to create benchmarks in growth and deliver great value to all its stakeholders. However, the sector faces several challenges, including forest clearances, land acquisition, and right of way (RoW) issues. These challenges are being addressed with the support of the Government of India, respective state governments, and innovative technological solutions. Additionally, the rapid growth in transmission has made the timely availability of critical equipment, such as transformers and GIS, another significant challenge. In today's interconnected world, cybersecurity is also a major concern, and protecting transmission infrastructure from cyber threats is essential to maintaining grid security and reliability.

With the rapid expansion of renewable energy, grid stability challenges are inevitable due to the intermittent nature of sources like solar and wind. Implementing energy storage solutions, smart grid technologies, enhanced forecasting, and grid modernization will be crucial to maintaining a reliable and resilient power supply. Towards this, POWERGRID is modernizing the national grid with initiatives like ULDC systems, URTDSM, NTAMC, RTAMCs, REMCs, and investments in voltage stability solutions like SVCs and STATCOMs. ■

Grid Modernisation

Technology trends shaping the transmission sector

India's power transmission sector is rapidly adopting advanced technologies to enhance grid resilience and support rising renewable energy integration. By leveraging digital tools and technologies, new and advanced construction methods, and state-of-the-art solutions for asset management and maintenance, transmission utilities are improving operational efficiency, managing bidirectional energy flows and ensuring stable power evacuation. A look at the new technologies and trends shaping the power transmission segment…

Substations and transformers

Advanced substation technologies are being adopted to improve grid efficiency, optimise space and tackle emerging challenges. Hybrid substations, combining air-insulated busbars with SF6 gas-insulated switchgear, offer a compact solution for upgrading existing infrastructure, as seen in the 220 kV Hapur and Ghaziabad substations. To address urban space constraints, utilities are exploring underground gas-insulated substations, with Karnataka Power Transmission Corporation Limited planning one in Bengaluru. Additionally, eco-friendly alternatives are being introduced to replace SF6 gas and reduce environmental impact.

Digital substations employing IEC 61850 process and station buses, replacing conventional transformers with digital sensors, have been employed – reducing wiring costs, enhancing safety and minimising cybersecurity risks. A notable example is Power Grid Corporation of India Limited's (Powergrid) 400 kV Malerkotla digital substation. The digital substation retrofitted the existing conventional Malerkotla substation (commissioned in 1992) with comprehensive digital technology.

Further, a fault current limiter offers an alternative to conventional methods for controlling short-circuit levels in substations where fault levels exceed or may exceed design limits. Unlike reactors or high-impedance transformers, it restricts fault currents without adding impedance during normal operation.

Mobile substations also serve as rapid-response solutions for emergency power restoration or temporary industrial power supply. Additionally, tank rupture-proof transformers improve safety in urban areas by preventing catastrophic failures. Meanwhile, the adoption of resin-impregnated paper and resin-impregnated synthetic bushings, which are more resilient than oil-impregnated paper bushings, has been mandated for 145 kV and above transformers.

Remote substation operation is another key technology trend. Powergrid has set up the flagship National Transmission Asset Management Centre in Manesar, Haryana, which can remotely monitor the entire transmission system in real time. It has also taken up the development of autonomous robots powered with artificial intelligence (AI)/machine learning (ML) algorithms for detecting faults in substation equipment to ease routine inspection activities. Meanwhile, Bharat Heavy Electricals Limited (BHEL) has 3D modelling software with significant capabilities, particularly in managing large substations.

Renewable energy integration

The implementation of flexible AC transmission system devices, such as static synchronous compensators (STATCOMs) and static var compensators, is enhancing grid stability and voltage regulation.

STATCOMs were considered for the first time in India with multivendor inverter-based resources at renewable energy pooling stations in the Rajasthan renewable energy complex. The presence of STATCOMs at strategic locations with unique control features near solar power parks enhances grid stability, improves power quality and facilitates the smooth integration of renewable energy sources into the existing power infrastructure. STATCOMs can provide dynamic reactive power support to regulate voltage levels, ensuring grid stability and reliability.

High voltage direct current (HVDC) projects are also expected to play a critical role in integrating renewable energy sources such as solar and wind power into the grid. According to the National Electricity Plan, during the 2027-32 period, around 32,250 MW of HVDC-based transfer capacity is expected to be added to the grid.

Powergrid has successfully built several HVDC projects, including the Northeast-Agra link as well as the Raigarh-Pugalur project. The pipeline of HVDC projects is steadily growing. Recently, Powergrid selected the consortium of Hitachi Energy India Limited and BHEL to design and execute the HVDC link to transmit renewable energy from Khavda in Gujarat to the industrial centre of Nagpur in Maharashtra. The ±800 kV, 6,000 MW bipole and bidirectional HVDC link is part of the transmission system to transfer power from the potential renewable energy zone in the Khavda area of Gujarat under Phase V (8 GW): Part A.

Transmission lines and towers

Innovative technologies in transmission lines are being integrated to enhance capacity, optimise space utilisation and improve grid reliability. Insulated cross arms allow voltage upgradation and better ground clearance without increasing tower height, with successful implementations in Telangana and Kerala. Extra high voltage cross-linked polyethylene cables help mitigate right-of-way (RoW) challenges in urban areas, though they have length limitations, making gas-insulated lines (GILs) a viable alternative in high-power applications. High-performance conductors operate at higher temperatures, increasing power transfer without requiring major structural modifications, while photonic coatings on conductors enhance thermal radiation, improving

capacity at the 66/132/220 kV levels.

Further, the covered conductors prevent electrocution risks in forested areas, reducing outages caused by vegetation contact. Dynamic line rating optimises transmission capacity by adjusting to real-time weather conditions, especially wind speed. Monopole structures are increasingly preferred for their reduced footprint and faster deployment compared to lattice towers.

Further, GILs are being deployed in space-constrained areas despite their high cost, while travelling wave fault-locating technology is improving fault detection accuracy by identifying transmission faults within metres instead of kilometres, enhancing grid reliability and reducing downtime.

Monopoles and multi-circuit towers are also being adopted to conserve RoW in projects. Monopoles have distinct advantages over lattice towers, including lesser space utilisation, faster construction and quicker delivery. Emergency restoration system towers, also known as rapid restoration towers, are also being deployed to facilitate the rapid restoration of electrical power in the event of any damage or failure of high voltage transmission lines.

Traditional survey methods, such as walkover surveys, can be time-consuming and less accurate. To overcome these limitations, utilities are leveraging advanced technologies such as light detection and ranging (LiDAR) and drones for site assessments, topographic mapping, 3D visualisations and RoW estimations. Additionally, helicopters and drones equipped with LiDAR, thermovision cameras and corona cameras are being used by leading developers to enhance aerial patrolling, as well as the operations and maintenance (O&M) of transmission lines and towers.

Communications and cybersecurity

With the increasing complexity of grid management due to rising interconnections, renewable energy integration and smart grid applications, real-time dynamic monitoring has become essential. Traditional supervisory control and data acquisition systems face latency issues, making technologies such as phasor measurement units and wide area measurement systems crucial for real-time grid monitoring, enabling adaptive control mechanisms such as remedial action schemes and system integrated protection schemes. To support these high-bandwidth, low-latency applications, fibre optic communication systems, including optical ground wire, underground fibre optic cables and all-dielectric self-supporting cables, are replacing power line carrier communication in transmission networks.

The Central Electricity Authority has mandated the installation of optical ground wire in all new 110-kV-and-above transmission lines as per its 2022 technical standards. Additionally, the transition from synchronous digital hierarchy and plesiochronous digital hierarchy to multiprotocol label switching is being explored for improved scalability, dynamic routing and bandwidth management.

Utilities have also developed cyber crisis management plans, while the National Critical Information Infrastructure Protection Centre safeguards critical infrastructure. The Ministry of Power has established Computer Security Incident Response Team-Power to handle cyber incidents, and disaster recovery plans are in place. Grid Controller of India Limited's 24x7 security operations centre leverages AI/ML for threat mitigation, and the Cyber Swachhta Kendra monitors vulnerabilities.

Regular alerts, mock drills and cybersecurity training enhance resilience, and imported equipment is tested for cyber threats. Cybersecurity coordination forums address sector-specific security gaps, and audits are conducted to ensure vulnerabilities are resolved. The draft Cyber Security Regulations for the Power Sector are being developed to further enhance security measures.

Outlook

The integration of advanced technologies represents a transformative shift in India's transmission sector, enhancing capacity, reducing losses, optimising power distribution and strengthening grid resilience. However, to fully realise these benefits, it is crucial to establish clear standards and regulations for implementation and operation. Additionally, skill development plays a vital role in supporting infrastructure growth, particularly in erection, commissioning and O&M. As smart grids and automation become more prevalent, the demand for skilled professionals continues to rise. Looking ahead, continued advancements in automation, AI and energy storage will drive further innovation, ensuring India's transmission infrastructure remains resilient, efficient and future-ready. ■

Perspective

Dr Yatindra Dwivedi

Director (Personnel), POWERGRID

As the power sector embraces digitalisation, automation and renewable energy integration, the need for a highly skilled workforce has never been greater. POWERGRID, with over 9,000 skilled professionals, has been at the forefront of human capital development. The company invests in continuous training programmes, equipping employees with expertise in AI, IoT, smart grids and predictive maintenance.

Leadership development programmes groom future industry leaders, while AR/VR-based training modules, on-the-job learning and certifications enhance technical capabilities.

Knowledge-sharing remains key, with global experts, international exchange programmes and employee knowledge portals fostering continuous learning. Mentorship programmes and leadership workshops will prepare the next generation of power professionals.

G. Ravisankar

Director (Finance), POWERGRID

India's power sector has evolved from regional grids to a unified national grid, supported by diverse energy sources. Over the last 75 years, government policies have encouraged private investments, competitive pricing and new financing instruments, driving massive expansion while ensuring financial efficiency. POWERGRID has played a crucial role in India's electrification.

Established in 1989, POWERGRID has played a crucial role in India's electrification, operating a vast transmission network of over 180,000 ckt. km with a transformation capacity of over 4,60,000 MVA. Financially strong, POWERGRID reported a revenue of over Rs 45,000 crore in 2023-24 and holds gross block (assets) as Rs 2.8 lakh crore, with a Rs 1.6 lakh crore investment pipeline planned till 2030. POWERGRID is committed to expanding its network while maintaining one of the lowest transmission tariffs globally. A financially sound transmission network is essential for economic growth and clean energy expansion.

Naveen Srivastava

Director (Operations), POWERGRID

As India advances as a global economic leader, a strong and efficient power infrastructure is essential. The country's transmission network is evolving with advanced technologies, renewable energy expansion, and digital transformation, setting new global benchmarks. AI-driven grid management and modernisation efforts are positioning India at the forefront of future-ready power systems.

With the rapid growth of renewable energy, grid resilience has become a top priority. Challenges such as renewable integration, cybersecurity threats, infrastructure modernisation, and regulatory complexities persist. The increasing digitisation of power infrastructure demands proactive cybersecurity measures. Additionally, upgrading transmission networks and strengthening climate resilience are critical for a secure energy future.

Through technological advancements, strategic investments, and global collaboration, India is building a resilient, sustainable, and future-ready power grid, ensuring reliable energy for its growing economy and reinforcing its position as a global leader in the energy sector.

Vamsi Rama Mohan Burra

Director (Projects), POWERGRID

India's power transmission sector is the backbone of its energy transition and economic growth, ensuring reliable and efficient power delivery. With rising energy demand, the sector is expanding, integrating advanced technologies, scaling renewable energy and strengthening grid stability to set a global benchmark.

India aims to achieve 50 per cent installed capacity from non-fossil fuels by 2030, integrating over 500 GW of renewable energy while ensuring grid stability.

POWERGRID's Green Energy Corridors, the 85 MW Solar PV Project at Nagda and a solar-powered green hydrogen pilot at Neemrana highlight its commitment to sustainability.

Advanced monitoring tools and stakeholder collaboration will further ensure efficient project execution. As the nation accelerates renewable integration and infrastructure expansion, collective efforts will drive a sustainable, resilient power sector.

Strengthening Transmission

Key trends, challenges and network expansion plans

India's transmission network is expanding rapidly to meet the country's increasing power demand and align with the growing power generation capacity. In recent years, this expansion has been characterised not only by the physical growth of the transmission network, but also by the adoption of higher transmission voltages and advanced technologies for bulk power transmission. Furthermore, there is a growing emphasis on transmission network planning and operations to enhance grid resilience and flexibility. The expansion of the transmission system is crucial for addressing the country's rising electricity demand and facilitating the integration of renewable energy sources. A robust transmission infrastructure is critical for efficiently transmitting power over long distances, maintaining grid stability and ensuring an uninterrupted electricity supply.

Size and growth

As of January 2025, the total length of transmission lines at the 220 kV and above levels stood at 491,871 ckt km, comprising 56,333 ckt km at the 765 kV level, 206,182 ckt km at the 400 kV level and 209,981 ckt km at the 230/220 kV level. At the high voltage direct current (HVDC) level, line length stood at 9,655 ckt km at the ±800 kV level, 9,432 ckt km at the ±500 kV level and 288 ckt km at the ± 320 kV level.

The total transmission line capacity addition during 2023-24 was 14,203 ckt km. In 2024-25, as of January 2025, 6,327 ckt km of line length has been added.

Further, the country's total interregional capacity stood at 118,740 MW as of January 2025. Meanwhile, the total transformation capacity stood at 1,269 GVA, comprising 306,700 MVA at the 765 kV level, 481,213 MVA at the 400 kV level and 481,167 MVA at the 230/220 kV level. HVDC capacity currently stands at 18,000 MW at the ±800 kV level, 13,500 MW at the ±500 kV level and 2,000 MW at the ±320 kV level. The total transformation capacity addition during 2023-24 was 70,728 MVA, while for 2024-25, it stood at 51,500 MVA as of January 2025.

In order to fast-track the development of the country's transmission network, tariff-based competitive bidding (TBCB) was introduced in 2006. As of January 2025, 135 interstate transmission system (ISTS) projects have been bid out to public and private players since 2009 under the TBCB mechanism. Of these, 60 projects have been commissioned. In terms of player-wise allocations, 61 projects were secured by Power Grid Corporation of India Limited (Powergrid) and 74 by private players. The key private players in the transmission segment are Sterlite Power Transmission Limited, Adani Energy Solutions Limited, IndiGrid, ReNew Transmission Ventures Private Limited, Apraava Energy Private Limited, Resurgent Power, Sekura Energy, G R Infraprojects as well as recent entrants including Techno Electric, Reliance Industries Limited and DRAIPL.

Emerging trends

Transmission utilities are increasingly adopting predictive maintenance strategies, and leveraging data analytics to assess equipment health and make proactive, informed decisions. Advanced technology solutions, such as drones equipped with thermal imaging, high resolution video and corona cameras, are being deployed for real-time monitoring of transmission lines, substations and reactors. These tools enable utilities to detect grid vulnerabilities swiftly and efficiently, offering a faster, more cost-effective alternative to traditional ground-based inspections. Aerial surveillance and remote inspection technologies are now being integrated with artificial intelligence (AI) to develop intelligent digital twins–accurate digital replicas of transmission lines and towers that enhance maintenance and record-keeping. For instance, Powergrid has introduced digital applications, such as PG DARPAN, for routine patrolling and network assessments, enabling real-time monitoring to improve patrol efficiency, geographical mapping, automated reporting, defect cataloguing, rectification tracking, and resource planning. Another initiative, Asset Management through AI in Transmission, utilises image processing to identify over 30 types of defects with more than 95 per cent accuracy.

To support the reliable integration of renewable energy, renewable energy management centres (REMCs) have been set up at both state and national levels. The REMCs are strategically co-located with load despatch centres across various regions. A total of 11 REMCs have been established at locations including the National Load Despatch Centre in Delhi, the Northern Regional Load Despatch Centre in Delhi, and state-level centres in Andhra Pradesh, Gujarat, Rajasthan, Maharashtra, Karnataka and Tamil Nadu. Additionally, regional centres have been set up at WRLDC in Mumbai and SRLDC in Bengaluru. Currently, these REMCs oversee 62.5 GW of renewable energy capacity, monitoring data from 654 pooling stations across India. Their responsibilities include forecasting renewable generation, handling imbalances, and scheduling power from solar and wind plants. Furthermore, they provide real-time situational awareness, enabling better decision-making for grid operators.

Transmission expansion plans

In October 2024, the Central Electricity Authority released the National

Transmission line and substation capacity addition by 2031-32

Transmission system type/voltage class	Likely addition during 2022-27	Likely at the end of 2026-27 (March 31, 2027)	Likely addition during 2027-32	Likely at the end of 2031-32 (March 31, 2032)
Transmission lines (ckt km)				
HVDC ± 320 kV/500 kV/800 kV Bipole	80	19,455	15,432	34,887
765 kV	36,558	87,581	27,138	114,719
400 kV	34,618	228,596	20,989	249,585
230/220 kV	43,431	235,771	13,228	248,999
Total: Transmission lines	**114,687**	**571,403**	**76,787**	**648,190**
Substations (MVA)				
765 kV	343,500	600,700	319,500	920,200
400 kV	284,970	678,083	135,745	813,828
230/220 kV	147,860	568,497	42,610	611,107
Total: Substations	**776,330**	**1,847,280**	**497,855**	**2,345,135**
HVDC (MW)				
Bi-pole link capacity	1,000	31,500	32,250	63,750
Back-to-back capacity	0	3,000	0	3,000
Total - HVDC	**1,000**	**34,500**	**32,250**	**66,750**

Source: National Electricity Plan, Transmission, October 2024

Electricity Plan (NEP) – Transmission, outlining the transmission network requirements up to 2031-32. The NEP projects an investment of over Rs 9 trillion during 2022-32 in inter and intra-state transmission networks. The plan aligns with the revised (draft) Electric Power Survey, which projects a peak demand of 296 GW by 2026-27 and 388 GW by 2031-32.

As per the NEP, during the 2022-27 period, almost 114,687 ckt km of transmission lines and 776,330 MVA of transformation capacity will be added at an investment of Rs 4,252.22 billion. In the subsequent period, 2027-32, the addition of 76,787 ckt km of transmission lines and 497,855 MVA of transformation capacity are expected at an investment of Rs 4,909.2 billion.

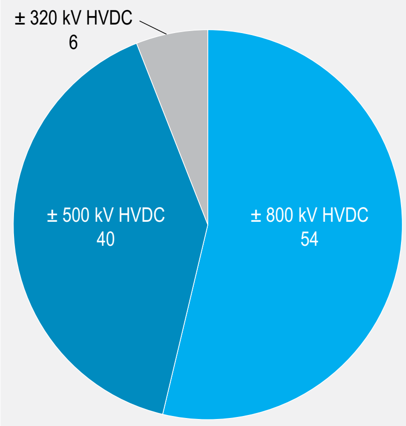
In addition, 1,000 MW of HVDC bipole capacity is expected to be added during the 2022-27 period while almost 32,250 MW is expected to be added during 2027-32. By the end of 2031-32, the total transmission line length is estimated to reach 648,190 ckt km, with a transformation capacity of 2,345,135 MVA. Furthermore, HVDC bipole capacity, including back-to-back systems, is expected to increase to 66,750 MW by the end of 2031-32.

The planned addition of interregional transmission capacity during 2022-27 is 30,690 MW. Several interregional transmission corridors are planned for this period, with 24,600 MW of interregional transmission capacity expected to be added. This expansion will increase the total interregional transmission capacity to approximately 167,540 MW by the end of 2031-32.

Significant plans are also under way for evacuating green power. Under the Green Energy Corridor (GEC) scheme, Phase I of the ISTS was completed in 2020, enabling the evacuation of 6 GW of renewable energy. Intra-state transmission systems (InSTS) are under implementation in eight renewable-rich states – Andhra Pradesh, Gujarat, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Tamil Nadu – connecting 18.72 GW of renewable energy to the grid. While most of the projects are nearing completion, some states have been granted extensions until 2024-25 due to delays in land acquisition and clearances. The InSTS GEC-II scheme aims to add 10,750 ckt km of intra-state transmission lines and 27,500 MVA of substations, with an outlay of Rs 120.31 billion. The GEC-II transmission schemes will be implemented by seven states – Gujarat, Himachal Pradesh, Karnataka, Kerala, Rajasthan, Tamil Nadu and Uttar Pradesh – for the evacuation of approximately 20 GW of renewable energy. Currently, the state transmission utilities are preparing the packages and are in the process of issuing tenders for implementing the projects. The scheduled commissioning for projects under Phase II is March 2026.

Also, as per initial estimates by the Ministry of New and Renewable Energy (MNRE), additional electricity demand from green hydrogen/green ammonia production is projected to reach 70.5 GW by 2031-32. The planned transmission system will be implemented in a phased manner, in line with the development of green hydrogen/green ammonia manufacturing hubs.

Share of HVDC capacity (%)
(as of January 2025)



The electricity demand of the Andaman & Nicobar Islands is mainly met through diesel generator sets, supplemented by small-scale renewable energy sources such as solar and wind power. As per the NEP, the Andaman & Nicobar Islands are planned to be connected to the mainland via HVDC undersea cables. This ±320 kV, 250 MW HVDC (VSC-based) interconnection, spanning 1,150 km, will be the first of its kind in the country. The estimated cost of this transmission project is approximately Rs 151.2 billion. This interconnection aims to help the islands' transition to green energy by 2028-29.

Issues and challenges

India's power transmission sector faces several challenges that impact its growth. Right-of-way constraints and land acquisition hurdles remain key bottlenecks, causing project delays and cost escalations. Acquiring land for transmission corridors is a complex and time-consuming process, often met with resistance from local communities and environmental concerns.

Further, the huge renewable energy capacity addition presents significant challenges. Low gestation period of renewables vis-à-vis transmission is a key challenge. Long UHV/EHV lines are needed to evacuate bulk intermittent/variable power to the grid.

To address the variability of renewable energy sources, various technology initiatives are being taken such as the deployment of VSC-based HVDC, storage and FACTS devices, and synchronous condensers. There is also a strong focus on the development and integration of energy storage devices, including batteries and pumped hydro, into the grid. To incorporate the latest international best practices in transmission planning, the CEA has updated and released the Manual on Transmission Planning Criteria.

Addressing these challenges is crucial to ensure a reliable and efficient transmission network, which is essential for meeting India's growing energy needs and facilitating its transition to clean energy sources. Ambitious plans are shaping the future of the sector, with significant capital investments allocated to expanding transmission infrastructure and improving interconnectivity. Moving forward, these efforts aim to strengthen India's energy resilience, support the seamless integration of renewable energy, and drive India toward a sustainable energy future. ■

Promoting Sustainable Practices

O&M and transmission asset management

Transmission companies are increasingly focusing on sustainable operations and maintenance (O&M), particularly with the construction and operation of high voltage networks. Significant strides have been made in operating high voltage direct current links, with several ongoing expansion projects. Utilities are increasingly adopting cutting-edge technology to improve their operational performance and efficiency, while also increasing the sustainability of their operations. However, the introduction of new technologies, combined with the need to phase out obsolete systems, presents challenges to the seamless operation of these networks. To address the issues and enhance decision-making, risk predictability and asset longevity, transmission companies are leveraging data analytics and advanced technologies.

Emerging O&M practices

One of the key initiatives involves the incorporation of weather analytics into maintenance protocols to mitigate weather-related risks. By linking preventive maintenance activities with weather data, companies can better plan their workforce and adjust operations if conditions are unfavourable. Real-time weather monitoring solutions support effective risk management, while drone-based inspections enhance safety and predictive maintenance efforts. Moreover, the Asset Health Index Platform offers health assessments at portfolio, substation and equipment levels, allowing for more informed decision-making regarding asset management.

Reliability, robust risk mitigation plans and the adoption of digital technologies are essential for ensuring optimal asset performance. The shift toward predictive maintenance is a top-driven strategy supported by upper management in many transmission companies. This approach focuses on utilising pattern-based analysis, leveraging artificial intelligence (AI) tools and conducting studies to anticipate maintenance needs and potential failures. Moreover, the innovative "zoning" concept divides transmission lines into segments representing 10 per cent of the line's length, allowing for performance monitoring within each zone. Issues can be identified through data visualisation tools, enabling targeted interventions based on specific problem areas. Digitalisation is being embraced for every installation, utilising supervisory control and data acquisition systems to mine data for challenges that might otherwise go unnoticed. Furthermore, centralised data on critical applications allows for early detection of anomalies in equipment, such as circuit breakers, enabling rapid corrective action.

Drones are being implemented for inspections, moving towards unsupervised learning, where drones equipped with edge devices can autonomously report detected anomalies. A novel safety feature has also been introduced – if a worker falls from a transmission tower and remains inactive for over a minute, an automatic alert is triggered to initiate help. Going further, utilities plan to enhance their O&M and asset management practices with the use of robots for substation inspections and digital twins for vegetation management. This will involve mapping vegetation data to optimise patrolling and right-of-way management. Additionally, utilities aim to transition to paperless maintenance through augmented reality glasses, QR code-based equipment identification, digitised task lists and auto-logging of field records into a central repository.

The O&M of transmission assets faces several challenges, including changing climate patterns, unauthorised construction beneath transmission lines, the lack of coordination in infrastructure development and frequent regulatory changes. To mitigate these challenges, transmission companies are adopting cutting-edge technologies such as AI, machine learning and satellite-based vegetation management. These tools help manage risks associated with lightning strikes and thunderstorms that can affect insulators and end equipment. Additionally, protective structures have been installed to safeguard critical transmission lines from landslides and snow avalanches.

Overall, transmission companies are actively leveraging data analytics, digital tools and predictive maintenance strategies to overcome the evolving challenges in the O&M of transmission assets. By adopting innovative technologies such as AI, drones, and internet of things-based sensors, these companies are enhancing asset reliability, improving safety and ensuring the long-term sustainability of their operations. Proper O&M practices are crucial for enhancing the overall reliability and safety of the transmission sector, ultimately contributing to a more resilient and efficient energy infrastructure. As these companies continue to refine their O&M practices, they underscore the critical role of advanced analytics and technology in promoting operational excellence and safeguarding the integrity of the transmission network. ■

Interview with Pralhad Joshi

"India has remained steadfast in its transition towards clean energy"

In an interview with *Power Line*, Pralhad Joshi, Union Minister for New and Renewable Energy and Consumer Affairs, Food and Public Distribution, spoke about his key priorities, the achievements of the Indian renewable energy sector, and the progress in the residential rooftop solar, offshore wind and domestic manufacturing segments. He also talked about solutions to decarbonise the coal, food and public distribution sectors. Edited excerpts…

What have been the key recent achievements in the renewable energy sector?

In line with the prime minister's announcement at COP26, the Ministry of New and Renewable Energy (MNRE) is working towards achieving 500 GW of non-fossil fuel-based installed power capacity by 2030. India has remained steadfast in its transition towards clean energy, achieving the fastest pace of renewable capacity addition among all major economies. As of December 31, 2024, 217.62 GW of non-fossil fuel capacity has been installed in the country. This includes 162.47 GW of renewable energy, 46.97 GW of large hydro and 8.18 GW of nuclear power. This accounts for a 47.24 per cent share of the total installed capacity of 460.68 GW as of December 31, 2024. Further, India ranks fourth globally in installed renewable energy capacity, fourth in wind power capacity and fifth in solar capacity (as per IRENA's Renewable Energy Statistics 2024, with data as of December 2023). During the past 10 years, the installed renewable capacity has increased from 76.37 GW in March 2014 to 209.44 GW in December 2024, an increase of around 2.74 times. Installed solar energy capacity has increased from 2.82 GW in March 2014 to 97.86 GW in December 2024, an increase of over 35 times, while wind capacity has increased from 21.04 GW in March 2014 to 48.16 GW in December 2024, an increase of around 2.3 times. Renewable energy generation has increased from 190.96 BUs in 2014-15 to 359.88 BUs in 2023-24. Solar power tariffs have reduced significantly, from Rs 10.95 per unit in 2010-11 to Rs 6.17 per unit in 2014-15 to around Rs 2.60 per unit in 2023-24. Moreover, wind turbine manufacturing capacity has increased from 10 GW in 2014 to 18 GW in 2024, and solar module manufacturing capacity has increased from 2.3 GW in 2014 to 80 GW in 2024.

What are your priority areas as Union Minister for New and Renewable Energy?

My topmost priority is to achieve the Panchamrit target of 500 GW of non-fossil fuel-based installed capacity by 2030. So far, 218 GW of non-fossil fuel-based capacity has been installed and several measures are being taken to achieve the remaining target of 282 GW. These include inviting bids for 50 GW annually and ensuring transmission connectivity. Further, the PM Surya Ghar: Muft Bijli Yojana aims to install rooftop solar systems covering 10 million households by 2026-27. Under the National Green Hydrogen Mission, efforts are being made to establish robust hydrogen infrastructure to achieve the target of 5 million metric tonnes per annum of production capacity by 2030. The MNRE is also working towards the development of offshore wind projects and the promotion of energy storage systems.

What progress has been made so far in the implementation of the PM Surya Ghar: Muft Bijli Yojana?

The government launched the PM Surya Ghar: Muft Bijli Yojana in February 2024 with the aim of increasing the share of rooftop solar capacity and empowering residential households to generate their own electricity. The scheme targets to achieve rooftop solar installations across 10 million households by 2026-27, with an outlay of Rs 750.21 billion. So far, 16.4 million consumers have registered under the scheme, 3,939,000 applications have been received and 806,600 household installations have been completed. Subsidy has been released for 498,000 consumers. The scheme also provides for easy, collateral-free loans from public sector banks at a 7 per cent rate of interest, which can be accessed seamlessly through the PM Surya Ghar portal. Currently, 187,459 loan applications have been received under the scheme, of which 90,215 applications have been sanctioned and 70,585 have been disbursed.

India has a huge offshore wind potential along its coastline. What steps is the government taking to tap this resource?

India is blessed with a coastline of about 11,098 km as was revised recently, surrounded by water on three sides with significant potential for offshore wind energy generation. To tap this potential, the government has taken several steps, including:

- Notification of the Offshore Wind Energy Policy in October 2015 to provide a facilitative framework for offshore wind development.
- As per the preliminary mesoscale study, the National Institute of Wind Energy (NIWE) has identified eight zones each off the coasts of Gujarat and Tamil Nadu, estimating 70 GW of offshore wind potential. Light detection and ranging (LiDAR) technology installed off the coast of Gujarat in November 2017 collected two years of wind data. In addition, the NIWE has conducted geophysical, geotechnical, rapid environmental impact assessment, and oceanographic (wave and tide current) studies off the Gujarat coast for 1 GW capacity in Zone B and obtained in-principle clearances for the same. LiDAR was also installed off the Tamil Nadu coast in October 2024 and wind resource measurements are under way.

> "At a rate of 5 per cent, approximately 50-60 million tonnes of agricultural residue will be consumed annually, generating wealth from waste for farmers and reducing air pollution."

- The MNRE has devised a strategy for establishing offshore wind energy projects, with a bidding trajectory of 37 GW by 2030, as well as various business models for project development (revision issued on September 26, 2023). The Offshore Wind Energy Lease Rules, 2023 have been notified to regulate the grant of lease of offshore areas for offshore wind development.
- Central Transmission Utility of India Limited has completed the planning of the transmission and evacuation network for an initial 10 GW of offshore capacity (5 GW each off the coasts of Gujarat and Tamil Nadu). Further, the governments of Gujarat and Tamil Nadu have agreed for power offtake at Rs 4.50 per unit and Rs 4 per unit respectively from initial offshore wind energy projects on their respective coasts.
- The MNRE, through the Solar Energy Corporation of India (SECI), has issued the first tender for "Leasing out Seabed for Development of 4 GW of Offshore Wind Power Projects". Based on the pre-bid meeting, the tender has been revised and published.
- On June 19, 2024, the union cabinet approved the viability gap funding (VGF) scheme for offshore wind energy projects, with a total outlay of Rs 74.53 billion. The scheme envisages the installation of 1 GW of offshore wind energy projects (500 MW each off the coasts of Gujarat and Tamil Nadu), and grants for the upgradation of two ports to meet logistics requirements.
- The guidelines for the VGF scheme for offshore wind energy projects have been issued. SECI issued a tender for 500 MW of offshore wind energy capacity off the Gujarat coast under the scheme on September 13, 2024. The pre-bid meeting for the same was convened on December 6, 2024.

How does the government plan to secure the supply of critical minerals that are needed for the energy transition?

This subject relates to the Ministry of Mines (MoM). However, the government is actively working to secure a steady supply of critical minerals essential for its energy transition goals, particularly to achieve the target of 500 GW of installed capacity from non-fossil-fuel sources, to promote electric vehicles and other advanced technologies.

There have been several policy changes that focus on enhancing domestic mineral exploration and mining. First, the MoM has conducted four tranches of auctions for critical mineral blocks from November 2023 to June 2024. Second, Khanij Bidesh India Limited has made several efforts to collaborate on critical mineral projects with governments in Australia, Argentina and Chile.

In addition, Union Budget 2024 covered key initiatives being implemented by the MoM, including the auction of offshore mineral blocks; the Critical Minerals Mission; the elimination of customs duties on 25 critical minerals and reduction of basic customs duties on two critical minerals; and the elimination of customs duty on blister copper.

The elimination of import duties on critical minerals will reduce costs for industries reliant on these minerals, attract investments in processing and refining, and support the growth of downstream industries, shielding India from elevated levels of import reliance and supply risks from geopolitical turbulence.

Moreover, the government is promoting policies for recycling materials such as lithium-ion batteries to reduce dependence on virgin mineral imports. In this regard, the Ministry of Environment, Forest and Climate Change has notified the E-Waste (Management) Rules, 2022, and the Battery Waste Management Rules, 2022. These rules promote environmentally efficient management of e-waste generated from electrical and electronic equipment, including solar PV modules or cells.

What are the key challenges and opportunities in achieving India's renewable energy goals, and how does your ministry plan to address them?

Currently, 218 GW of non-fossil fuel-based capacity has been installed, with 174 GW capacity under implementation and 86 GW capacity at the tendering stage. In order to achieve the target of 500 GW of non-fossil fuel-based installed power capacity by 2030, an investment of Rs 30 trillion-Rs 32 trillion will be required in the renewables sector, presenting significant opportunities for the green energy transition. Being a fast growing sector, India's renewable energy sector faces challenges on a day-to-day basis, which are being addressed regularly by the MNRE and the Ministry of Power. The major challenges highlighted by developers include compliance with the renewable purchase obligation and delays in transmission connectivity, both of which are being addressed. ■

Efficient Transmission

Growing role of HVDC technology in India's power sector

The uptake of high voltage direct current (HVDC) technology in India's power transmission segment has been steadily increasing. Since the 1990s, HVDC has played a pivotal role in the development of India's national grid from a zonal division into a unified synchronous grid. HVDC technology enables long-distance power transmission with minimal losses, making it ideal for bulk power transfer and the integration of high-quality power and renewables into regional and national grids. Modern HVDC systems in India are incorporating advanced control and protection systems, enhancing grid controllability and flexibility. These are essential for managing the dynamic changes associated with renewable power sources, ensuring robust and reliable grid operations.

Efficient long-distance power transmission

HVDC is highly efficient for transmitting large amounts of power over long distances with lower losses compared to AC transmission. It is ideal for special purpose applications such as grid interconnections and renewable power integration. HVDC enables the secure and stable interconnection of power networks that operate on different voltages and frequencies (asynchronous) or are otherwise incompatible. HVDC also provides instant and precise control of power flow and enhances AC grid capacity and resilience through its stabilising features.

Further, HVDC provides enhanced stability, which is crucial for integrating renewable energy sources and managing dynamic grid conditions. HVDC also allows for flexible power management and interconnections between regional grids, improving the overall reliability of the national grid.

An HVDC system consists of converters transforming AC to DC and vice versa, and transmission lines designed to efficiently handle high voltage levels.

- **Converters:** These are used at both ends of the transmission line to convert AC to DC (rectifiers) and DC to AC (inverters). Modern HVDC systems use either line-commutated converters (LCC) or voltage-source converters (VSC).
- **Transmission lines:** These can be overhead lines, underground cables or submarine cables. They carry DC power across hundreds to thousands of kilometres.
- **Inverter stations:** Located at the receiving end, inverter stations convert DC power back to AC for local distribution.

The success of HVDC technology is largely attributed to significant advancements in the field of power electronics (PE), which have been instrumental in enhancing the efficiency and reliability of power conversion and control processes. The development of mercury arc rectifiers at the turn of the 20th century marked an important step toward the conversion of AC to DC.

Technology evolution

Advancements in semiconductor technology significantly improved the performance, reliability and efficiency of HVDC systems. General Electric's invention of silicon controlled rectifiers in 1957, later known as thyristors, ushered in a new era of HVDC. Continued research and development throughout the 1960s and 1970s led to the widespread adoption of thyristor valves-based converters in HVDC applications. These HVDC systems utilised line commutated converters (LCC), which allowed the transmission of large amounts of power over long distances with much lower losses compared to mercury-arc-valve-based systems.

LCC-HVDC systems were particularly beneficial for linking remote power generation sites, such as hydroelectric plants, to urban centres. The first fully thyristor-based HVDC transmission system was built in 1972 and featured two back-to-back converter stations. Each station housed 4,800 thyristors and transmitted 320 MW of power at 80 kV between the Hydro-Québec stations in Canada and New Brunswick through the Eel River.

The 1990s saw a revolutionary advancement in HVDC technology, VSC. Unlike LCC, VSC-HVDC systems use insulated gate bipolar transistors (IGBTs), which allow self-commutation. This means VSC systems do not rely on the AC network for commutation, making them more versatile and capable of operating independently of grid conditions. IGBTs' ability to switch rapidly and efficiently at high voltages has enabled successful implementation of VSC technology. In 1997, the first experimental VSC project, a 3 MW +/- 10 kV link (Hällsjön Project), was installed in Sweden. Shortly after, in 1999, a 50 MW +/- 80 kV VSC-based system was commissioned in Gotland, Sweden, marking the commercialisation of VSC-HVDC.

The two HVDC technologies — LCC and VSC — are suited for different applications. LCC technology offers high transmission capacity and is suitable for traditional bulk transmission and ultra-high-voltage DC (UHVDC) systems. Meanwhile, VSC technology offers greater controllability and flexibility, making it ideal for integrating large-scale renewables and managing more complex grid interconnections. While LCC technology is available at power levels up to 12 GW and 1,100 kV, VSC technology is developed for power levels up to 3,600 MW and ±640 kV.

Development of HVDC systems in India

The ongoing research and development on HVDC continues to push boundaries, aiming to optimise HVDC systems to meet the growing demands of modern power networks. In order to bring power to load centres in an efficient, cost-effective and environment-friendly way, a notable technology trend has been the development of multi-terminal links. The ±800 kV North-East Agra UHVDC link,

Picture Courtesy: Hitachi Energy

commissioned in 2017, helps transmit clean hydroelectric power from India's hydro-rich Northeast region to the city of Agra, covering a distance of 1,728 km. Officially known as the +/-800 kV / 6,000 MW HVDC Multi Terminal NER/ER-NR/WR Interconnector-I, the link was built by Power Grid Corporation of India Limited. This is the world's first multi-terminal UHVDC transmission link at 800 kV.

Following this, another ground-breaking UHVDC project, the Raigarh-Pugalur link, was commissioned in India in 2021. The +/-800 kV, 6,000 MW multi-terminal project uses VSC technology instead of conventional HVDC technology. It can meet the electricity needs of over 80 million people and spans 1,800 km, traversing seven states to connect Raigarh in Central India to Pugalur in the southern state of Tamil Nadu.

Another engineering milestone was the phased commissioning of the ±800 kV Champa–Kurukshetra UHVDC link in central India, which spans 1,305 km and transmits 6,000 MW of power. This required development of new 800 kV switchgear, transformers and converters, alongside overcoming challenges such as electromagnetic interference and insulation coordination at unprecedented voltage levels.

Engineering solutions such as unified power flow controllers and reactive compensation (switchable shunt reactors, etc.) are used alongside UHV lines to manage their voltage profile. UHVAC and UHVDC advancements have significantly enhanced grid capacity, transforming India's transmission network into "transmission superhighways".

Challenges and outlook

To promote the successful integration and expansion of HVDC systems, several key measures need to be implemented. First, it is crucial to ensure that detailed future network models are available early in the project's planning phase. By providing these models at the tendering stage, stakeholders can significantly enhance the accuracy of system studies and reduce execution time, essential for maintaining grid stability. Additionally, a proactive design approach is necessary to anticipate and plan for evolving grid requirements. Considering future scenarios during the design phase, typically 5-10 years ahead, will enable HVDC systems to adapt effectively to changing grid conditions and requirements.

Developing a robust local supply chain is another critical measure. Investing in long-term planning and establishing local manufacturing and testing facilities for HVDC equipment will address the limited supplier base and support the growth of a strong local supply chain. Furthermore, optimising the transportation of heavy HVDC equipment is vital to overcome logistical challenges. Implementing optimised design models and streamlining permission processes will facilitate the efficient transport of equipment and help minimise project delays.

Finally, addressing the shortage of skilled professionals with expertise in HVDC technology is essential. Investing in comprehensive training and development programmes will build a knowledgeable workforce capable of supporting the successful implementation and operation of HVDC systems. By adopting these measures, stakeholders can foster a more effective and efficient HVDC integration, advancing the power grid and meeting future energy demands.

Future outlook for HVDC in India

The continued advancement and adoption of HVDC systems will play a critical role in meeting the country's energy needs and supporting its transition to more sustainable and resilient power infrastructure. A key opportunity lies in the need for efficient bulk power transmission from remote generation sites to major load centres. As India continues to expand its power generation infrastructure, HVDC technology will be crucial for transporting large amounts of electricity over long distances with minimal losses. Additionally, the rising power demand in India's large urban areas will require more city infeed projects. HVDC systems can address this by ensuring a stable and reliable supply of electricity to densely populated cities with increasing energy consumption.

The development of an interconnected DC grid also presents a significant opportunity for HVDC technology. Such a grid would enhance the integration of renewable energy sources into the national power grid, enabling more efficient distribution of clean energy across different regions. Furthermore, as India strengthens its power transfer agreements with neighbouring countries, the demand for HVDC interconnections will grow. These cross-border links will facilitate efficient power exchange, and contribute to regional energy security and stability. ■

Tapping Potential

Key requirements for developing offshore wind

One of the priority areas for India's transmission grid is to connect offshore wind power. The global energy transition is accelerating, with wind power playing a central role in decarbonising electricity generation. While onshore wind has been the dominant source of wind energy, offshore wind is rapidly emerging as a critical and complementary solution.

Given the rising energy demand, land constraints and the benefits that offshore wind power offers, it no longer remains an alternative. For instance, wind speeds over waterbodies are not only higher but also more consistent, tackling the issue of intermittency that onshore wind power faces. As a result, offshore wind farms can potentially generate more electricity per installed capacity. A major challenge that renewable energy developers face is the issue of land availability. Offshore wind addresses these problems since it utilises open seas and allows larger turbines, and hence, gives hgher energy output without requiring agricultural or residential land.

Offshore wind landscape

With a long coastline of over 7,600 km, India is a good candidate for offshore wind energy generation. In 2015, the Ministry of New and Renewable Energy (MNRE) notified the National Offshore Wind Energy Policy and designated it as the nodal agency. Later, in 2023, the MNRE launched a strategic road map that introduced three primary business models and set an ambitious target of 37 GW capacity to be auctioned in various tranches by 2030. Three models were outlined for project development. Model A applies to sites where studies/surveys have been or will be conducted by the National Institute of Wind Energy/government entities, with the MNRE procuring offshore wind capacity through bidding and providing viability gap funding (VGF) to ensure a uniform power tariff. Model B covers sites where developers conduct their own studies with seabed exclusivity, allowing project development through bilateral agreements, captive consumption or power exchange, with potential power procurement bids for discoms after two years but without central financial assistance (CFA). Model C allows developers to identify offshore wind sites within the exclusive economic zone (excluding Model A and B sites), conduct studies/surveys, and participate in site-specific bidding, with the original surveyor having the first right of refusal, but without CFA support.

With an estimated offshore wind potential of 71 GW, the Facilitating Offshore Wind in India (FOWIND) project and the First Offshore Wind Project in India (FOWPI) led to a 1 GW tender plan in Gujarat and Tamil Nadu. This was followed by an offshore wind bidding trajectory and the waiver of interstate transmission charges for offshore wind projects.

The sector received a major boost in 2024 when the government approved a VGF of Rs 74.53 billion. This included an outlay of Rs 68.53 billion for installing and commissioning 1 GW of offshore energy projects and a grant of Rs 6 billion to upgrade ports for meeting the logistical requirements for these projects. The VGF has been a major step towards the implementation of the National Offshore Wind Energy Policy. This support is likely to reduce the cost of power. Further, an additional surcharge will not be applicable for offshore wind projects commissioned up to December 2032, provided that power from such projects is supplied to open access consumers.

Transmission infrastructure requirements

As per the Global Offshore Report 2024 by the Global Wind Energy Council, offshore grid delivery usually involves several steps such as marine spatial planning, site investigation, grid planning, geophysical surveys, environmental studies and permitting, tendering, financing, procurement, and operations and maintenance. Unlike onshore wind, offshore wind farms require transmission networks that can transport power over long distances. For this, high voltage direct current (HDVC) transmission has become the preferred choice for large offshore projects due to its ability to minimise energy losses over extended distances.

HVDC cables have transformed offshore wind transmission by offering significantly lower energy losses compared to traditional alternating current cables. HVDC is particularly advantageous for projects located far from shore, where AC transmission faces reactive power losses. Recent advancements in HVDC cable technology have increased their efficiency and reliability.

Additionally, HVDC converter stations are critical components in offshore wind transmission, converting the electricity generated by wind turbines from AC to DC for efficient long-distance transport and then back to AC for integration into onshore grids.

The transmission system for integrating offshore wind power involves the establishment of offshore pooling stations, submarine power cables for integrating offshore pooling stations with onshore pooling stations, and transmission systems beyond onshore pooling stations. Central Transmission Utility of India Limited has identified the transmission system for Phase I of offshore wind power evacuation for Gujarat and Tamil Nadu.

Offshore wind transmission also involves several critical components, including array cables connecting individual turbines, offshore substations, export power cables and onshore substations. For the upcoming 500 MW project off Gujarat's coast, a 66 kV array cable will connect turbines to a 220 kV offshore substation. This infrastructure is necessary to stabilise transmission from offshore turbines to onshore stations.

Challenges

Although transmission infrastructure for offshore wind power generation is evolving, several challenges still require attention. Environmental and logistical concerns are particularly pronounced in offshore wind projects. For instance, cable installation must navigate sea-floor mapping, cable burial and environmental impact on marine ecosystems. Moreover, offshore wind projects being set up in India require specialised technology to withstand the country's relatively low wind speeds. While Tamil Nadu benefits from a more favourable wind profile, Gujarat's offshore sites may struggle with lower wind availability, necessitating further adaptations in turbine design. It is important to develop a robust local supply chain to minimise dependence on imported components. An indigenous supply chain would reduce project costs and increase the sector's resilience against global price fluctuations.

Subsea cabling also presents another challenge as these cables must endure extreme underwater conditions, potential damage from marine activities and the risk of faults, which can be costly and time-consuming to repair. Additionally, integrating large offshore wind capacities into the national grid or state-level grid requires careful planning to maintain stability. Overcoming these challenges will require continuous technological advancements and policy support.

Outlook

Offshore wind energy presents a promising opportunity for India's energy transition and the diversification of wind energy. By harnessing high and consistent wind speeds over the sea, offshore wind can contribute significantly to the country's renewable energy targets. However, the sector still faces hurdles, particularly in terms of cost competitiveness, infrastructure readiness and private developer confidence. While Tamil Nadu and Gujarat have been identified as the initial target states for offshore wind development, projected tariffs remain high, in the range of Rs 5.50-Rs 6 per kWh compared to onshore wind tariffs. The government has introduced VGF to address the cost gap and stabilise tariffs.

Further, the government aims to support grid connectivity up to offshore substations, a significant cost-saving measure that could cover nearly 25 per cent of the capex. Ensuring seamless grid connectivity and coastal security will be essential for long-term sector growth. Despite the challenges, offshore wind energy has the potential to play a transformative role in India's clean energy future. ■

Enhancing Grid Stability

CEA's advisory on co-locating energy storage with solar power projects

India has set an ambitious target of achieving 500 GW of non-fossil fuel capacity by 2030. To accomplish this goal, the country must significantly expand its variable renewable energy capacity, including solar and wind power. However, the inherent intermittency and variability of these sources pose challenges to grid stability, making the integration of energy storage systems (ESSs) crucial for a reliable and resilient power supply. Recognising this need, in a key development, the Central Electricity Authority (CEA) recently issued an advisory on co-locating ESS with solar power projects. This measure aims to enhance grid stability, improve cost efficiency and ensure a steady energy supply during periods of low renewable energy availability or high electricity demand.

A look at the advisory and implications for the sector…

Details of the CEA advisory

To facilitate the large-scale integration of renewable energy, the CEA has recommended that renewable energy implementing agencies and state utilities include co-located ESSs in upcoming solar tenders.

The advisory specifies that storage capacity equivalent to 10 per cent of the installed solar project capacity, with a minimum duration of two hours, should be mandated. Further, the tender documents should include a clear compliance mechanism to ensure the availability of stored energy during non-solar hours.

This approach is expected to improve grid reliability during peak demand periods while also optimising the utilisation of renewable energy sources. Additionally, distribution licensees could consider requiring rooftop solar installations to include a minimum of two-hour energy storage. This would not only enhance supply reliability for consumers but also reduce the burden on distribution networks by curbing excess power injection during peak solar generation hours.

ESSs can operate in two distinct modes. In single-cycle operation, they can charge exclusively from the co-located solar power plant and discharge during evening hours. In double-cycle operation, they can charge from both the co-located solar plant and the grid during periods of low demand, allowing for discharge during peak hours when solar generation is unavailable.

Impact

ESSs are vital in mitigating the challenges associated with renewable energy integration. By storing surplus energy generated from renewable sources, an ESS helps bridge the gap between generation and demand, ensuring a steady and dependable power supply. This capability is particularly important for balancing supply fluctuations and optimising energy usage in India's rapidly expanding renewable energy landscape.

As per the CEA, as of December 31, 2024, India's installed ESS capacity stands at 4.86 GW, comprising 4.75 GW of pumped storage plants (PSPs) and 0.11 GW of battery energy storage systems (BESSs). According to the National Electricity Plan published by the CEA, India will require 73.93 GW/411.4 GWh of storage capacity (26.69 GW/175.18 GWh from PSPs and 47.24 GW/236.22 GWh from BESS) by 2031-32 to accommodate 364 GW of solar and 121 GW of wind capacity.

The government has been taking several measures to promote energy storage and drive the adoption of BESS, such as providing legal status to storage, introducing the energy storage obligation, waiver of inter-state transmission system charges, and granting captive status for energy stored in BESSs.

As per the CEA, implementing the proposed storage requirements could result in the installation of approximately 14 GW per 28 GWh of energy storage capacity by 2030. Furthermore, the declining costs of battery technology may help lower power procurement expenses, particularly during evening hours when solar generation is absent, and energy prices on the exchange are elevated. The storage cost of using BESS has declined from over Rs 8-Rs 9 per unit in 2022 to Rs 6-Rs 7 per unit in 2024. As per industry estimates, 2.5 GW/4.9 GWh solar and BESS projects are currently under tendering, while 4.6 GW/6.7 GWh of tenders have been awarded. All tenders have a storage duration of two to four hours, with an average ESS penetration of 50 per cent.

Overall, the CEA advisory has been welcomed by the industry, as integrating ESSs with solar power projects offers significant long-term benefits beyond grid stability. It enables better utilisation of transmission infrastructure during evening hours, reduces the need for additional transmission capacity and associated costs, enhances energy security, and improves the overall efficiency of renewable energy systems. As India moves forward in its clean energy transition, co-locating ESSs with solar projects will be instrumental in achieving a stable, reliable and cost-effective power sector. ■

Key Statistics

Growth in the power transmission network

Growth in interregional transfer capacity

Year	Interregional capacity (MW)
2019-20	102,050
2020-21	105,050
2021-22	110,750
2022-23	112,250
2023-24	116,540
2024-25*	118,740

Source: Central Electricity Authority
**Till January 2025*

Region-wise interregional transfer capacity

Region	Transmission capacity (MW)
East-North	22,530
East-West	21,190
West-North	38,320
East-South	7,830
West-South	22,320
East-Northeast	3,550
Northeast-North	3,000
Total	**118,740**

Source: Central Electricity Authority

Growth in voltage-wise transmission line length (ckt km)

Year	± 800 kV HVDC	± 500 kV HVDC	± 320 kV HVDC	765 kV	400 kV	220 kV	Total
2019-20	6,124	9,432	–	44,853	184,521	180,141	425,071
2020-21	9,655	9,432	288	46,090	189,910	186,446	441,821
2021-22	9,655	9,432	288	51,023	193,978	192,340	456,716
2022-23	9,655	9,432	288	52,678	197,750	201,538	471,341
2023-24	9,655	9,432	288	54,797	203,838	207,534	485,544
2024-25*	9,655	9,432	288	56,333	206,182	209,981	491,871

Source: Central Electricity Authority
**Till January 2025*

Key Statistics

Utility-wise development of transmission capacity in 2024-25

Transformation capacity addition in 2024-25 (up to January 2025) (MVA)

Sector	State/Developer	220 kV	230 kV	400 kV	765 kV	Total
State	Andhra Pradesh	1,040		500		1,540
	Bihar	320				320
	Chhattisgarh	480				480
	Delhi	200				200
	Gujarat	1,200				1,200
	Haryana	1,960				1,960
	Himachal Pradesh	200				200
	Jammu & Kashmir					-
	Jharkhand	300		630		930
	Karnataka	500				500
	Kerala					-
	Madhya Pradesh	1,400		185		1,585
	Maharashtra	900		315		1,215
	Odisha	400				400
	Punjab	1,340		1,500		2,840
	Rajasthan	1,070		1,000		2,070
	Tamil Nadu		690	1,985	1,500	4,175
	Telangana			630		630
	Uttar Pradesh	3,060		1,460		4,520
	West Bengal	640		315		955
Central	POWERGRID	200		9,315	10,500	20,015
	DVC			945		945
Private		320		4,500		4,820
Total		**15,530**	**690**	**23,280**	**12,000**	**51,500**

Source: Central Electricity Authority

Transmission line addition in 2024-25 (up to January 2025) (ckt km)

Sector	State/Developer	220 kV	230 kV	400 kV	765 kV	Total
State	Andhra Pradesh	234		118		352
	Bihar	514		21		535
	Chhattisgarh	45				45
	Delhi	10				10
	Gujarat	203				203
	Haryana	92				92
	Himachal Pradesh	12				12
	Jharkhand			83		83
	Karnataka	265				265
	Kerala					-
	Madhya Pradesh	156				156
	Maharshtra	260		24		284
	Odisha	4				4
	Punjab	111		14		125
	Rajasthan	68		72		140
	Tamil Nadu		21	140		161
	Telangana	77		208		285
	Uttarakhand					-
	Uttar Pradesh	152		587		739
	West Bengal	75				75
Central	POWERGRID			360	1,536	1,896
	DVC	52				52
Private	ReNew			187		187
	Sterlite	95		530		625
Total		**2,426**	**21**	**2,344**	**1,536**	**6,327**

Source: Central Electricity Authority

GRIDCON 2025

Agenda: Sunday, March 9, 2025 (Day 1)

Time	Agenda	Speaker	Details
15:00 - 15:02	Safety Briefing	Venue Manager	Safety instructions and evacuation plans
15:02 - 15:05	Introduction of Dignitaries	Master of Ceremonies	Brief introduction of all dignitaries on stage
15:05 - 15:08	Welcome Address	Director (Operation), POWERGRID	Welcome address and overview of GRIDCON
15:08 - 15:13	Lighting of the Lamp	All dignitaries	Accompanied by a traditional invocation
15:13 - 15:18	Technical Show	Master of Ceremonies	Technical show with AV
15:18 - 15:25	Theme Address	CMD, POWERGRID	Theme of GRIDCON and its relevance
15:25 - 15:40	Keynote Address	CIGRE Chairman (Dr Konstantin O. Papailiou)	CIGRE and energy transition
15:40 - 15:55	Keynote Address	Director General, International Solar Alliance (Dr Ajay Mathur)	Role of renewable energy, solar integration and global partnerships
15:55 - 16:10	Keynote Address	Central Electricity Authority, Chairman (Ghanshyam Prasad)	Focus on India's transmission sector, regulatory frameworks and innovations
16:10 - 16:25	Focus Address	Secretary (Power), Govt. of India	
16:25 - 16:45	Special Address	Minister of State, Power & MNRE, Govt. of India	
16:45 - 17:15	Inaugural Address	Minister of Power, Govt. of India	
17:15 – 17:20	Vote of Thanks	Director, POWERGRID	Acknowledgment of participants, partners and organising team

MEDIA AND KNOWLEDGE SUPPORT

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